Agronomy Handbook

424-100 (SPES-299P)

Virginia Cooperative Extension

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Contents

Introduction

Agronomy is a diverse science that focuses on the production of field crops and turfgrass. Specific disciplines that contribute to the successful production of crops include (but are not limited to) crop and variety or cultivar selection, seed science, soil management, nutrient management, soil ecology, pesticide usage, and postharvest handling of crops.

This publication is intended to serve as a source of agronomic information to assist farmers and producers as well as students pursuing basic knowledge of agronomic practices. Pesticide and varietal recommendations change frequently and are, therefore, not included. This type of information is published annually in the Virginia Tech Pest Management Guides and commodity specific publications such as the Virginia Corn Hybrid and Management Trials. Contact your local Extension agent for a copy of the latest publication or visit the **Virginia Cooperative Extension web page** at http://www.ext.vt.edu. For specific updates on crop production in Virginia, contact your local Extension agent for the latest information from the Virginia Agricultural Statistics Bulletin or contact the Virginia Agricultural Statistics Service in Richmond, Virginia, directly at (800) 928-5277, or at **their website** http://www.nass.usda.gov/va/.

We at Virginia Cooperative Extension appreciate the support of our stakeholders and should you have questions, we stand ready to support you.

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Part I.

Crop Descriptions

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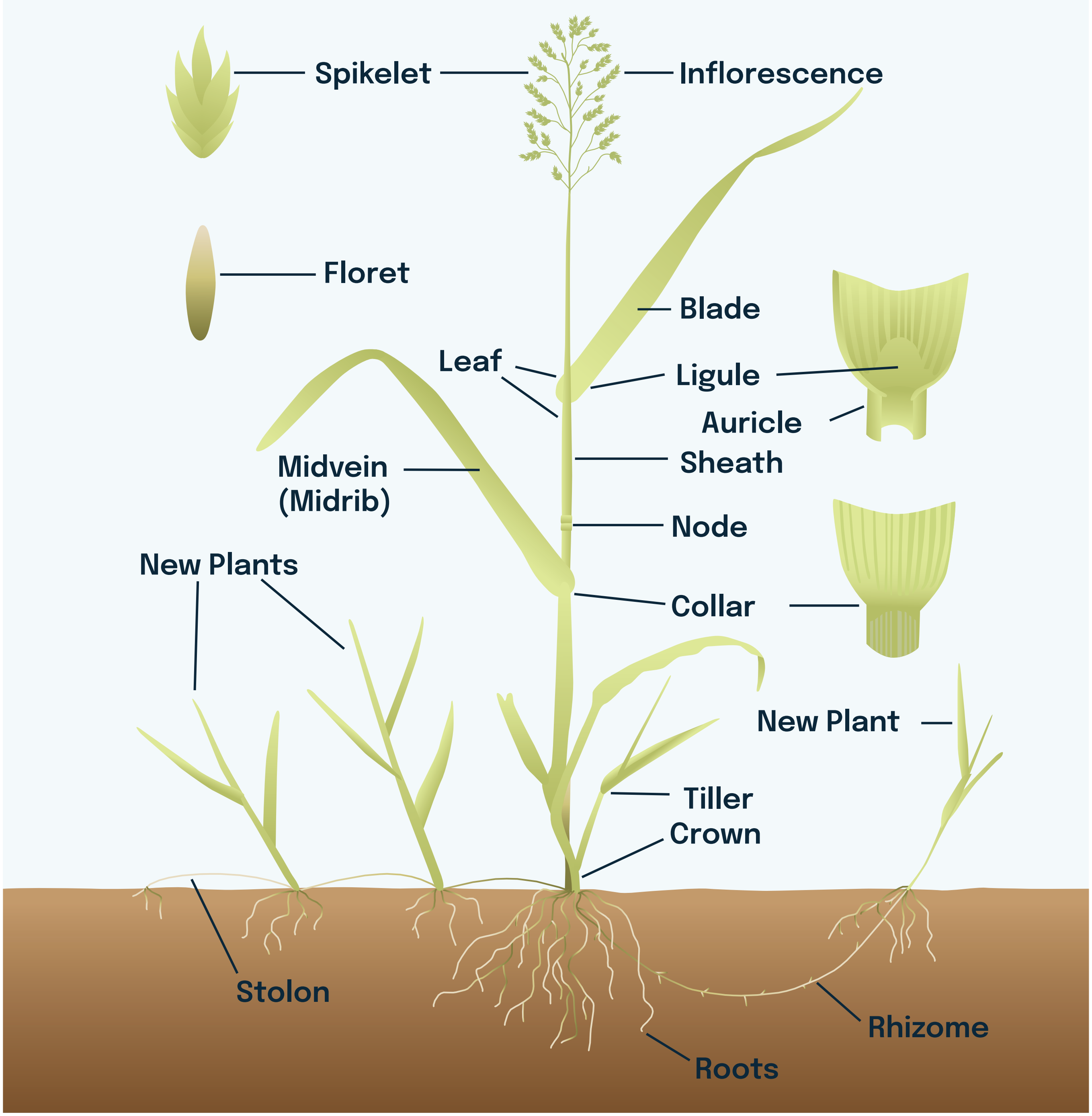
This section provides basic yet detailed information about most plants used for cropping in Virginia. All values are generalizations which may vary with specific conditions. Rates of fertilizer application depend, to a large extent, on initial soil test levels and the productive potential of the soil. The fertilizer recommendations presented assume an average or medium soil test level and soils that are average to above average in productivity. For more specific recommendations, rely on soil test results. Fertilizer application rates and crop yields in this section are expressed on a per acre basis.

Parts of the grass plant used for identification



Alfalfa – Perennial (***Medicago sativa***)	
Description	Distinct deep taproot; erect stems 2-3 feet tall from woody crown; purple flowers for most improved varieties; smooth stem and leaves; leaves arranged alternately on stem; each leaf has 3 leaflets with smooth edges.
Uses	Hay, pasture, and silage
Varieties	Consult current varietal information from Virginia Cooperative Extension.
Weight per bushel	60 lbs
Seeds per pound	220,000
Germination time	7 days
Fertilizer	At seeding: zero N, 110-140 lbs P_2O_5, 110-140 lbs K_2O at medium soil test levels. Use borate fertilizers (2-4 lbs B) annually. For topdressing: 70-90 lbs P_2O_5 and 220-360 lbs K_2O annually for medium soil test levels. Split application: half in fall and half in spring. Lower levels required for pasture.
pH range	6.8-7.0
Soil adaptation	Deep, well-drained soils with sandy clay loam to clay subsoils.
Inoculation	**Essential:** Use commercial inoculants. Cross-inoculates with sweet and bur clover.
Time of planting	30-60 days before first killing frost in fall or 30 days before last killing frost in spring at 15-25 lbs alone, or 10-20 lbs with 3-5 lbs of orchardgrass.
Method of planting	6-8 inch rows or solid-seeded. Conventional seeding: cover no deeper than 1/4-1/2 inch, preferably with cultipacker. A firm and compact seedbed is essential. No-till seeding (graze or mow to have sod short). Kill all vegetative competition with herbicide; use insecticide; plant 1/2-3/4 inch deep with no-till drill.
Harvesting (hay or silage)	Harvest at late bud to 1/4 bloom, except first cutting. First cutting should be made in bud stage or when orchardgrass begins to head. Alfalfa may be cut 3-5 times/year at 30- to 40-day intervals, depending on location in state and average rainfall. Make the last cutting 3-4 weeks before the average date of first killing frost in fall or in time to allow 6-8 inches of regrowth. Allow at least one harvest to reach 1/10 bloom to help persistence.
Harvesting (pasture)	Use grazing-tolerant varieties under continuous stocking. Hay-type varieties should be rotationally stocked with 1-7 day grazing periods and 25-40 day rest periods. Avoid bloat by seeding with grass, turning cattle into new paddock only after forage is dry (no dew) and not allowing cattle to get too hungry prior to turn-in.
Approximate yield	3-6 tons hay/A

Alsike Clover – Perennial (***Trifolium hybridum***)	
Description	Tillers from crown and stem, leaves smooth; pink or white blooms; stems do not terminate in a flower.
Uses	Hay and pasture; however, it does not make sufficient recovery after the first cutting for a second hay crop.
Weight per bushel	60 lbs
Seeds per pound	680,000
Germination time	7 days
Fertilizer	At medium soil test levels, apply 40-60 lbs P_2O_5 and 85-110 lbs K_2O per season.
pH range	5.8-6.5
Soil adaptation	Well-drained to somewhat poorly drained soils. More tolerant to a high water table and acid soils than other clovers.
Inoculation	**Important:** Cross-inoculates with red, crimson, ladino, and white clover.
Time of planting	30-60 days before last killing frost in spring or 30-45 days before first killing frost in fall at 3-4 lbs in mixtures or 5-8 lbs alone.
Harvesting (hay)	1/2 to full bloom, about June 1-20.
Harvesting (seed)	When about 3/4 of the heads are ripe. Handle as any other clover.
Approximate yield	1-2 tons hay/A

Austrian Winter Pea – Annual (***Pisum arense***)	
Description	Winter annual with purple flowers. Plants resemble those of garden pea.
Uses	Forage or cover crop
Weight per bushel	60 lbs
Seeds per pound	5,000
Germination time	8 days
Fertilizer	Zero N. Apply 60-80 lbs P_2O_5 and 60-90 lbs K_2O on medium testing soils. Adjust rates based on soil test levels.
pH range	6.0-6.5
Soil adaptation	Well-drained soils
Inoculation	Cross-inoculates with garden peas, vetch, and Canadian field peas.
Time of planting	Fall: Sept. 15-Oct. 15; spring: March 1-April 15; in 6-8 inch rows or solid-seeded at 20-30 lbs with small grains, 30-40 lbs alone.

Austrian Winter Pea – Annual (***Pisum arense***) (cont.)	
Harvesting (hay)	When barley or other small grain is in soft dough for silage or in full bloom for hay. Difficult to cure for hay.
Harvesting (seed)	When pods begin to turn brown.
Approximate harvest dates	Hay: May 1–June 1
Approximate yield	Hay: 1 1/2-2 tons; silage: 6-9 tons; seed: 300-500 lbs/A

Barley – Annual (***Hordeum vulgare***)	
Description	Leaves are green with long, clasping auricles and a long ligule. Seed usually contains the husk (lemma and palea) that gives the seed a wrinkled appearance. The lemma and palea are removed during harvest for some varieties, making them "hulless."
Uses	Grain is generally used for animal feed in Virginia. Also used for silage and in mixtures with other small grains for cover crops and winter grazing. Limited use in human food except malting barley.
Weight per bushel	48 lbs hulled; 57.6 lbs hulless (for feed); and 60 lbs hulless (for human consumption)
Seeds per pound	13,000
Germination time	6-7 days
Fertilizer	20 lbs of N in the fall plus 40-80 lbs each of P_2O_5 and K_2O. Topdress with 80 lbs N in February or early March. These rates assume no carryover N from the previous crop. In general, a high-yielding crop will take up to 20-25 lbs/A fall N, plus at least 80 lbs in the March-May period. For best results, the winter/early spring N should be split into two applications: one in February and one in late March.
pH range	6.0-6.5. Barley is very sensitive to low pH.
Soil adaptation	Any well-drained soil. Barley will not tolerate poor drainage.
Time of planting	About 2 weeks before first average frost in fall: Sept. 15-Oct. 10 west of the Blue Ridge and Northern Piedmont; Oct. 1-Nov. 1 in Eastern and Southern Piedmont. Aphids should be controlled if they build up in the fall or early winter.
Rate of seeding	120 lbs/A (hulled) or approximately 30 seeds/sq ft (18 seeds/drill foot in 7-inch rows)
Method of planting	Planting with a grain drill is best, but broadcast disk-in to a depth of 1-1 1/2 inches can be successful.
Harvesting	Combine grain when fully ripe and 12%-14% moisture. Cut for silage in the soft dough stage or boot stage, depending on forage requirements.
Approximate harvest dates	Grain: June 1-20; silage: May 1–June 1

Barley – Annual (***Hordeum vulgare***) (cont.)	
Approximate yields	8-20 bushels grain or 6-12 tons 35% dry matter silage/acre

Bentgrass, Creeping – Perennial (***Agrostis paulustris***)	
Description	A stoloniferous grass used for golf greens; high maintenance required. Some varieties can be seeded while others must be vegetatively planted.
Seeds per pound	7,800,000
Rate of seeding	1/2-1 lb
Germination time	10-14 days
pH range	6.0-6.5
Time of planting	Early spring or late summer

Bermudagrass – Perennial (***Cynodon dactylon***)	
Description	Spreads by soil surface runners (stolons) and underground modified stems (rhizomes); stems 6-12 inches tall; flowers are slender spikes, usually with 3 per cluster, similar to crabgrass; ligule is a fringe of hairs.
Uses	A warm-season grass that makes most of its growth during June, July, and August in Virginia; pasture, hay, silage, and turf. Greatest forage potential is in the Southern Piedmont and Coastal Plain.
Types and strains	Common: Occurs naturally in Virginia and throughout the South. Propagated by sprigs (rhizome and stolon pieces) and seed. Can be a major weed in crop fields. Hybrid forage types: Improved strains that are high-yielding, leafy, and cold tolerant enough for use in the Southern Piedmont and Coastal Plain. Midland, Tifton 44, and Quickstand have more cold tolerance than Coastal. All must be established using vegetative sprigs. Fine-textured bermudagrass: Developed for athletic fields, lawns, golf greens, fairways, etc. All improved varieties propagated by sprigs or sod. Seed is available for common bermudagrass.
Seed weight per bushel	35-36 lbs
pH range	6.0-6.5
Soil adaptation	Will grow on all types of soil but is better suited to sandy and droughty soils than other grasses. Prefers well-drained soils.
Time of planting	April 1-June 1
Rate of planting	For pasture use, 15-20 bushels of sprigs per acre in rows, or 30-40 bushels/A if broadcast. For turf, use 1 lb seed or 2-7 bushels of sprigs per 1,000 sq ft.

Bermudagrass – Perennial (***Cynodon dactylon***) (cont.)	
Fertilizer	At planting, 70 lbs N, plus 70-90 lbs P_2O_5, and 70-90 lbs K_2O for medium testing soil. For turf: see Turfgrass section. For hay: 175-300 lbs N, 80 lbs P_2O_5, and 80-205 lbs K_2O annually, based on soil test levels. Lower rates required when used as pasture.
Method of planting	Seed broadcast by hand or seeder. Sprigs planted in rows manually or with a planter. May be broadcast, disked-in, and cultipacked. Cover sprigs with 2-4 inches of soil.
Harvesting (hay)	Cut when 8-12 inches tall before heading or every 35-45 days.
Harvesting (pasture)	Can be continuously stocked if grazed no shorter than 2-3 inches. Rotational stocking is preferred; turn in at 6-8 inches; move cattle at 2-3 inches. Minimize seed production to maintain quality and growth rate. Do not graze during establishment year; cut for hay instead.
Approximate yield	4-8 tons hay/A

Birdsfoot Trefoil – Perennial (***Lotus cornicalatus***)	
Description	A fine-stemmed legume with a branching taproot. Adapted to higher elevations in Virginia. Grows 12-30 inches or more in length from a branching crown. Flowers are orange-yellow in groups of 4-8 at end of stems. Leaves consist of 5 leaflets alternately arranged with 2 at the base near the stem. Several seedpods attached to a single point give the appearance of bird toes. Short-lived perennial that can reseed.
Uses	Hay or pasture (nonbloating)
Varieties	No varieties have been developed for Virginia conditions. The erect or European types have been most satisfactory. These varieties include Viking, Granger, Cascade, and Mansfield. The Empire variety is a decumbent pasture type.
Seed weight per bushel	60 lbs
Seeds per pound	375,000
Germinating time	7 days
pH range	5.8-6.5
Soil adaptation	Does best on well-drained soil but can be grown with impervious subsoils.
Time of planting	March 1-April 15 or Aug. 1-Sept. 1. Should be sown with a grass such as orchardgrass or Kentucky bluegrass. In mixtures: 4-8 lbs; alone: 8-10 lbs.
Fertilizer	Zero N; medium soil test levels; apply 40-70 lbs P_2O_5 and 50-80 lbs K_2O.
Planting	6-8 inch rows or solid-seeded. Well-prepared, compact seedbed is needed. Cover not more than 1/2-inch deep. Use cultipacker if surface-seeded. Can also be no-till drilled or frost-seeded on killed sod. Poor seedling vigor.

Birdsfoot Trefoil – Perennial (***Lotus cornicalatus***) (cont.)	
Harvesting (hay)	When in bloom. Avoid clipping close if extremely dry.
Management	Permit seedlings to become well-established before grazing or harvesting. Clip weeds. Use rotational or moderate continuous grazing for pastures.

Bluegrass, Canada -- Perennial (***Poa compressa***)	
Description	Sod-forming from underground rhizomes; blue-green foliage; sheath distinctly flattened, with a short, compact seed head; short ligule.
Uses	Pasture, but not recommended for Virginia. Makes very little regrowth when grazed.
Weight per bushel	14 lbs
Seeds per pound	2,500,000
pH range	5.0-6.5
Soil adaptation	Best suited to fine-textured, well-drained soils. Will dominate Kentucky bluegrass on acid, droughty, or low-fertility soils.

Bluegrass, Kentucky – Perennial (***Poa pratensis***)	
Description	A low-growing, sod-forming perennial grass that spreads by underground rhizomes. The narrow leaves have tips shaped like the bow of a boat and reach a length of 7 inches; sheath flattened, short ligule.
Uses:	Permanent pasture and lawns. Requires several years to become well established. Good early grazing, goes dormant in summer, revives in fall to furnish good grazing.
Weight per bushel	14 lbs
Seeds per pound	2,200,000
Germinating time	14 days
Fertilizer	With white clover at seeding: 20 lbs N; at medium soil test levels: apply 90-120 lbs P_2O_5 and 60-90 lbs K_2O. For pasture: topdressing every 3 or 4 years, 40-125 lbs P_2O_5 and 40-125 lbs K_2O at medium soil test levels. For turf, see Turfgrass section.
pH range	6.0-6.5
Soil adaptation	Best suited to fine-textured, well-drained soils.
Time of planting	Late summer or early spring at 4-5 lbs in mixture for forage.

Bromegrass, Smooth – Perennial (***Bromus inermis***)	
Description	Sod-forming because it spreads by underground rhizomes; leafy and grows to height of 3-4 feet; head is an open panicle; stem smooth and round; short ligule, fused leaf sheath.
Uses	Hay and pasture-drought tolerant
Varieties	Historically not well-adapted to Virginia because of diseases; however, newer varieties may have potential.
Weight per bushel	14 lbs
Seeds per pound	137,000
Germinating	14 days
Fertilizer	100-200 lbs N. Lower levels required when used as pasture in split applications; 40-90 lbs P_2O_5 and 85-185 lbs K_2O annually on soils testing medium.
pH range	5.8-6.7
Soil adaptation	Well-drained, fertile soils
Time of planting	Early spring or with small grain in fall. Seeded at 10 lbs in mixture. Do not seed alone.
Harvesting	Early bloom stage. Do not graze or cut during stem elongation.

Buckwheat – Annual (***Fagopyrum esculentum***)	
Description	Erect plant, 2-4 feet tall; single stem may have several branches; flowers light green, pink, or red in color.
Uses	Grain used for livestock, especially poultry; ground into flour (middlings for livestock). Good honey and green manure crop.
Weight per bushel	48 lbs
Seeds per pound	15,000
Germinating time	6 days
pH range	5.5-6.0
Fertilizer	20-30 lbs N, at medium soil test levels apply 40-50 lbs P_2O_5 and 40-50 lbs K_2O.
Soil adaptation	Any well-drained soil. Will grow on infertile, acid soils better than most crops, but responds well to proper treatment.
Depth of planting	1/2-2 inches. Do not plant deeper than 2 inches.
Time of planting	Late May to mid-July. Seeds do not set well in warm weather. Likes cool, moist climate. Seed at 48-72 lbs in 6-8 inch rows or solid-seeded. No-till can work well.

Buckwheat - Annual (***Fagopyrum esculentum***) (cont.)	
Harvesting (grain)	Combine when the maximum number of seeds has matured and plants have lost most of their leaves. Drying may be necessary for safe storage.
Approximate harvest dates	Sept. 1-15
Approximate yield	20-25 bushels/A

Caucasian Bluestem - Warm-Season Perennial (***Bothriochloa caucasica***)	
Description	Long-lived perennial bunchgrass. It is an erect, fine-stemmed, leafy bunchgrass that produces many seed heads above the leaf base throughout the summer. Begins growth 2-3 weeks later than switchgrass in spring.
Uses	Primarily for pasture, but also for hay
Seeds per pound	1,000,000
Germination time	3-30 days
Fertilizer	Responds to N; apply 60-120 lbs N/A/year in split applications. Maintain P and K at medium levels.
pH range	5.5-6.2
Soil adaptation	Adapted to a wide range of soils. It performs better on the finer textured soils such as loams, clay loams, and silty loams, but will also grow well on sandy loam soils. Caucasian bluestem does not do well on extremely sandy soils and wetland soils.
Time of planting	After soil temperature reaches 65˚F in late May or early June.
Rate of planting	2-3 lbs/A pure live seed
Planting	Plant into a prepared, firm seedbed no deeper than 1/4 inch. However, no-till seeding can be done if plant residue is not thick enough to prevent seed-to-soil contact.
Harvesting (hay)	Harvest in boot stage.
Harvesting (pasture)	Maintain in vegetative stage. Loses palatability after seedhead emergence. Tolerates close grazing. Rotational stocking best.
Approximate yield	3-5 tons hay/A

Comfrey, Quaker (Russian Comfrey) – Perennial (***Symphytum peregrinum***)	
Description	Grows to a height of 3-4 feet; very large leaves feel somewhat sticky; large, fleshy roots that grow to 8-10 feet deep; purple or red-purple flowers borne in clusters at tips of stems.
Uses	Green manure; can be fed as forage.
Fertilizer	60 lbs N; Apply 60 lbs P_2O_5 and 60 lbs K_2O at medium soil test levels.
pH range	6.0-6.5
Soil adaptation	Wide range
Time of planting	Fall or early spring. Root cuttings in rows 3 feet apart in a prepared seedbed.
Harvesting	Cut to a 2-inch stubble when leaves reach a length of 18-24 inches.
Approximate yields	Hay: 3-5 tons/A

Corn, Field Corn – Annual (***Zea mays***)	
Description	Often referred to as maize. Leaves are arranged alternately on the stem. The tassel or male part of the flower is at the top of the plant, and the ear located below the tassel is the female portion. Even number of rows of kernels on each ear.
Uses	Grain and silage
Weight per bushel	Shelled: 56 lbs; ear corn: 70 lbs at 15.5% moisture
Seeds per pound	1,200-1,400
Germinating time	7 days
Fertilizer	For grain, 125-150 lbs N. Apply 40-60 lbs P_2O_5 and 40-60 lbs K_2O at medium soil test levels. For silage, increase the amount of P_2O_5 applied by 1/3, and double the amount of K_2O. Follow soil sample results for zinc and manganese and use tissue analysis to evaluate any other micronutrient needs. Consideration should be given to N and P residual from previous crops or organic sources.
pH range	5.8-6.2
Soil adaptation	Well-drained to somewhat poorly drained soils
Time of planting	Full-season corn should be planted one week before to one week after the average date of last killing frost in spring. Corn will germinate at 50˚F, but growth rate is slow until temperatures reach 60˚F. Corn can be planted up to July 1.
Rate of planting	On soils with high production potential where good production practices are followed, plant 25,000 to 33,000 kernels per acre. If planted on droughty soils, the rate of planting should be decreased by 10%-15%.

Corn, Field Corn – Annual (***Zea mays***) (cont.)	
Pesticides	Herbicides are used on almost all corn grown in Virginia, and insecticides are used on considerable acreage. For pesticide recommendations, contact your Extension agent.
Cultivation	Cultivation may aid in weed control and reduce surface compaction on some soils, but most of the corn currently grown in Virginia is not cultivated.
Reduced-tillage or no-till corn	An annual cover such as small grain, permanent sod, or mulch from a previous crop is important for success with no-till. Herbicides are used to kill existing vegetation and reduce weed competition throughout the season. A specially designed planter is used to plant the corn in the mulch with no soil preparation. Yields of no-till corn are typically greater than corn grown on plowed land. Other advantages are water conservation and reduction in soil erosion.
Harvesting (silage)	Hard dough stage when kernels are dented and a black layer is formed at their bases; lower leaves and husks are turning brown. Dry matter content should be 35%-42%.
Harvesting (grain)	Corn is mature at 30%-35% moisture. A black layer of cells is formed at the base of the kernel at maturity. If corn is harvested with a picker and cribbed, the moisture content should be no more than 20%. The optimum moisture for field shelling is between 18% and 26%. It should be dried to 13% moisture before storage.
Approximate harvest dates	Silage: Aug. 15-Oct. 1; grain: Sept. 1-Nov. 1
Approximate yields	Silage: 14-25 tons of 35% dry matter; grain: 75-225 bushels/A

Corn, Popcorn – Annual (***Zea mays everta***)	
Description	See Field Corn
Uses	Confection and meal
Fertilizer	Same as field corn
pH range	Same as field corn
Time of planting	1-2 weeks after the date of last killing frost at 22,000-28,000 seeds/A
Seeds per pound	3,000-6,000, depending on grade
Germinating time	7 days
Isolation	Do not plant where it will cross with other corn. Crossing reduces popping qualities.
Harvesting (grain)	Yields 1/3-2/3 less grain per acre than ordinary field corn. Shuck from standing stalks after it is thoroughly ripe. Do not put in the crib until well-cured. Maximum popping expansion is reached when kernel moisture is about 13%-14%.

Corn, Popcorn – Annual (***Zea mays everta***) (cont.)	
Cultivation	Refer to Field Corn for information on fertilization and weed control.
Rotation	Same as field corn when grown commercially.

Cotton - Annual (***Gossypium hirsutum***)	
Uses	Grown primarily for fiber; seed used for stock feed, fertilizer, and oil; primarily adapted to the Eastern Shore and Southeastern Virginia.
Weight per bushel	30 lbs
Seeds per pound	4,800 acid delinted
Germinating time	12 days
Fertilizer	50-70 lbs N. At medium soil test levels, apply 60-120 lbs P_2O_5 and 10-80 lbs K_2O. Side-dress with 25-75 lbs N.
pH range	5.8-6.2
Soil adaptation	Well-drained sandy loans and loam soils but does well on some fine-textured upland soils.
Time of planting	After soil begins to warm, usually about April 5-May 1.

Crimson Clover – Annual (***Trifolium incarnatum***)	
Description	Central taproot with many fibrous roots; 3 leaflets per leaf; hairy stem and leaves; pointed, conical flower at top of stem is bright crimson color; plants 1-3 feet tall.
Uses	Green manure, hay, and pasture crop
Weight per bushel	60 lbs
Seeds per pound	150,000
Germinating time	7 days
Fertilizer	Zero N. 40-120 lbs P_2O_5 and 60-90 lbs K_2O at medium soil test levels.
pH range	5.8-6.5
Soil adaptation	Well-drained and moderately well-drained soils; best suited to the Coastal Plain and Eastern Piedmont.
Inoculation	**Important:** Cross-inoculates with red, alsike, ladino, and white clovers.
Time of planting	In the fall, 30-60 days before frost. Plant 20-30 lbs hulled seed alone; 15 lbs in mixtures.

Crimson Clover - Annual (*Trifolium incarnatum*) (cont.)	
Harvesting (hay)	Cut when most advanced heads are beginning to show faded flowers at base. **Dangerous as horse feed if cut when ripe**.
Approximate yield	Hay: 1-2 tons/A
Seed yield	6-10 bushels; shatters easily when ripe
Approximate harvest dates	Hay: May 15-June 1; seed: June 15-July 1. For green manure, spray or till 20-30 days before planting succeeding crop.

Crownvetch - Perennial (*Coronilla varia*)	
Description	Creeping underground roots; stems are leafy, hollow, and weak, reaching a height of 2-4 feet if supported; flowers white with shading to rose or violet; blooms all summer; seedpods break apart at maturity.
Uses	Ornamental, erosion control, and stabilization; limited potential for pasture and hay because of limited regrowth after defoliation.
Weight per bushel	55 lbs
Seeds per pound	110,000
Fertilizer	Zero N. 90-120 lbs P_2O_5 and 60-90 lbs K_2O at medium soil test levels.
pH range	5.5-6.5
Soil adaptation	Does best on well-drained soils but will persist on moderately acid, rather infertile soils.
Inoculation	**Important:** Specific inoculum required.
Time of planting	Late winter or early spring at 5-10 lbs scarified seed. Plant in rows or solid-seeded. Rhizomes can be planted.

Dallisgrass - Perennial (*Paspalum dilatatum*)	
Description	Leaves broad and flat; grows in clumps of a few to many stems; extremely short rhizomes; stems slender and usually drooped from the weight of flower clusters; flowers arranged in 2 rows along the tip of seed stalk. Grows 10-20 inches tall. Tufted, deep-rooted, and long-lived, with dark green leaves; no rhizome, but forms strong sod; small auricles; short ligule.
Uses	Dallisgrass is a hay and pasture grass in the more southern states that is not generally recommended for Virginia. It is a slow-starting grass and usually takes 2 or more years to establish a stand. Found in many native pastures in Virginia, but not usually seeded.
Weight per bushel	12-15 lbs
Seed per lb	340,000

Dallisgrass – Perennial (***Paspalum dilatatum***) (cont.)	
Germinating time	21 days
Fertilizer	40-60 lbs N, 30-40 lbs P_2O_5, and 30-60 lbs K_2O at medium soil test levels.
pH range	5.8-6.2
Soil adaptation	Well-drained to somewhat poorly drained soils. Prefers rich, moist soils; does not do well on sandy soil.
Time of planting	Spring at 10-15 lbs/A alone, 3-5 lbs in mixtures.
Description	Tufted, deep-rooted, long-lived, with dark green leaves; no rhizome but forms strong sod; small auricles; short ligule.

Eastern Gamagrass – Warm-Season Perennial (***Tripsacum dactyloides***)	
Description	3-8 feet tall, erect bunchgrass. Stem flattened at the purplish base and growing from stout, scaly rhizomes. The blades are wide with rough and sharp margins. The inflorescence has 1-3 spikes, can be up to one foot long. It has both male and female parts in the same spike (male spikelets above and female spikelets below the spike). Crowns of established plants can be 3 feet across.
Uses	Primarily for grazing, but also for hay, silage, erosion control, and wildlife.
Fertilizer	Responds well to N. Apply 100-150 lbs N/A/year, in split applications. Maintain P and K in medium range.
pH range	5.8-6.5
Soil adaptation	Grows in fertile bottomland, swamps, and along stream banks.
Time of planting	Seed dormancy is high, so special treatment is needed before planting. Plant wet, chilled seed about 1-1 1/2 inches deep after the soil temperature reaches 60-65˚F. Alternatively, dormant seed can be sown in November-December.
Rate of planting	8-10 lbs/A
Method of planting	Best stands are obtained when planted in 6-10 inch rows using conventional or no-till drill. Alternatively, a corn planter can be used to seed in 30-36 inch rows.
Harvesting	Harvest 2-3 times per year in vegetative to early head stages. Can harvest to 5-inch **(hay and silage)** stubble.
Harvesting (pasture)	Use rotational stocking; turn in at 18-24 inches; graze to 8 inches residual.
Approximate yield	3-7 tons hay/A

Fescue, Creeping Red – Perennial (***Festuca rubra***)	
Description	Narrow leaves that are folded with a very short ligule; base of stem is usually red.
Uses	Primarily for lawns in shade. Very similar to sheep's fescue except the leaves are bright green instead of bluish, and it spreads by underground-modified stems (rhizomes).
Weight per bushel	10-15 lbs
Seeds per pound	400,000
Germinating time	14 days
Fertilizer	See Turfgrass section.
pH range	5.0-6.2
Soil adaptation	Well-drained to moderately well-drained soils. Does best on sandy soils. Will tolerate shade and low pH better than ryegrass or bluegrass.
Time of planting	September or early spring at 3-5 lbs per 1,000 sq ft for turf.

Fescue, Meadow – Perennial (***Festuca elatior***)	
Description	Tufted, deep-rooted, long-lived, with dark green leaves; no rhizome but forms strong sod; small auricles; short ligule.
Uses	Pasture. Found in many native pastures in Virginia but not usually seeded.
Weight per bushel	10-15 lbs
Seeds per pound	230,000
Germination time	21 days
Soil adaptation	Prefers rich, moist soils; does not do well on sandy soil.

Fescue, Sheep's – Perennial (***Festuca ovina***)	
Description	A long-lived bunch grass that forms dense turf; numerous stiff, rather sharp, nearly erect bluish-gray leaves; a tough grass, eaten eagerly by sheep but to a lesser degree by cattle.
Uses	Pastures, seldom seeded.
Weight per bushel	10-15 lbs
Seeds per pound	530,000 **Note:** Commercial seed comes from Europe.
Germinating time	21 days

Fescue, Sheep's – Perennial (***Festuca ovina***) (cont.)	
Fertilizer	40-60 lbs N, 30-40 lbs P_2O_5, and 30-60 lbs K_2O
pH range	5.0-6.2
Soil adaptation	Most well-drained soils. Does better than most grasses on sandy soils.
Time of planting	August or early fall is best but may be sown in spring at 25 lbs alone; 10-12 lbs in mixtures.

Fescue, Tall – Perennial (***Festuca arundinacea***)	
Description	Long-lived, tufted, deep-rooted; noted for early spring and late fall growth; leaves are dark green, shiny, and barbed along the edges, making them feel rough; leaves rolled in bud; very short ligule; sheath reddish pink belowground. Most existing tall fescue stands are infected with a fungal endophyte that induces fescue toxicosis in cattle.
Varieties	Endophyte-free varieties are somewhat less hardy than endophyte-infected tall fescue, requiring more careful management. Modern endophyte-free varieties are stronger than earlier varieties. Endophyte-enhanced varieties have potential for greater adoption.
Uses	Pasture, hay, and turf. Excellent when seeded at high rates for turf. Widely used for winter grazing.
Weight per bushel	24 lbs
Seeds per pound	220,000
Germinating time	14 days
Fertilizer	Establishment: 40 lbs N, 120-140 lbs P_2O_5, and 120-140 lbs K_2O at medium soil test levels. Pasture topdressing 30 lbs P_2O_5 and 30-60 lbs K_2O annually, or 40-125 lbs P_2O_5 and K_2O every 3-4 years. (For winter grazing, apply 60-75 lbs N in mid-August.) Hay topdressing: 120-200 lbs N, 40-90 lbs P_2O_5, and 85-185 lbs K_2O. For turf, see Turf section.
pH range	5.6-6.2
Soil adaptation	Adapted to practically all tillable soils. Tolerant to both dry and wet soils.
Time of planting	Early fall or spring at 15-25 lbs when seeded alone, and 6-12 lbs in mixtures for pasture; 4-6 lbs per 1,000 sq ft for turf.
Harvesting (hay)	First cut when heads begin to emerge. **Stems and seedheads of endophyte-infected fescue are highly toxic.** Approximate yields 2-6 tons hay/A.
Harvesting (seed)	When the field takes on a yellowish-brown cast and heads droop.
Harvesting (pasture)	Tolerant of continuous stocking. With rotational stocking, turn in at 8 inches; remove cattle at 2-3 inches. Keep vegetative to reduce potential problems with endophyte. **Remove pregnant mares from endophyte-infected fescue during last 3 months of gestation.**

Field Peas, Canadian – Annual (*Pisum arvense*)

See Austrian Winter Pea.

Johnsonsgrass – Perennial (*Sorghum halepense*)

Description	Bushy shrub that grows 3-6 feet tall; strongly ridged and grooved stems. A coarse, tall-growing grass of the sorghum group that spreads by seed and strong underground stems; used as hay and pasture in some of the southern states, but is considered a serious pest in crop fields in Virginia and most of the eastern U.S.
Precautions	Johnsongrass is considered a NOXIOUS weed in Virginia and is prohibited as a seed contaminant. It is also against the law to seed this plant. It spreads easily by seeding to other fields. Precautions are similar to sudangrass.
Uses	Primarily as food for game birds and for erosion control. Not adapted to high altitudes because seed will not ripen in a short season. Not adapted to wet areas.
Weight per bushel	60 lbs
Seeds per pound	85,000
Germination time	21 days
Fertilizer	Zero N, 60-90 lbs P_2O_5, and 30-60 lbs K_2O
pH range	5.5-6.2
Rate of planting	Seed in rows 3 feet apart at rate of 10 lbs/A, or set plants 2 feet apart in rows spaced 3 feet apart. Use scarified seed.

Kudzu – Perennial (*Pueraria thunbergiana*)

Description	Legume, deep-rooted, long-lived, coarse-growing vine with runners that often grow 50-100 feet per season. Produces few seeds, but once established can be a serious pest.
Uses	For reclaiming gullies and wasteland. Tolerates medium acidity. May be used for pasture and hay.
Fertilizer	At 3-year intervals, 60-100 lbs P_2O_5 and 60-100 lbs K_2O
pH range	5.5-6.2
Inoculation	Cross-inoculates with cowpeas, peanuts, and lespedezas.
Planting	Plant crown in holes or trench 15 inches deep and 18 inches wide. On gullied areas, plant in holes 15 inches deep and 18 inches wide on 20-foot squares. On wasteland, plant in deep furrows 20 feet apart and space crowns 4 feet in furrow.

Lespedeza, Bicolor - Perennial (***Lespedeza bicolor***)	
Description	Bushy shrub; grows 3-6 feet tall; strongly ridged and grooved stems.
Uses	Primarily used as food for game birds and for erosion control. Not adapted to high altitudes because seed will not ripen in short season. Not adapted to wet areas.
Weight per bushel	60 lbs
Seeds per pound	85,000
Germination time	21 days.
Fertilizer	Zero N, 60-90 lbs P_2O_5, and 30-60 lbs K_2O
pH range	5.5-6.2
Time of planting	In spring after frost
Rate of planting	Seed in rows 3 feet apart at rate of 10 lbs/A, or set plants 2 feet apart in rows spaced 3 feet apart. Use scarified seed.

Lespedeza, Korean - Annual (***Lespedeza stipulaceae***); Lespedeza, Common - Annual (***Lespedeza striata***)	
Description	Warm-season reseeding legume. Slender, branched stems; branched taproot; 3 leaflet stipules at base of leaf; stipules very prominent on Korean. Nonbloating.
Uses	Hay, pasture, and wildlife cover. Killed by frost and furnishes poor winter cover. Seed in mixtures with grasses or other legumes, or if seeded alone, use winter cover crop. May not reseed above 2,500-foot elevation.
Weight per bushel	Kobe: 30 lbs; Korean: 45 lbs
Seeds per pound	Kobe: 185,000; Korean: 240,000
Germinating time	14 days
Fertilizer	At seeding: zero N, 60-90 lbs P_2O_5, and 60-90 lbs K_2O
pH range	5.5-6.2
Soil adaptation	Will grow on almost any well-drained soil. Korean adapted to all areas of Virginia; Kobe is best adapted to Southeastern Virginia. Tolerant of acidity and low soil P. Cross-inoculates with perennial lespedezas, peanuts, and cowpeas.
Time of planting	February and March at 15-25 lbs alone; 10 lbs in mixtures. Plant in 6-8 inch rows or solid-seeded in small-grain fields. Harrow grain before seeding if soil is hard on top. Can be frost-seeded in late winter.
Harvesting (hay)	Early bloom stage
Harvesting (seed)	Combine in fall when ripe.

Lespedeza, Korean - Annual (***Lespedeza stipulaceae***); Lespedeza, Common - Annual (***Lespedeza striata***) (cont.)	
Approximate harvest dates	Hay: Aug. 1-Sept. 1; seed: Sept. 15-Nov. 1
Approximate yield	Hay: 1-2 tons; seed: 200-500 lbs/A

Lespedeza, Sericea - Perennial (***Lespedeza cuneata***)	
Description	Growth habit similar to alfalfa; stems grow from crown buds in a height of 2-4 inches; deep-branched taproot. Warm-season, drought-tolerant, nonbloating.
Varieties	High- and low-tannin types. Low-tannin varieties AV-Lotan and AV-Donnelly are more palatable but less persistent.
Uses	Erosion control, hay, pasture, and cover for wildlife.
Weight per bushel	60 lbs
Seeds per pound	335,000
Germination time	28 days
Fertilizer	Zero N, 60-90 lbs P_2O_5, and 30-60 lbs K_2O
pH range	5.0-6.2
Inoculation	Cross-inoculates with annual lespedezas, cowpeas, and peanuts.
Soil adaptation	Will grow on almost any well-drained soil. Very tolerant of acid soil and low fertility.
Time of planting	Unhulled seed: late fall or early spring; scarified seed: March or April. Plant 30-40 lbs unhulled seed; plant 15-20 lbs scarified seed in 6-8 inch rows or solid-seeded. Slow establishment.
Harvesting (hay)	When plants are about 15-24 inches tall. High tannin levels drop when harvested for hay, improving palatability and digestibility.
Harvesting (seed)	Direct combined. Second growth produces more uniform seed and is easier to thresh than the first crop, but yield of the first crop is usually higher.
Harvest (pasture)	Begin grazing at 8-10 inches; do not graze lower than 4 inches.
Approximate harvest dates	Hay: June 15-July 1; seed: Aug. 15-Sept. 15
Approximate yield	Hay: 2-3 tons; seed: 300-600 lbs/A

Matua Prairie Grass (Kunth) - Perennial (***Bromus willdenowii***)	
Description	Matua, also known as "rescuegrass," is a cool-season, short-lived perennial grass. Matua is an erect growing plant with a bunch-type growth habit. It grows up to 2-3 feet, including the inflorescence. It looks like orchardgrass except that basal leaf sheaths of prairie grass are densely covered with fine hairs, and the ligule is shorter and has no auricles. Matua grass leaves are light green to green rather than bluish green like orchardgrass.
Uses	Suited for hay, greenchop, or silage and can be used for dairy or beef pastures under rotational stocking management. It is not suited for continuous grazing.
Seeds per pound	90,000
Fertilizer	Requires high level of N: 40 lbs N/A at seeding recommended. For high level of production, apply 50-60 lbs N/A following mechanical harvest or 30-40 lbs N/A following each grazing. Apply 40-90 lbs P_2O_5/A and 85-185 lbs K_2O/A annually. Lower P and K amounts needed on pasture.
pH range	6.0-7.0
Soil adaptation	Adapted to well-drained, high fertility soils.
Time of planting	May be seeded in the fall or spring when the soil temperatures are at least 55°F. Seed treatment with fungicide prior to seeding may control head smut.
Rate of planting	25 lbs/A for drilled plantings; 30-40 lbs/A for broadcast seeding; and 10-15 lbs/A in mixture.
Method of planting	No-till or conventional planting methods can be used. Seed must be planted no more than 1/4-1/2 inch deep.
Harvesting (hay)	Mechanical harvest for hay or grazing should begin at the boot stage for best quality, yield, and longevity. A regrowth/rest period of 30-42 days, depending on the season, is essential. Matua has a yield potential of 3-6 tons/A/year. One regrowth per year must be allowed to set seed to maintain the stand.

Millet, Pearl - Annual (***Pennisetum glaucum***)	
Description	Erect growth habit: thick stems that grow to 3-7 feet tall; spike head. Regrows after cutting/grazing.
Uses	Supplemental pasture, hay crop, green chop. Requires 60-70 days to mature.
Weight per bushel	40-55 lbs
Seeds per pound	86,000
Germination time	10 days
Fertilizer	At seeding: 60-80 lbs N, 70-90 lbs P_2O_5, and 70-90 lbs K_2O at medium soil test level. After each cutting: 40-60 lbs N.
pH range	5.5-6.5

Millet, Pearl - Annual (***Pennisetum glaucum***) (cont.)	
Time of planting	May 1-July 1 at 25-40 lbs alone; 15-20 lbs in mixtures in 6-8 inch rows or solid-seeded.
Harvesting (hay)	Cut when heads begin to emerge from boot or at 30-40 inches.
Harvesting (pasture)	Requires high stocking rate, preferably with rotational stocking.
Approximate first harvest	July 1-15
Approximate yield	Hay: 2-4 tons/A

Millet, Foxtail - Annual (***Setaria italica***)	
Description	Erect growth; slender, leafy stems 2-5 feet tall; spike-like head.
Uses	Supplemental pasture and hay crop, nurse crop for late spring and early summer forage seedings, smother crop prior to late summer no-till forage seedings. Requires 60-70 days to mature. Lower yield and regrowth than pearl millet.
Weight per bushel	40-55 lbs
Seeds per pound	220,000
Germinating time	10 days
Fertilizer	60-80 lbs each of N, P_2O_5 and K_2O, at medium soil test levels.
pH range	5.8-6.2
Time of planting	May 1-July 1 at 15-30 lbs alone; 15-30 lbs in mixtures in 6-8 inch rows or solid-seeded.
Harvesting (hay)	Cut at seedhead emergence. **Do not feed to horses.**
Approximate yield	Hay: 1-3 tons/A

Milo (***Sorghum bicolor***)
See Sorghum, Grain.

Oats – Annual (*Avena sativa*)

Description	Panicle-type head; long ligule, auricles absent; leaf margins are heavy; seed usually retains the husk (lemma and palea), which has a very smooth surface; seed color varies with variety from white, yellow, gray to somewhat red. Winter oats require a period of cold temperature to initiate heading. Spring oats have no temperature requirement.
Uses	For grain, hay, and grazing. Excellent rotational crop for wheat or barley because it is not susceptible to the same species of diseases. Does not get "take all" disease.
Weight per bushel	32 lbs
Seeds per pound	14,000
Germinating time	10 days
Fertilizer	20 lbs N in the fall, plus 40-90 lbs each of P_2O_5 and K_2O at medium soil test levels. Topdress with 60-80 lbs N in February or early March. These rates assume no carryover N from the previous crop.
pH range	6.0-6.5
Soil adaptation	Well-drained loams and silt loams are best.
Time of planting	Winter oats: (Not recommended west of the Blue Ridge.) Fall: Sept. 25-Oct. 15 in Eastern Virginia, and Sept. 1-Oct. 1 in Piedmont; midwinter: Feb. 1-March 1 for the entire state. Spring oats: March 5-April 1 in Piedmont; March 15-April 10 in areas west of the Blue Ridge. Spring oats are not recommended in Eastern Virginia. Plant at 65-80 lbs or 12-15 seeds per row foot in 6-8 inch rows or solid-seeded.
Harvesting (hay)	Cut in boot to early dough stage.
Harvesting (seed)	Combine when fully ripe at 10%-15% moisture.
Approximate harvest dates	Winter: June 20-July 15; spring: July 1-15
Approximate yield	80-120 bushels or 2 tons hay/A

Orchardgrass – Perennial (*Dactylis glomerata*)

Description	Long-lived, deep-rooted bunch grass; leaves light green and folded and flat at the base, tufted seed heads, long ligule. Flowers only in spring. Regrowth is vegetative with no stem or seedhead production
Uses	Pasture, hay, and silage.
Weight per bushel	14 lbs
Seeds per pound	590,000 unhulled, 625,000 hulled

Orchardgrass - Perennial (***Dactylis glomerata***) (cont.)	
Germinating time	10 days
Fertilizer	At medium soil test levels. Establishment: When seeded alone, 40-50 lbs N, 120-140 lbs P_2O_5, and 120-140 lbs K_2O. Maintenance (hay): 120-200 lbs N applied half in early spring and the other half after first cutting, plus 40-90 lbs P_2O_5 and 85-185 lbs K_2O. When seeded with clover, N rate should be reduced to 20 lbs. For maintenance, where there is more than 35% clover, no N is needed.
pH range	5.8-6.2
Soil adaptation	Does best on well-drained loam soil.
Time of planting	In Eastern Virginia, seed after first good rain in September and up to Oct. 15, or during February or early March. In the Piedmont and west of the Blue Ridge, seed after first good rain in August and up to Sept. 15, or March 1-April 15. Plant 8-12 lbs alone; 3-6 lbs in mixtures.
Harvesting (hay and silage)	Cut in boot to early head stage. Fiber percentage increases rapidly after blooming.
Harvesting (pasture)	Do not graze below 3 inches. Rotational stocking with 1-4 day grazing periods is best.
First harvest dates	Hay: May 15-June 1; seed: June 1-July 1
Approximate yield	Hay: 2-5 tons/A/year; seed: 200-600 lbs/A

Peanuts - Annual (***Arachis hypogeae***)	
Description	Legume plant native to South America. Growth habit varies from prostrate to upright. Bright yellow flowers on either the main stem or lateral branches. Flowers contain both male and female parts and are self-fertile. Following fertilization, a "peg" bearing ovaries in its top elongates from the leaf axil and penetrates the soil. The peg then turns horizontally and pod and seed formation take place. Seed per pod varies from 1-5 depending on market type. A pod will most often have two seeds.
Uses	Food for humans and livestock.
Weight per bushel	18-22 lbs in shell; 48-52 lbs shelled
Seeds per pound	Virginia-type: 500-800; runner-type: 700,000; Spanish-type: 1,000-1,400 lbs in shell
Germinating time	7-10 days
Fertilizer	Direct fertilization not recommended. Increase the fertilizer application on the crop that precedes peanuts in rotation by 50-100 lbs P_2O_5 and 10-60 lbs K_2O. Apply 900 lbs gypsum broadcast or 600 lbs banded over the row as plants begin to bloom.
pH range	5.8-6.5

Peanuts – Annual (***Arachis hypogeae***) (cont.)	
Inoculation	Cross-inoculates with lespedezas, cowpeas, and kudzu.
Soil adaptation	Best quality peanuts are produced on well-drained, light, sandy soils. May be produced anywhere east of the Blue Ridge Mountains, but yield and quality are usually poorer on heavier soils. Rotate peanuts with other non-legume crops.
Time of planting	April 20-May 10. Soil temperature should be at least 65°F for 3 consecutive days.
Planting	Peanuts should be planted 3-4 inches apart in 30-36 inch rows. This requires approximately 75-175 lbs of shelled nuts, depending on seed size. Plant 1 1/2-2 inches deep.
Weed control	Herbicides and cultivation may be used. Cultivation should be shallow and often enough to control weeds until pegs enter the ground. Do not cover any portion of the vine with soil. Rotary hoeing when crust forms can be beneficial.
Harvesting	Dig when about 70% of the shells turn brown on the inside, usually 130-170 days after planting.
Approximate harvest date	Sept. 15-Nov. 1
Approximate yield	2,500-5,000 lbs/A
Storage	Peanuts contain about 50% moisture when dug; must be dried to 10% moisture for storage.

Rape – Annual (***Brassica napus***)	
Description	Cool-season plant in the mustard family. Closely resembles kale, with large, dark green leaves. At maturity it reaches a height of 3-6 feet with brilliant yellow flowers and pods that produce 15-40 small black seeds. Winter and spring varieties are available.
Uses	Pasture and as an oil crop. Usually ready for grazing about 8 weeks after seeding. Sometimes causes bloating in sheep.
Weight per bushel	50 lbs
Seeds per pound	160,000
Germinating time	7 days
Fertilizer	60-80 lbs N, 30-50 lbs P_2O_5, and 30-50 lbs K_2O at medium soil test levels.
pH range	5.2-6.2
Soil adaptation	Well-drained and moderately well-drained loams and silt loam soils.
Time of planting	February and March, or August and September at 2-3 lbs in rows, 6-9 lbs broadcast, 4-6 lbs when seeded with oats.

Red Clover – Perennial (***Trifolium pratense***)	
Description	Numerous leafy stems arising from a crown growing to a height of about 2 feet; stems and leaves are hairy; flowers reddish purple on heads at tips of branches; branched taproot. Short-lived perennial that often behaves as biennial.
Varieties	New varieties are more persistent.
Uses	Hay, pasture, silage, and commercial seed production
Weight per bushel	60 lbs
Seeds per pound	260,000
Germinating time	7 days
Fertilizer	At seeding, 120-140 lbs P_2O_5 and 120-140 lbs K_2O; for topdressing, 40-90 lbs P_2O_5 and 85-185 lbs K_2O at medium soil test levels. Lower amounts needed when used as pasture.
pH range	5.8-6.5
Soil adaptation	Well-drained to moderately well-drained loams and silt loam soils properly limed and fertilized.
Inoculation	**Important:** Cross-inoculates with alsike, crimson, ladino, and white clovers.
Time of planting	45 days before last killing frost in spring or 30 days before first killing frost in fall. Plant at 8-10 lbs alone; 2-6 lbs in mixtures. Plant in 6-8 inch rows or solid-seeded usually with a grass. Broadcast or drill on small grain or closely grazed grass pasture in later winter or early spring.
Harvesting (hay)	Cut with a combine when heads have turned brown, flowers and stalks are deep yellow, and seeds have begun to show a distinct violet color. Will shatter badly if cut later. May use a desiccant to aid in drying the plant.
Approximate first harvest	Hay: June 1-20. Seed: Aug. 15-Sept. 1.
Approximate yield	Hay: 2-4 tons over season. Seed: 120-240 lbs/A.

Redtop (***Herdsgrass***) – Perennial (***Agrostis alba***)	
Description	Produces numerous stems from a well-developed base; spreads by rhizomes but does not produce a strong sod; flat, light green, sharp-pointed leaves; lacks leafiness under close grazing; long prominent ligule.
Uses	Primarily for erosion control and soil stabilization.
Seeds per pound	5,100,000
Weight per bushel	14 lbs
Germinating time	10 days

Redtop (***Herdsgrass***) – Perennial (***Agrostis alba***) (cont.)	
Fertilizer	40-60 lbs N, 60-100 lbs P_2O_5, and 60-100 lbs K_2O. The N is for annual applications; the P_2O_5 and K_2O are rates for 3-4 years.
pH range	5.8-6.2
Soil adaptation	Well-drained and moderately well-drained loams and silt loams. Tolerant to wet conditions.
Time of planting	August and September. May be seeded in spring. Plant at 3-5 lbs alone; 3 lbs in mixtures. Plant in 6-8 inch rows or solid-seeded.
Harvesting (hay)	Shortly before full bloom.

Reed Canarygrass – Perennial (***Phalaris arundinacea***)	
Description	Tall, coarse, sod-forming, cool-season grass; grows 2-5 feet tall; spreads underground by short, scaly rhizomes; semidense, spike-like panicles.
Uses	Hay, pasture, and silage. Conservation cover in wet areas and areas irrigated for disposal of liquid wastes.
Weight per bushel	45 lbs
Seeds per pound	430,000
Germinating time	21 days
Fertilizer	Establishment: 50 lbs N, 120-140 lbs P_2O_5, and 120-140 lbs K_2O. Maintenance (pasture): 40-60 lbs N, 30-40 lbs P_2O_5, and 30-60 lbs K_2O. Maintenance (hay):120-200 lbs N applied, half in early spring and the other half after first cutting, plus 40-90 lbs P_2O_5, and 85-185 lbs K_2O. When seeded with clover: N rate should be reduced to 20 lbs. For maintenance where there is more than 35% clover, no N is needed.
pH range	5.8-6.2
Soil adaptation	Tolerates poorly drained soils. More drought-tolerant than many other cool-season plants.
Time of planting	Early fall or spring. Often slow to establish. Plant 12-14 lbs alone; 6-8 lbs in mixtures. Plant in 6-8 inch rows or solid-seeded.
Harvesting	First cut when heads begin to emerge.
Approximate harvest dates	Hay: May 15-June 15
Approximate yield	Hay: 2-4 tons/A

Rye - Annual (*Secale cereale*)

Description	The most winter-hardy of small grains. Seedings often have a reddish coloration; leaves have small auricles with short ligules; seeds are round with the germ end distinctly pointed; seed color varies from greenish gray and tan to dark brown or black.
Varieties	Abruzzi types provide earlier grazing in late winter/early spring.
Uses	Cover crop, grain, silage, winter and spring pasture.
Weight per bushel	56 lbs
Seeds per pound	18,000
Germinating time	7 days
Fertilizer	20 lbs of N in fall, plus 40-80 lbs each of P_2O_5 and K_2O. Topdress with 60 lbs N in February or early March.
pH range	5.8-6.2
Soil adaptation	Any well-drained soil. Will do better on poor soils than wheat, oats, or barley.
Time and rate of planting	60-90 lbs; 90-100 lbs for grazing. Plant from 2 weeks before to 4 weeks after first killing frost. Plant in 6-8 inch rows or solid-seeded.
Harvesting (yield)	Combine when fully ripe at 10%-15% moisture. Rye ripens slowly, and seed is easily damaged during harvesting.
Harvesting (silage)	Harvest at the boot stage.
Harvesting (pasture)	Earlier fall planting allows some late fall grazing. Stock heavily and rotationally to maintain leafy growth.
Approximate harvest date	Grain: June 20-July 10; silage: April 10-May 1
Approximate yield	25-50 bushels grain; 5-8 tons 35% dry-matter silage/A

Ryegrass - Annual (Italian) (*Lolium multiflorum*)

Description	Shiny, smooth leaves rolled in the bud, auricles narrow and long; short ligule; spikelets edgewise on stem with awns on seed. Bunchgrass.
Uses	Grows rapidly and in bunches to height of 3 feet. Used for hay and pasture, especially as a supplementary pasture mixed with crimson clover and/or small grain. Also used for green manure, winter turf, and overseeding bermudagrass. An annual that can volunteer in small-grain fields to become a pest.
Weight per bushel	24 lbs
Seeds per pound	227,000
Germinating time	7 days

Ryegrass - Annual (Italian) (***Lolium multiflorum***) (cont.)	
Fertilizer	Pasture: 20 lbs N in fall and 30-50 lbs each of P_2O_5 and K_2O. Add 50-70 lbs N topdressed in spring.
pH range	5.8-6.2
Soil adaptation	Will grow well on most soils used for crops in Virginia.
Time of planting	Aug. 15-Nov. 15. Use the earlier seeding date for Northern Piedmont and west of the Blue Ridge. Plant for pasture: 10-15 lbs in mixtures, 20-30 lbs alone. For turf: 3-5 lbs per 1,000 sq ft.
Harvesting (pasture)	Tolerates close, continuous stocking

Ryegrass - Perennial (English) (***Lolium perenne***)	
Description	Similar to Italian in use, adaptability, and all other ways, but can be distinguished from Italian by flowers being awnless and leaves folded in the bud, not rolled. Special varieties adapted for turf purposes.
Uses	Pasture. High yielding during first year, but decreased yields in subsequent years due to poor persistence.
Time of planting	Alone: 20-30 lbs; in mixtures: 10 lbs
Approximate yield	2-6 tons hay/A

Sorghum, Forage - Annual (***Sorghum bicolor***)	
Description	Sorghum is very similar to corn in the vegetative stage. Leaves tend to be narrower than for corn. Heavily covered with a white waxy coating that can be rubbed off the leaf sheath. Flowers are perfect in that both male and female parts are produced in a panicle-type head on top of the plant. Forage sorghum is 6-10 feet tall with a large stem, medium-size grain head.
Uses	Silage, hay, grazing
Weight per bushel	56 lbs
Seeds per pound	13,000-20,000
Germinating time	10 days
Fertilizer	60-80 lbs each of N, P_2O_5, and K_2O
pH range	5.8-6.2
Soil adaptation	Well-drained to somewhat poorly drained soils.
Time of planting	1-2 weeks after corn. Soil needs to be warm (at least 60°F). Plant 5-20 lbs in rows with a drill or corn planter.

Sorghum, Forage – Annual (***Sorghum bicolor***) (cont.)	
Harvesting	Do not graze until 30 inches tall. Cut for hay or wilted silage no later than early head emergence. Cut in dough stage for direct ensiling.
Approximate yield	Hay or wilted silage: 3-5 tons dry matter. Silage: 14-18 tons of 35% dry matter/A.

Sorghum, Grain – Annual (***Sorghum bicolor***)	
Description	See Forage Sorghum. Same genus and species except plant types that are shorter and produce lighter grain have been bred. Plant height 3-5 feet with high grain yield. Will recover from high temperature and drought better than corn.
Uses	Grain and silage
Weight per bushel	56 lbs
Seeds per pound	13,000-20,000
Germinating time	10 days
Fertilizer	Apply approximately the same amount that would be applied to corn when grown under comparable conditions.
pH range	5.8-6.2
Soil adaptation	Well-drained to somewhat poorly drained soils.
Time of planting	1-2 weeks after corn. Early-medium maturing hybrids can be planted following small-grain harvest in Eastern Virginia. Plant for grain at 5-7 lbs in rows; forage alone: 7-10 lbs.
Harvesting	Harvest grain with combine when seed is mature and shells easily from head. Chop for silage when grain is in the dough stage. Artificial drying can be a problem because the small seed size reduces air flow through the grain.
Approximate yield	Grain: 80%-90% of adapted hybrid corn yield. Silage: 11 tons 35% dry matter/A.

Sorghum, Sweet – Annual (***Sorghum bicolor var saccharum***)	
Description	Similar in appearance to forage sorghum
Uses	Syrup
Weight per bushel	45-60 lbs
Seeds per pound	28,000-40,000
Germinating time	10 days
Fertilizer	30-50 lbs N, 60-90 lbs P_2O_5, and 60-90 lbs K_2O. Side-dress with N to make a total of no more than 70 lbs N when plants are 25-35 days old.

Sorghum, Sweet - Annual (***Sorghum bicolor var saccharum***) (cont.)	
pH range	5.8-6.2
Soil adaptation	Any well-drained soil suited for corn.
Time of planting	2-4 weeks after corn, at 3-5 lbs in rows 30-36 inches apart. Plant 1-1 1/2 inches deep.
Cultivation	Shallow, level, and often enough to keep down weeds. Chemical control also practiced.
Harvesting (syrup)	When seeds are in the hard-dough stage.
Approximate harvest date	Sept. 1-Oct. 1
Approximate syrup yield	100-300 gal/A

Soybean - Annual (***Glycine max***)	
Description	Legume 2-4 feet tall. Broad trifoliate leaves with small white or purple flowers. Flower initiation is very sensitive to day length, but all plants do not respond the same way. Some cultivars bloom under relatively short days while others bloom under longer days. In Virginia, shorter-day cultivars are classified as maturity group 3 or 4; longer-day cultivars are classified as maturity groups 5 and 6. Two types of growth habit: determinate and indeterminate. Determinate cultivar's terminal bud ceases to grow when the plant starts to flower; indeterminate cultivar's terminal bud continues to grow several weeks after flowering. Tan or brown seedpods contain 2-3 round yellow seeds. Stems, leaves, and pods are covered with gray or tawny hairs.
Uses	Seed, hay, and silage
Weight per bushel	60 lbs
Seeds per pound	Small: 3,600; medium: 3,000; large: 2,500; extra-large: 1,600
Germination time	3-6 days
Fertilizer	Zero N, 40-60 lbs each of P_2O_5 and K_2O
pH range	5.8-6.5
Inoculation	Use soybean inoculum where soybeans are not grown regularly. Does not cross-inoculate with other legumes.
Soil adaptation	Well-drained to somewhat poorly drained soils. Rotate with other non-legume crops.

Soybean - Annual (***Glycine max***) (cont.)	
Time of planting	Two weeks after corn planting time for the area (full season); double-cropped with small grain, generally after June 15. Time of planting prior to June 10 results in maximum potential yield. Yield declines rapidly if planted later due to lack of time to develop adequate growth. Planting in 20-inch rows or less is recommended in order to meet canopy requirements and maximize yield. No-tillage planting requires the use of a "burndown" herbicide to kill existing vegetation either mixed together with a preemergence herbicide or followed approximately 2-3 weeks later by a postemergence herbicide.
Pest management	An integrated approach with cultural, biological, and chemical controls is necessary. Control weeds by 3 weeks after planting and maintain control until canopy closure. Rotation with nonhost crops becomes necessary to prevent buildup of several nematode species. Several insect pest species are occasionally a problem in Virginia. Frequent scouting is needed to detect infestations. Control measures should be implemented when pests exceed economic thresholds.
Harvesting (hay and silage)	When lower leaves begin to turn yellow and pods are about half-filled.
Harvesting (seed)	When leaves have fallen and pods are brown and dry; seed moisture will be 10%-15%.
Approximate harvest dates	Hay: Aug. 15-Oct. 1; seed: Sept. 20-Dec. 1
Approximate yield	Hay: 2-4 tons; seed: 25-70 bushels/A

Sudangrass - Annual (***Sorghum sudanense***) or Sorghum-Sudangrass Hybrid - Annual	
Description	Smooth, erect stems, reach height of 5-7 feet; open panicle head; large leaves.
Uses	Supplemental pasture in 40-45 days.
Weight per bushel	25-40 lbs
Seeds per pound	Sudangrass: 55,000; sorghum-sudangrass hybrids: 20,000
Germination time	10 days
Fertilizer	60-80 lbs each of N, P_2O_5, and K_2O, plus 40-60 lbs N after each cutting.
pH range	5.8-6.2
Soil adaptation	Well-drained to somewhat poorly drained soils.
Time of planting	Two weeks after corn. Sudangrass: 25-35 lbs broadcast, 15-20 lbs in rows. Sorghum-sudangrass: 30-40 lbs broadcast, 20-30 lbs in rows. Plant in narrow rows or solid-seeded.

Sudangrass – Annual (***Sorghum sudanense***) or Sorghum-Sudangrass Hybrid – Annual (cont.)	
Precaution	Do not graze or harvest for green chop until plants are 24-30 inches tall to reduce danger of prussic acid poisoning.
Harvesting (hay)	Cut just as heads emerge.
Harvesting (silage)	Cut direct when grain is in the dough stage or as heads emerge and wilt.
Approximate harvest dates	Hay or silage: July 1-15.
Approximate yield	Hay or wilted silage: 2-5 tons dry matter; silage: 12-15 tons 35% dry matter/A.

Sugar Beets – Biennial (***Beta vulgaris***)	
Description	Same species as the red garden beet but grows much larger. Leaves are large and shiny; white roots average 1-3 lbs. Sugar content 14%-16%.
Uses	Sugar production and livestock feed
Seeds per pound	72,000
Germination time	10-14 days
Fertilization	40 lbs N, 100 lbs P_2O_5, and 100 lbs K_2O prior to seeding. An additional 40 lbs N will be needed 4-6 weeks later. Use a borated fertilizer.
pH range	6.0-6.5
Soil adaptation	Well-drained silt or silty loam soil free of stones and roots.
Time of planting	Late winter or early spring. If a field is to be thinned, drop 1 seed per inch of row. Thin when plants have 4-6 leaves, spacing plants 10-12 inches apart.
Approximate harvest dates	October-December
Approximate yield	20-30 tons/A

Sunflower – Annual (***Helianthus annus***)	
Description	Plants with large leaves and bright yellow flowers; young leaves and flowers tend to face the sun. Very susceptible to bird damage.
Uses	Oil crop, bird feed, snack food
Weight per bushel	26-30 lbs
Seeds per pound	5,000-8,000

Sunflower – Annual (***Helianthus annus***) (cont.)	
Germination time	10-14 days
Fertilization	100 lbs of N plus 40-60 lbs each of P_2O_5 and K_2O
pH range	5.8-6.0
Soil adaptation	Any well-drained soil
Time of planting	Tolerates freezing temperatures better than most crops. Can plant 2-3 weeks prior to last killing frost. Because of early maturity, planting can continue until Aug. 1 in Eastern Virginia.
Planting rate	19,000-20,000 plants/A
Cultivation	1-2 cultivations will usually be necessary to control weeds. Herbicide selection limited.
Harvesting	110-120 days required from planting to harvest. Mature when the backs of heads turn yellow. Special attachments necessary on small-grain combine headers to prevent shatter loss.
Approximate yield	Seed: 1,200-2,000 lbs/A

Sweet Clover – Biennial (***Melilotus alba; Melilotus officinalis***)	
Description	Erect with many branches; deep taproot; stems grow from crown second year; yellow or white flowers; 2-5 feet tall; leaflets notched on edges toward tips (unlike alfalfa with smooth edges). Plants and flowers have a sweet vanilla odor.
Varieties	Biennial white sweet clover preferred. Stems of the biennial yellow are finer, and the plant does not grow so high. Yellow blooms 10 days earlier.
Uses	Pasture, hay, and green manure. **Poorly cured hay can result in hemorrhaging in livestock due to accumulation of dicoumarin.**
Weight per bushel	60 lbs
Seeds per pound	250,000
Germinating time	10 days
Fertilizer	Zero N, 40-70 lbs P_2O_5, and 50-80 lbs K_2O
pH range	6.5-7.0
Soil adaptation	Well-drained to moderately well-drained soils.
Inoculation	**Important:** Cross-inoculates with alfalfa and bur clover.
Time of planting	February, using unhulled seed. Use scarified seed in late March or April. Hulled: 15 lbs; unhulled: 25 lbs. Drill on grain in February or March or sow on frozen ground.
Harvesting (hay)	Cut in the bud stage before any bloom appears.

Sweet Clover - Biennial (***Melilotus alba; Melilotus officinalis***) (cont.)	
Approximate harvest dates	Hay: May 10-June 1
Approximate yield	Hay: 2-3 tons/A

Switchgrass - Perennial (***Panicum virgatum***)	
Description	Native warm-season sod-forming tall grass (3-6 feet) that produces an open panicle seedhead. Scaly creeping rhizomes. Can be identified by the cluster or nest of hair at the base of the blade where it joins the sheath.
Uses	Summer pasture or hay. Will not persist under close or frequent grazing.
Seeds per pound	330,000
Germinating time	14-21 days
Fertilizer	Generally low fertility requirement. At establishment: zero N, 80 lbs each of K_2O and P_2O_5. Maintain K_2O and P_2O_5 test in the medium soil test range. Apply 40-60 lbs N annually if legumes are not present.
pH range	5.5-6.5
Soil adaptation	Deep, well-drained to moderately well-drained soils.
Time of planting	May 15-July 15 using 6-8 lbs pure live seed.
Harvesting (hay)	Cut prior to seedhead emergence.
Harvesting (pasture)	Begin grazing when 18-24 inches tall. Do not graze below 8 inches.
Approximate first harvest	July 15-Aug. 1
Approximate yield	Hay: 2-5 tons /A

Tall Meadow Oatgrass - Perennial (***Arrhenatherum elatius***)	
Description	Bunchgrass that grows 3-5 feet tall; has an open panicle head similar to oats.
Uses	Hay and pasture. Makes early spring growth but very little aftermath growth.
Weight per bushel	10-15 lbs
Seeds per pound	150,000
Germinating time	14 days

Tall Meadow Oatgrass - Perennial (***Arrhenatherum elatius***) (cont.)	
Fertilizer	40-60 lbs N, 30-40 lbs P_2O_5, and 30-60 lbs K_2O
pH range	5.8-6.2
Soil adaptation	Well-drained to moderately well-drained sandy loam to silt loam soils.
Time of planting	Late summer or fall using 15-20 lbs alone or 10-12 lbs in mixtures.
Harvesting (hay)	Cut at early heading stage.
Approximate harvest dates	Hay: May 15-June 1
Approximate yield	Hay: 1-2 tons/A

Timothy - Perennial (***Phleum pratense***)	
Description	Semi-bunchgrass; erect and dull green leaves gradually tapering to a point; in late spring, the lower joint swells to form a small bulb; spike-like head; shallow, fibrous roots; round stem with prominent ligule.
Uses	Primarily hay; best adapted to the northern U.S., but does fairly well in Northern Piedmont and western Virginia. Makes very little regrowth after spring cutting compared to orchardgrass or tall fescue.
Weight per bushel	45 lbs
Seeds per pound	1,230,000
Germinating time	10 days
Fertilizer	40-60 lbs N, 30-40 lbs P_2O_5, and 30-60 lbs K_2O
pH range	5.8-6.2
Soil adaptation	Well-drained to somewhat poorly drained fine-textured soils.
Time of planting	8-10 lbs alone; 2-8 lbs in mixtures. Usually seeded in mixtures with clovers or alfalfa.
Harvesting (hay)	When alone: in full bloom; in mixtures: when legume is in early bloom.
Approximate harvest dates	Hay: June 1-July 1
Approximate yield	Hay: 1-3 tons/A

Tobacco, Burley - Annual (***Nicotiana tabacum***)	
Description	See Flue-Cured Tobacco. Plants typically larger than flue-cured. Stalk and leaf midribs are light green to cream-colored. Typical culture is for 18-22 leaves that are lighter green than flue-cured. The crop is grown from transplants historically produced in plant beds but now typically produced in greenhouses.
Uses	Primarily cigarette blends with a small amount used in the manufacture of pipe and chewing tobacco products. Approximately 30% is exported.
Seeds per ounce	330,000
Germinating time	7-12 days
Viability of seed	6-8 years under proper conditions (temperature in °F and relative humidity should add to 100).
Fertilizer	175-200 lbs N, 60-120 lbs P_2O_5, and 150-300 lbs K_2O per acre. Follow soil test recommendations.
pH range	When checked in the spring, a pH of 5.8-6.2 is preferred. **If the pH drops to 4.9 during the season, there is a danger of manganese toxicity.**
Soil adaptation	Fertile silt loam soils that have good internal and surface drainage.
Time of planting	Transplant from seedbeds May 15-June 1 using 6,225-8,300 plants/A in 3 1/2-foot rows, with plants spaced 18-24 inches in the row.
Disease control	The most successful disease management program uses multiple control strategies. Crop rotation and the use of disease-resistant varieties should be used in combination with chemical control methods.
Weed control	Herbicides alone will not control certain weeds closely related genetically to tobacco. Tobacco benefits from some soil aeration, so always cultivate tobacco at least one time, usually at lay-by time, even though weeds are not a problem.
Insect control	The Integrated Pest Management approach to insect control recognizes that a certain amount of insect damage will not reduce tobacco yield or quality enough to pay for the cost of treatment. Natural control should be promoted by delaying insecticide applications until a pest insect reaches an economic threshold level and by using the insecticides that are least harmful to beneficial insects.
Sucker control	Top the tobacco when the 50% bloom stage has been reached. Growth of suckers is controlled through the use of plant growth regulators. Typical control is through backpack sprays of maleic hydrazide or a combination of maleic hydrazide and a local systemic material.
Method of harvest	Hand-harvest plants by stalk cutting. Spear 5-6 plants onto each stick according to the size of tobacco. Leave tobacco in the field on standing sticks long enough to wilt sufficiently to handle without breakage of the leaves.
Method of curing	Air-cure in ventilated barns by placing sticks of speared tobacco 9 inches apart on the tier rails. Any temperature from 65°F to 95°F is satisfactory as long as the daily average relative humidity is between 65% and 70%. An alternative curing method is one that uses laborsaving field-curing structures covered with black plastic.

Tobacco, Burley – Annual (***Nicotiana tabacum***) (cont.)	
Approximate harvest date	Aug. 15-Oct. 1
Approximate yield	2,400-2,800 lbs/A of cured leaves

Tobacco, Dark-Fired – Annual (***Nicotiana tabacum***)	
Description:	See flue-cured tobacco
Uses:	The majority is exported for the manufacture of smoking tobacco, chewing tobacco and cigars. The domestic use is for dry snuff.
Seeds per oz:	330.000
Germination time:	7-12 days.
Viability of seed	6-8 years under proper conditions (temperature in °F and relative humidity should add to 100).
Fertilizer	135 lbs N, 40-100 lbs P_2O_5, and 100-175 lbs K_2O
pH Range	5.6-6.0
Soil adaptation	Well-drained loams and silt loams.
Planting	May 1-June 1 using 5,000-5,300 plants/A. Rows: 42-48 inches apart; plants: 24-30 inches in row.
Topping and sucker control	Plant should be topped at 12-14 leaves depending on the vigor of the plant after the bud has formed, before the flowers begin to open. Growth of suckers is controlled through the use of plant growth regulators. Foliar sprays of contact fatty alcohols and maleic hydrazide (in sequential applications) are effective with minimal hand labor. Alternative control uses treatment of individual plants with local systemic plant growth regulators.
Method of harvest	Cutting stalk.
Method of curing	Numerous small, smoldering fires on the barn floor. Hardwood or sawdust may be used to generate smoke. Smoke several times during the 6-week curing period.
Approximate harvest date	Aug. 15-Sept. 1
Approximate yield	1,200-2,500 lbs cured leaf

Tobacco, Flue-Cured - Annual (***Nicotiana tabacum***)	
Description	Central taproot with numerous short lateral roots. Single round stem 4-8 feet tall when not topped. Leaves are alternate, forming an ascending spiral up the stem. Leaves are 1foot or more in width and 3-4 feet long, with a unique ability to accumulate nicotine. All green parts of the plant are covered with sticky hairs. Flowers are pink or rose-colored and self-pollinated. The crop is grown from transplants historically produced in plant beds but now typically produced in greenhouses.
Uses	Primarily used in cigarettes. Approximately 40% is exported as unmanufactured leaf.
Seeds per ounce	330,000
Germinating time	7-12 days
Viability of seed	6-8 years under proper conditions (temperature in °F and relative humidity should add to 100).
Fertilizer	50-80 lbs N, 40-100 lbs P_2O_5, and 100-150 lbs K_2O. If necessary, topdress with a nitrate source of N. Use materials low in chlorine (less than 2%).
pH range	5.5-6.0
Soil adaptation	Well-drained soils with sandy loam surface and sandy clay loam subsoils.
Time of planting	Transplant between April 25 and May 20.
Rate of planting	6,000-6,500 plants per acre; 44-48 inch rows, plant 20-24 inches in row. The optimal number of leaves per acre is 110,000-120,000.
Side-dressing	Pre-plant fertilizer rates should not exceed 40 lbs of N and 120 lbs K_2O per acre. Additional N and K_2O can be applied as a side application to obtain the total amount of nutrients desired. Side-dressing applications of the base rate of nutrients should be made as soon as the stand is established. When leaching occurs, N and K_2O in addition to the base amounts recommended may be necessary. The quality of N and K_2O required depends on the amount of water that percolates through the plow layer and the stage of plant growth at the time this occurs.
Topping	Plants should be topped at the button to early flower stage of development, which is about the time harvest begins. Plants should be topped at 17-22 leaves, depending on plant vigor and weather conditions.
Suckering	After topping, suckers develop in the leaf axils and should be removed or controlled. Growth and suckers is controlled through the use of plant growth regulators. Foliar sprays of contact fatty alcohols and maleic hydrazide (in sequential applications) are effective with minimal hand labor. Alternative control uses treatment of individual plants with local systemic plant growth regulators.
Method of harvest	Leaves harvested individually by removing or priming as ripening begins at the bottom of the stalk and progresses upward.
Method of curing	Typically in bulk curing barns following a schedule lasting 6-7 days regulating temperature and drying rate. Supplemental heat (maximum (165-170°F) is required to yellow the leaf, dry the lamina, and finally dry the leaf midrib.

Tobacco, Flue-Cured - Annual (*Nicotiana tabacum*) (cont.)	
Approximate harvest date	Typically, 3 harvests or primings as leaves ripen. Harvest period may last 8-12 weeks, beginning as early as mid-July and ending as late as October.
Approximate yield	2,000-3000 lbs of cured leaves/A

Tobacco, Sun-Cured - Annual (*Nicotiana tabacum*)	
Description	See Flue-Cured Tobacco. Smaller plants than flue-cured.
Uses	Primarily exported for making smoking and chewing tobacco. A small portion is used domestically for plug chewing tobacco.
Seeds per ounce	330,000
Germination time	7-12 days
Viability of seed	6-8 years under proper conditions (temperature in °F and relative humidity should add to 100).
Fertilizer	125 lbs N, 40-100 lbs P_2O_5, and 100-175 lbs K_2O
pH range	5.6-6.0
Soil adaptation	Well-drained loams and silt loams.
Time of planting	May 1-June 1
Rate of planting	5,000-5,300 plants/A. Rows: 3 1/2 feet; plants: 28-30 inches in row.
Topping and sucker control	Plants should be topped at 12-14 leaves, depending on the vigor of the plant after the bud has formed, before the flowers begin to open. Growth of suckers is controlled through the use of plant growth regulators. Typical control is from hand application of a local systemic plant growth regulator to individual plants.
Method of harvest	Cutting stalk.
Method of curing	Air-cured in barns constructed to permit good ventilation. Heat needed only in periods of extremely high humidity.
Approximate harvest date	Aug. 15-Sept. 1
Approximate yield	1,000-2,000 lbs/A

Tobacco Greenhouses	
Production system	Transplants typically grown in Styrofoam plug trays floating in shallow plastic-lined pools containing a nutrient solution. An overhead-watered production system using plastic plug trays is an alternative production system.
Plant density	80-157 plants per sq ft in trays containing 200-392 plants.
Time of planting	Seed greenhouse with highest quality pelletized seed approximately 7-8 weeks before expected transplanting.
Fertilization	Use a complete (N-P_2O_5-K_2O) water-soluble fertilizer. More than 50% of fertilizer N should be derived from nitrate N. Fertilizer is added to the nutrient solution at a concentration of 100-150 ppm N.
Clipping	Clipping with a rotary mower is used to increase transplant uniformity, remove excess foliage, and regulate seedling growth. Clipping should begin when seedlings are 2-2 1/2 inches tall to the bud and clip 1-1 1/2 inches above bud. Clip 4-6 times before transplanting, raising blade height with successive clippings. Proper sanitation is critical for disease prevention.

Tobacco Plant Beds	
Seeding	1/8-1/6 ounce of seed per 100 sq yards of bed
Plant bed space	75-100 sq yards/A to be transplanted
Fertilizer	1/2-3/4 lb of 12-6-6 to each sq yard
Soil adaptation	Locate beds near a source of clean water on well-drained, sandy loams or loams. Do not locate beds in a shady area or in low-lying areas along creeks or rivers.

Vetch, Hairy - Annual (***Vicia villosa***)	
Description	Semi-viney legume with tendrils; hairy plants; stems 3-5 feet long; flowers bluish violet and white.
Uses	Hay, pasture, and winter cover. Sometimes called winter vetch. Because of the hardness of the seed, it often becomes a weed in small grain crops that follow.
Weight per bushel	60 lbs
Seeds per pound	21,000
Germinating time	14 days
Fertilizer	90-120 lbs P_2O, and 60-90 lbs K_2O
pH range	6.0-6.5
Inoculation	**Important:** Cross-inoculates with garden peas and field peas.

Vetch, Hairy – Annual (*Vicia villosa*) (cont.)

Soil adaptation	Well-drained to moderately well-drained sandy loams to clay loams.
Time of planting	Aug. 1-Nov. 1, depending on location. Plant 20-30 lbs alone; 10-15 lbs in mixtures; usually mixed with 1/2-1 bushel of small grain. Plant in 6-8 inch rows with small grains or solid-seeded.
Harvesting (hay)	When seeds in the lower half of the plants are half-developed.
Harvesting (seed)	Cut when first pods are well-developed.
Approximate harvest dates	Hay: May 1-June 1
Approximate yield	Hay: 1-2 tons, or seed: 200-600 lbs/A

Weeping Lovegrass – Perennial (*Eragrostis curvula*)

Description	A warm-season perennial bunchgrass. Long, slender, drooping leaves that grow to a height of 2-5 feet but usually do not remain upright. Seedhead is an open panicle, 6-10 inches long. Produces relatively poor-quality pasture and hay. Several varieties available. Virginia is the northern limit of the adapted area.
Uses	Limited hay and pasture, relatively low in palatability. Its primary use in Virginia is for soil stabilization and critical areas.
Seeds per pound	1,500,000
Germination time	14 days
Fertilizer	40-50 lbs N, 60-70 lbs P_2O_5, and 40-50 lbs K_2O
pH range	4.5-6.2. Tolerance to low pH enhances its value for soil stabilization.
Soil adaptation	Best adapted to sandy soils but will grow in heavier soil types.
Time of planting	April 15-June 1 is best but can also be seeded June 1-Aug. 15; 1-2 lbs in rows; 2-3 lbs solid-seeded.
Harvesting	Cut for hay before seedhead forms. For grazing: stock at high rates to use all forage and then rotate as needed.

Wheat – Annual (*Triticum aestivum*)

Description	Dark green leaves with short hairy auricles and long ligule. Seeds thresh free of their husks and are caramel-colored with smooth surface and a whitish brush on the end opposite the germ. Soft red wheat is the traditional class of wheat grown in Virginia.
Uses	Grain, grazing, and cover crops.

Wheat - Annual (*Triticum aestivum*) (cont.)

Weight per bushel	60 lbs
Seeds per pound	13,000-16,000
Germinating time	7 days at 65°F; 14 days at 50°F
Fertilizer	20 lbs of N in the fall plus 40-80 lbs each of P_2O_5 and K_2O at medium soil test levels. Topdress with 30-50 lbs N in February if the stand is thin or shows obvious N deficiency. Additional N should be applied in late March (40-80 lbs).
pH range	5.8-6.2
Soil adaptation	Any moderately well-drained or well-drained soil.
Time of planting	One week before to one week after the first killing frost, Oct. 15-Nov. 15 in Eastern Virginia; Oct. 1-Nov. 1 in the Piedmont; Oct. 1-25 west of the Blue Ridge. Plant 120-150 lbs per acre (36 seeds per sq ft or 20 seeds per drill foot in 7-inch rows). Plant in 6-8 inch rows or solid-seeded.
Harvesting	Combine when fully ripe at 10%-15% moisture. Cut for silage in the soft dough stage.
Approximate harvest dates	June 20-July 10
Approximate yield	50-100 bushels grain; 8-12 tons 35% dry matter silage/A

White Clover, Common - Perennial (*Trifolium repens* var. *latum*)

Description	Low-growing, short-lived legume; smooth leaves with 3 leaflets; shallow-rooted; spreads by soil surface stolons that root at nodes; white flowers.
Uses	Pastures, especially with bluegrass. Tolerates close, continuous grazing.
Weight per bushel	60 lbs
Seeds per pound	700,000
Germinating time	10 days
Fertilizer	With bluegrass at seeding, 0-20 lbs N, 90-120 lbs P_2O_5, and 60-90 lbs K_2O. For topdressing, 60-100 lbs each of P_2O_5 and K_2O every 3-4 years.
pH range	5.8-6.5
Inoculation	Cross-inoculates with alsike, crimson, ladino, and red clover.
Soil adaptation	Well-drained and moderately well-drained loams and silt loams.
Time of planting	45 days before last killing frost in spring or 30 days before first killing frost in fall using 1-2 lbs in mixtures.

White Clover, Ladino – Perennial (***Trifolium repens latum***)	
Description	Giant variety of white clover that resembles white clover in every respect except size.
Uses	Primarily for pasture with tall growing grasses such as orchardgrass. May be used for silage and hay, but hay is difficult to cure. Less persistent and grazing tolerant than common white clover.
Weight per bushel	60 lbs
Seeds per pound	700,000
Germinating time	10 days
Fertilizer	Alone at seeding: zero N, 90-120 lbs P_2O_5, and 60-90 lbs K_2O. Topdressing: no N, 30-40 lbs P_2O_5, and 30-60 lbs K_2O annually.
pH range	6.0-6.5
Soil adaptation	Well-drained and moderately well-drained loams and silt loams.
Inoculation	**Important:** Cross-inoculates with alsike, crimson, red, and white clovers.
Time of planting	30-60 days before the average date of the first killing frost in fall or 30-45 days before the average date of the last killing frost in spring. Fall seedings are preferred, especially in the Tidewater area. Plant 1-2 lbs with grasses. May be seeded alone at a rate of 3-5 lbs when used for hog or poultry pasture.

Zoysia (Japanese Lawn Grass) – Perennial (***Zoysia japonica Steud.***); Korean or Matrella Lawn Grass (***Zoysia matrella L.***)	
Description	Closely resembles bermudagrass. Spreads by stolons and short rhizomes. Turns brown with frost but greens up earlier than bermuda in the spring. Ligule is a fringe of hairs with some hairs found on the upper surface of the leaf blade. Forms a dense turf with leaves upright, which provides more cushion than bermuda. Flower is a weak spike and is seldom branched.
Uses	General lawn areas. Sometimes used for lawns, athletic fields, and play areas.
Growth habit	Often sod-forming with both stolons and rhizomes. Slow-growing, particularly in areas having cold nights. *Matrella* is similar to *Japonica* except for a finer texture.
Climatic adaptation	Both species have low moisture requirements. *Japonica* is best adapted to the intermediate zone between cool-humid and warm-humid regions. *Matrella* is a warm-season grass best adapted to warmer sections of warm-humid regions. Severely injured by cold weather. Becomes dormant early in fall and starts late in spring.
Soil adaptation	Grows best on soils of medium or good fertility; will survive at low fertility levels. Tolerates medium acidity but needs good drainage. Moderately shade-tolerant.
Fertilizer	For fertilizer and other management practices, see Turfgrass section.

Zoysia (Japanese Lawn Grass) - Perennial (***Zoysia japonica Steud.***); Korean or Matrella Lawn Grass (***Zoysia matrella L.***) (cont.)	
Method of establishment	Sod, sprigs, and plugs. The latter two are slow to establish, usually requiring at least 2 seasons.
Time of planting	Spring: 4-7 bushels/100 sq ft from May 15-July 1 in Northern Piedmont and mountains; and April 30-July 15 in Coastal Plains and Southern Piedmont. Plugs: 4,000 on 6-inch centers/1,000 sq ft. Plant from May 1-July 15 in Northern Piedmont and mountains, and April 15-Aug. 1 in Coastal Plains and Southern Piedmont.

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Part II.

Forage Crops

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Pastures

Pastures are the backbone of Virginia's beef, sheep, and goat industries. They are also essential for the state's pasture-based dairies and are of great importance to horse owners. The over 2 million acres of pasture in Virginia provide feed for grazing livestock; with proper management, these lands can meet nutritional needs with relatively low labor and equipment inputs. In much of the state, pastures are grown on soils or topography that is unsuitable for row cropping, and livestock create economic opportunity by converting these forages to meat, milk, and fiber for human use. In 2017, Virginia's combined beef, dairy, and small ruminant sales were worth over $1 billion to the state's economy. The hay and haylage produced in the state were valued at $354 million (2020 estimates). Pastures and forage crops are the backbone of the feed resources for the state's livestock industries, and under proper management, they provide conservation services (e.g., preventing erosion) on sites that might otherwise be unsuitable for agriculture. Greatest success is achieved when species and management are tailored to match the soils and climate of the state's diverse regions.

Species Selection, Pasture Establishment, and Frost Seeding

Pasture species recommendations depend on the types of pasture already available in the system, its intended use, and the type of soil, climatic conditions, and intended management. Details given in **table 1 (page 55)** will be helpful in selecting the mixture for individual needs. Remember, no species is a silver bullet; management is key to long-lived, productive stands. More information on maintaining pasture stands is in the sections on fertility management and grazing management to support forage growth and composition.

Seeding may be done in prepared seedbeds (by plowing, disking, and firming with cultipacker or roller) or by no-till establishment. No-till is generally preferred for lower environmental impacts and energy costs, but getting a successful stand from no-till requires advanced planning. Please see **table 2** for recommended steps for successful no-till. Before seeding, consult an Extension agent who is familiar with local growing conditions and can provide specific recommendations for pasture establishment.

Table 2. Basic rules for a successful no-till establishment.
1. Prepare well ahead to seed in the proper season.
2. Properly test soils and amend accordingly. If lime is needed, apply several months in advance.
3. Minimize competition or access by preventing weeds and removing heavy thatch or residues. **To plant in existing sod:** • Closely graze or mow off fields at least 45 days ahead of the planting date. • Allow the plants to regrow 3" - 4" of new growth then apply a "burn down" herbicide. • Apply burn down herbicide again to kill new weeds and escapes at about the time of planting. • Fall/spring or spring/summer burn down regimes also work to prepare fields. **To plant in crop fields:** • Bale or burn crop residues the previous fall. Planting through crop residues can be a challenge if the field is full of thick stalks.
4. In fields with broadleaf weed pressure, establish grasses first and then add legumes.
5. Use high-quality seed.
6. Control seeding depth: 1/8" to 1/4" is typical for small-seeded species and challenging to achieve through crop residue.
7. Monitor developing stand and control emerging weeds. This can be achieved with periodic flash grazing, clipping, or judicious herbicide application.

Adapted in part from No-Till Seeding of Forage Grasses and Legumes, Virginia Cooperative Extension publication SPES-92P. https://vtechworks.lib.vt.edu/bitstream/handle/10919/93065/SPES-92P.pdf?sequence=1&isAllowed=y.

Table 1. Recommendations for pasture seedings in Virginia

Use	Species	Seeding rate (lb/ac)	Soil adaptation	Establishment tips
Frost seeding legumes into grass pasture	Red clover	3-6	Grow clovers on medium- to heavy-textured soils with pH > 5.8 and medium or greater fertility.	Graze grass sod closely by February and then broadcast seed. Allow livestock to tread seed into the ground for 1 week.
	White/ladino clover	1-2		
	Annual lespedeza	10-15	Grow annual lespedeza on more acidic, lower fertility soils.	Frost seed every 2-3 years as legume abundance declines.
Cool-season grass pasture and hay fields11	Cool-season grass mixtures	15-20	Broad drainage tolerance with pH > 5.8 and medium or greater fertility.	Late summer/fall seeding typically recommended. For no-till plantings, kill existing stands about 3 weeks before seeding and re-treat at time of seeding to kill any escapes.
	Orchardgrass	8-12		When novel fescue is to replace KY31 pasture, do not allow the KY31 seedheads to develop within 18 months of the scheduled planting. This can be managed by close grazing or clipping seedheads in spring ahead of a fall planting. Growing smother crops or warm-season annuals for forage ahead of fall seeding helps to meet forage supply needs.
	Novel fescue	15-25		
Warm-season grass pasture and hay fields	Hybrid bermudagrass	12-20 (bu/ac)	Lighter textured, well-drained soils.	Where bermudagrass is commonly grown, sprigs are planted with a sprigger, but hybrid sprigs can be spread onto tilled ground with a manure spreader then disked in. Light grazing or haying is preferred in the establishment year.
	Switchgrass	6-1022	Medium- to well-drained soils. Good flooding tolerance.	Late fall to early spring plantings can work, but fields must be kept weed-free to reduce competition. Late spring to early summer plantings can work if seeds are not highly dormant. Again, keep fields weed-free. Success and longevity are increased if stands are not hayed or grazed in the first year.
	Pearl millet	15-3033	Millet yields can be higher on heavy-textured soils.	
	Sudan	15-20		
	Sorghum-sudan	20-30		

[1] Seeding mixtures of perennial grasses and legumes is generally not recommended. Success with mixed seedings is particularly difficult in renovated pastures due to weed pressure from the existing seedbank. General recommendations are to first plant grasses and control broadleaf weeds. Once the grass stand is successfully established, legumes can be frost seeded or drilled into the grass stand. Exceptions include sowing cool-season perennial mixtures into crop fields (with limited weed pressure) or planting summer- or winter-annual cover crop mixtures.

[2] General recommendations are to base planting rate on percent pure live seed (PLS), but switchgrass and other native grasses can have both high PLS and high dormancy.

[3] Drilled seeding rate.

Seed after the first good rain in August or September or between Feb. 15 and April 15, depending on the area of the state. Fall seedings are generally preferred, although some legumes may be sensitive to pathogenic diseases (e.g., Sclerotinia and Phytophthora) that more typically occur in fall. Generally, as one moves from the west to the east of the state, seeding can occur later in the fall and earlier in the spring. A reliable rule to follow is to seed 30-40 days before the first killing frost in the fall or 30 days before the last frost in the spring.

Frost seeding clovers is an excellent way to establish clovers and thicken pasture stands. Graze or mow the sod very closely by midwinter and then broadcast the seed on the soil surface during the month of February. Freezing and thawing of the soil, plus traffic and early spring grazing by livestock, should result in good seed-to-soil contact for clover establishment.

Grazing for Profitable Livestock Operations

Most ruminant livestock production systems achieve an optimum economic output at roughly 280-300 days of grazing each year. Stocking rates that require feeding more than about 65-90 days add costs above the value of the additional animals produced. Making and feeding hay is one of the most expensive parts of forage-livestock operations, and high stocking rates usually lower individual animal performance.

The basics for achieving 300 days of grazing include maintaining appropriate stocking rates and adequate soil fertility, combined with proper grazing management to support forage growth. Minimizing periods of forage deficit is critical. To reduce summer slump, producers can stockpile excess spring growth or grow warm-season annual or perennial forages to fill the seasonal production gap **(e.g., see fig. 1)**. Grazing summer-stockpiled forage and feeding hay in late summer can also support fall growth that makes up the winter stockpile. Feeding hay during dry periods to prevent overgrazing also allows pastures to quickly respond to returning rains.

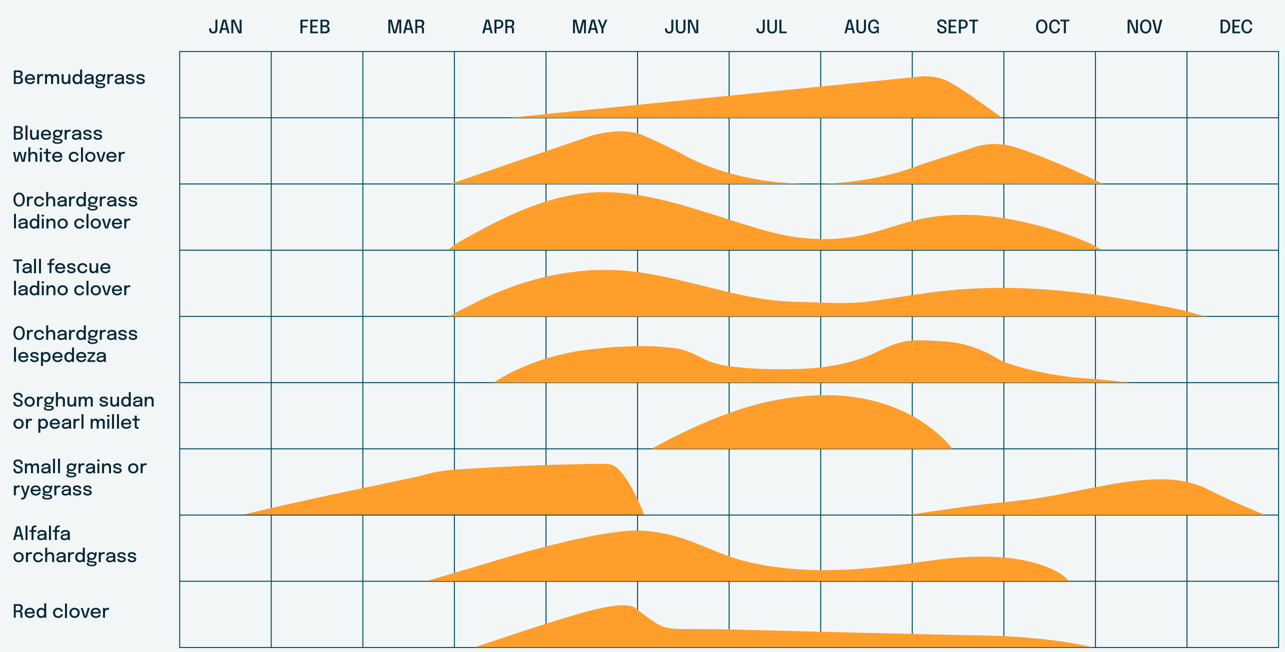

Figure 1. Generalized seasonal growth curves of several cool- and warm-season forage species.

Delayed grazing (or haying) also can benefit wildlife (particularly grassland bird survival). Producers interested in additional management information on grazing 300 days per season can find more at **Virginia Cooperative Extension's Graze 300 VA website:** https://ext.vt.edu/agriculture/graze-300.html.

Appropriate Stocking Rates

Matching stocking rates to the land base requires an understanding of animal needs and the potential productivity of a site. Soil productivity values are available through soil surveys and the National Resource Conservation Services' Web Soil Survey, found online. Your local agent or NRCS can help you use these tools that describe soil productivity in terms of animal unit months (AUM). An AUM represents the amount of forage required to sustain an animal unit for 30 days. (An animal unit (AU) is defined as a 1,000-pound cow with calf, two 500-pound steers, or five ewes with lambs. Note that the AU is based on body size and predicted intake, so adjustments for AUs must be made for heavier cows with larger frame size.) The AUMs for a soil map unit represent the months that one AU could graze on an acre. However, AUM ratings assume good pasture conditions and management (i.e., good ground cover, soil fertility maintenance, weed management, and rotational stocking of pastures). Actual productivity may be less than the soil's potential if past mismanagement (e.g., overgrazing or poor fertility practices) has degraded the soil resource. Thus, soil sample data, knowledge of site history, or both are important in understanding potential productivity and stocking capacity of a soil. General rules of thumb are that 1 acre of excellent pasture can feed an AU through the grazing season, whereas an AU needs about 1.5 acres of good pasture, 3 acres of average pasture, and as much as 6.5 acres of poor pasture to meet its needs for a season.

Fertility Management To Support Forage Growth and Composition

Meeting soil fertility requirements is foundational for productive forage crops and pastures that support good animal performance. In cool-season pastures, prioritize fertility management that supports legume growth. Most research indicates greater profitability for pasture systems that have abundant legumes. High quality pastures typically will contain 25%-40% clover. Pastures with a significant proportion of legumes also have lower total production costs because the legumes contribute nitrogen to the production system, minimizing or eliminating the need for supplemental nitrogen fertility inputs.

Soil testing provides benchmarks of fertility status for pastures and fields and provides a basis for lime and fertilizer inputs. Soil acidity often limits forage production, and liming is often the most impactful of fertility inputs to support improved forage production and species composition. Legumes generally require higher soil pH levels and greater soil phosphorus and potassium concentrations than forage grasses. Not all forages need higher pH levels, but most cool-season forages will do well in Virginia at a pH above 6.0 (see Part VIII. Soil Testing and Plant Analysis, Figure 1. Relationship Between Soil pH and the Availability of Minerals That Are Essential for Plant Growth).

Nitrogen fertilization for cool-season pasture or hay production should occur in early spring to support spring growth, or it may be applied in late summer to support production of fall stockpiled forage. Summer annual grasses should be fertilized in late spring to support summer growth. NOTE: No, or **limited, economic response** to applied nitrogen often occurs when fertilizer is applied to long-term pastures with high levels of soil organic matter, abundant clover, or both. Fertility timing, source, and climatic conditions can further affect this. Response to nitrogen is generally much greater on recently converted crop fields or soils with low organic matter. Nitrogen applications also must be managed to mitigate tall fescue toxicosis.

Grazing Management To Support Forage Growth and Composition

Successful grazing systems utilize livestock both as tools to manage the forage stands and as products for farm profitability. The challenge is to maintain optimal animal performance without compromising plant vigor. Rotational stocking management can give producers greater control over the livestock "tools" than continuous stocking and allows producers to make decisions about timing, intensity, and frequency of grazing events. Overgrazing pastures leads to weed invasion, increased soil temperatures (reducing cool-season plant growth), and reduced rain infiltration (increasing runoff, soil erosion, and nutrient losses among other negative effects). When to start and stop grazing will necessarily vary by species, season, and growing conditions. **Table 3** provides rough estimates for some common forage species.

Grazing Management To Support Animal Performance

Producers should strive to utilize the available forage without damaging the pasture, although forage management and stocking rate strategies will vary depending on markets and goals. Plan pasture rotations so that young, growing livestock have access to the highest quality grazing. Strategies for increased gain include use of leader-follower and creep grazing systems.

Table 3. Rule of thumb start and stop grazing heights and rest period length for common forage species.

Species	Start (inches)	Stop (inches)	Rest (days)
Alfalfa	10-16	2-4	30-40
Bermudagrass	4-8	1-2	7-15
Kentucky bluegrass	4-8	1-3	7-15
Orchardgrass	8-12	3-6	15-30
Pearl millet	20-24	8-12	10-20
Switchgrass	18-22	8-12	30-45
Tall fescue	8-10	2-3	15-30

Managing Excess Forage

To capture the excess forage that grows in spring, options are harvesting the forage, bringing in additional stock to graze the excess, or deferring grazing/harvest and using it as stockpile (see the following section, Stockpiling To Extend Grazing) during the summer deficit period. To harvest or stockpile, take pastures or hay fields that will have excess growth out of the rotation and allow livestock access only to those pastures that can be adequately grazed during the spring flush. When growth slows during the summer, make more pasture acreage available (or if animals were brought in, remove these extra stock). Occasionally, clipping pastures can be useful to remove tough, mature plant growth and prevent seed production by weeds. Generally, the best timing for clipping is around mid-June or late August, but proper grazing management helps minimize the need for clipping.

Mitigating Tall Fescue Toxicosis

Tall fescue is the predominant forage for livestock systems in Virginia. Most of this fescue contains a wild-type, fungal endophyte which supports the growth of the plant but which also produces toxic alkaloids that cause a number of health and production issues for grazing livestock. Alkaloid synthesis (and plant tissue concentrations) largely follow plant productivity; seasonality and management practices that support greater growth generally result in greater alkaloid concentrations. Alkaloid concentrations also vary by plant part, with highest concentrations in seedheads and stem bases. Alkaloids decay in standing forages during freeze-thaw events and also degrade with hay making. A longstanding idea is that toxins can be diluted by adding clover to pasture systems. However, the benefit from clovers is largely from improved intake, and the only way to eliminate toxicosis entirely is to remove toxic fescue from the diet. A number of strategies can help with mitigating toxicosis, and these are described in brief in **table 4**.

Table 4. Tips for mitigating alkaloid levels and the effects of fescue toxicosis.
1. Keep fescue vegetative. Remove seedheads or allow seed to drop before grazing (as with summer stockpiling).
2. Don't overgraze. Grazing into stem bases increases alkaloid intake.
3. Manage pastures and farm for greater forage diversity. Adding more species within fields or adding fields of other forage species (e.g., warm season grasses for summer grazing) can reduce overall fescue intake.
4. Incorporate legumes into pastures. Legumes can increase forage intake, and some legumes (e.g., red clover, trefoil, lespedezas,) contain compounds that bind or counter the effects of alkaloids.
5. Target fields dominated by fescue for hay production, stockpiling, and frost seeding with clover. Alkaloids decay during hay curing and also during freeze-thaw events in fall and winter. Grazing stockpiled fields creates better conditions for successful frost seeding.
6. Fertilize pastures sparingly with nitrogen, particularly in spring.
7. Harvest fescue hay in the boot stage.

Stockpiling To Extend Grazing

Winter Stockpiling

Additional grazing days in winter can be obtained by grazing or clipping tall fescue stands in August and then permitting plant growth to accumulate through late fall. Typical recommendations are to apply 40-80 pounds of applied nitrogen per acre following clipping/grazing. If necessary, feed hay during late summer to allow stockpiled pastures to grow. This is generally more economical (and logistically easier) than feeding hay in winter because it both supports forage growth (which doesn't happen in winter) and it can be done when soil and weather conditions are easier to navigate. Pasture that produces 3,500 pounds of forage by December can support 120 days of winter grazing for one AU, assuming intake is 2% of body weight each day and pasture utilization reaches 70%. Strip graze winter stockpile for greatest use efficiency.

Summer Stockpiling

Summer stockpiling is a more recent development in cool-season forage management. The basic protocol is to remove the livestock from a field by April 15 and allow the forage to grow throughout the spring and early summer. Leave the forage ungrazed or unmown until late summer. The standing forage shades the soil, retaining moisture and reducing the opportunity for summer annual weeds to develop. This forage is typically grazed between August and October. Summer stockpiling works well for dry cows, and the forage can be used as the primary feed resource when other pastures are stockpiling for winter. The same basic forage management principles apply to summer stockpiling in that strip grazing is recommended to increase efficiency of use and grazing days.

Making Hay and Haylage

Red clover, alfalfa, orchardgrass, and tall fescue are the most widely grown hay crops in Virginia. However, any forage that can be cut, dried, and stored can be used for hay. Refer to **table 1 (page 55)** for details on pasture and hay seedings.

Harvest hay or haylage in a timely fashion. Timely hay harvest can be challenged with variable weather, but harvesting hay well after the boot stage (when weather is usually drier) is a poor strategy. It may generate more bales, but the hay will be of low quality.Making haylage opens up the harvest window because less time is needed for wilting (rather than fully curing). This allows for earlier harvest, makes variable spring weather less of a harvest constraint, and allows for greater forage quality than overmature hay. NOTE: Making haylage with toxic (KY31) tall fescue is not recommended.

Cutting and Drying

Don't cut hay too close to the ground. Disc mowers allow significantly lower cutting heights and may need special shoes to keep cutting heights high enough. Cutting forage grasses as low as possible removes part of the stem bases and the energy reserves needed for regrowth. This also opens up the stand, allowing for greater weed invasion and higher soil temperatures (which negatively affects cool-season forages). Close cutting is made worse when the hay stand is cut late, and it also can result in significant contamination with dirt, which reduces forage quality. Desired cutting heights are similar to residual grazing heights described above.

Rapid drying is essential for making quality hay and haylage, and sunlight is the biggest driver of drying speed. Make wide swaths-cover at least 70% of the cut area-to increase solar exposure. Drying stemmy crops (e.g., alfalfa or sudex) is facilitated by crushing stems (conditioning) at the time of mowing. This permits the stems to dry at nearly the same rate as the leaves. Conditioning reduces curing time about one day for large-stemmed plants. Tedding hay turns and spreads the crop, increasing exposure to sunlight and reducing drying time. It is important to ted when the crop is moist to reduce leaf shatter. Rake, too, while hay is moist (about 40% moisture) and bale before hay is crisp (16%-20% moisture) to reduce field losses.

For haylage or baleage, the forage crop typically is chopped or baled after wilting, at moisture levels between 40% and 60%. Because the crop is harvested moist, field losses can be reduced. Critical components for ensiling forage include having moisture low enough and tight wrapping to avoid air pockets. Grasses generally ensile better than legumes because pH levels (which must be low enough to preserve the forage) are buffered by minerals in the legumes.

Hay Storage Losses

Hay baled with excess moisture results in mold growth and heating; this increases dry matter losses and decreases forage quality. Safe moisture levels for storage are 20% for rectangular bales, 18% for round bales, and 16% for large rectangular bales.

Hay dry matter and quality losses during storage can be high, particularly for round bales kept outside. For a 5-foot-diameter round bale, a 3-inch, 6-inch, or 12-inch layer of rot around the bale translates to a 10%, 19%, and 36% dry matter loss, respectively. **Table 5** summarizes losses with different storage systems.

Forage nutritive value also declines with dry matter loss from baling or storing moist hay. Soluble carbohydrates are lost while fiber and lignin concentrations increase. Protein concentrations may change little over time, but after weathering, the remaining protein will usually be less digestible. Losses in quality are usually greater for legumes than for grasses.

Factors to reduce outside storage losses of round bales:

1. The denser or more tightly the hay is baled, the lower the amount of spoilage as long as hay is baled at or below 18% moisture. Bale density is affected by the baling machine, the care/experience of the operator, and forage species. Fine-stemmed hays naturally produce a tighter bale. The density of round bales should be a minimum of 10 pounds of hay per cubic foot.
2. Closer twine spacing reduces storage losses but increases costs. Net wrap usually reduces storage losses compared to twine. Although it costs more than twine, net wrap is faster than twine wrap and bale form is generally more stable, making handling and storage easier.

Table 5. Summary of research results* on hay storage losses: percentage of dry matter lost after six months in storage.

	On bare ground	On gravel or pallets		On bare ground, covered			Inside a building
Source	No cover	No cover	Covered	Tarp	Wraps	Roof	
Michigan State University	35	30		15	23		12
Penn State University	15-40						4
Iowa State University	10-25	11					5
University of Georgia	50	35	14	10			4
• J. Production Ag. review							
• Anderson et al.	14						
• Belyea et al.	15			6			3
• Verma and Nelson	28-40			12	11		2
• Atwal et al.	40			30			2-9
• Baxter	33-35						9
University of Wisconsin (Holmes)	9.5	8	4				3-7
Oklahoma State (Huhnke)	5-20	3-15	2-4	5-10		2-5	2
University of Wisconsin (Saxe)	5-61	3-46	2-17		4-8	2-10	2
West Virginia University (Rayburn)	7-61	28-39	5-10				
Average loss after 6 mo. storage	**27**	**22**	**8**	**13**	**13**	**5**	**5**

Source: Iowa State University Extension and Outreach, Ag Decision Maker, November 2017.

3. Store bales on well-drained upland sites. Hay/soil contact should be avoided if possible. Wooden pallets, telephone posts, scrap pipe, cross ties, and rock pads are all effective.
4. If a multiple-bale cover is NOT being used, bales should be stored in rows with rounded sides at least 3 feet apart. Flat ends should be firmly butted against one another. Align rows north and south to allow maximum exposure of the rounded sides to the sun. A gently sloping site will allow rapid drainage of rainwater. Bales should be oriented up and down the slope near the top of slope, preferably with southern exposure. Never store bales under trees.
5. Place three or five rows of bales in triangular stacks under a tarp or plastic sheet that is secured firmly. Inside storage is the best way to ensure low storage losses. Investment in barns for hay storage is more easily justified with (1) increasing hay value or porosity, (2) the greater and/or more frequent the rainfall, (3) the longer the period of storage. For example, with an estimated construction cost of $7.50 per square foot, it pays to build a barn to store hay valued at $60 per ton that otherwise would experience losses of 20% or more when stored outside. Hay valued at $100 per ton justifies barn construction if outside storage losses approach 15%.

Feeding To Minimize Hay Losses

Several strategies can be utilized for hay feeding. Hay ring feeders are available to help limit wastage and their utility will vary with design. Using ring feeders but feeding from a stationary position can also cause significant disturbance to soils that need to be smoothed and reseeded. Producers might roll hay out on the ground, though this can result in large amounts of lost feed. Using a portable electric fence can reduce trampling and fouling losses. Newer approaches include “bale grazing” and fence line feeding. With bale grazing, bales are set out in late fall, and the cow herd is rotated through the pasture later in winter using portable fencing to control animal access in the pasture and ring feeders to reduce bale waste. This approach can keep nutrients in the field and better distributed, though some reseeding may be needed. With fence line feeding, the feeder stations are part of the fence line and provide multiple feeding points along a hardened access road. This approach can add significant nutrient loading around the feeder, but it minimizes traffic over wet pastures.

Making Silage

Most crops grown for livestock feed can be allowed to ferment and be fed as silage. **Table 6 (page 63)** provides generally expected yields, crude fiber, and acid detergent fiber of several silage crops.

Handling of the crop for silage should always favor proper fermentation. **Figure 2 (page 63)** describes what actually occurs during ensiling. The quantity and quality of silage varies with crop species.

Grain-crop silages such as corn, barley, wheat, oats, and grain sorghum are normally harvested directly as they stand in the field when the grain reaches the dough stage. The relatively high dry matter content of the grain in such silage, plus the drying effects of advancing maturity, results in silage within the desirable dry matter range (35%-42%).

When these same crops are harvested at a less mature stage or when the traditional hay crops are handled as silage, it is necessary to partially dry or “wilt” the plants in the field before ensiling. Wilting usually requires about one day under favorable drying conditions. Crushing the stems with a conditioner hastens the drying process.

Experience and good judgment are needed to determine when the crop is wilted to the proper dry matter level. The "grab test" is useful as a guide to determine forage dry matter content. Collect a fistful of fine forage and squeeze tightly for 90 seconds. Release and observe the condition of the ball based on the descriptions below in **table 7 (page 64)**.

Table 6. Annual yield and composition of silage crops.

Crop	Stage	Yield (ton/acre, 35% DM)	Crude protein (%, DM basis)	ADF* (%, DM basis)
Corn	Hard dough	15-25	8	28
Grain sorghum	Dough	10-15	9	42
Forage sorghum	Early head	10-15	11	29
Sorghum sudan	Early head	7-15	12	45
Barley	Dough	7-15	9	36
Wheat	Dough	7-15	9	36
Oats	Dough	5-10	10	38
Rye	Boot	4-6	13	40
Alfalfa (4X)	Late bud/early bloom	10-12	18	33
Red clover	Early bloom	7-8	12	43

*ADF = acid detergent fiber.

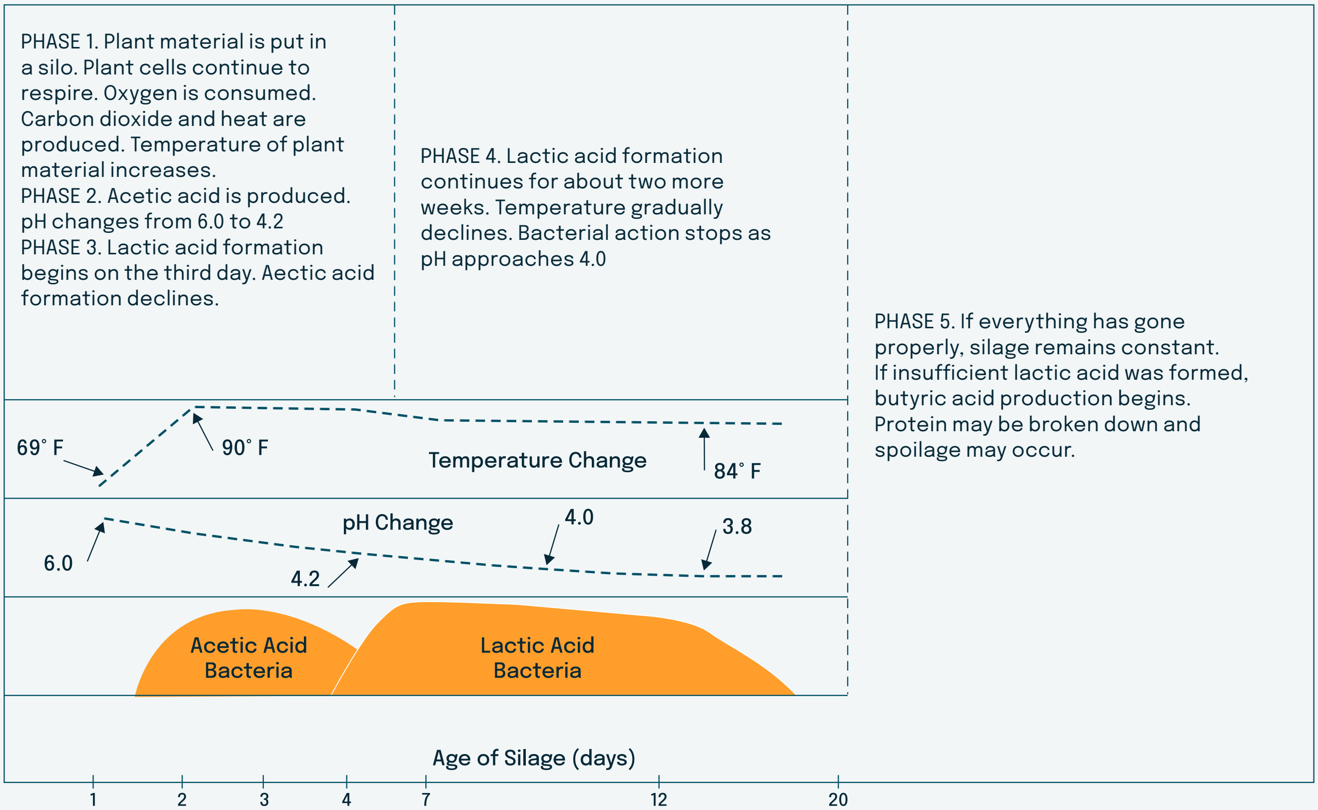

Figure 2. Changes in bacteria concentrations, pH, and temperature during the ensiling process.

Table 7. Estimated forage dry matter content based on a forage ball's characteristics.

Description of a forage ball	Approximate dry matter content (%)
Holds its shape but has considerable free juice	<25%
Holds its shape, hand is moist, little very free juice	25%-30%
Expands slowly with no free juice	30%-40%
Springs out and falls apart rapidly	>40%

High Moisture Corn and Earlage

Harvesting crops for silage generally utilizes the full plant. In some instances, only a portion of the plant is harvested. Corn ears can be harvested and ensiled as "earlage," or in some cases, the corn grain can be shelled and then fermented. This harvest method provides for grain storage without the costs of drying as well as a source of grain for balancing rations. These high-moisture materials can be easily mixed and fed with silage. Fewer harvest losses from shattering occur, and harvesting can be done two to three weeks earlier than dry corn, thus reducing lodging losses in some years and providing additional time for establishing cover crops.

High-moisture shelled corn and earlage should be harvested when the ear reaches physiological maturity. At this stage, kernels are well dented, and those near the center of the ear show the typical black layer at the base where they are attached to the cob.

Conventional concrete stave silos or oxygen-limiting units are effective means for storing high-moisture shelled corn or earlage. If stored in concrete stave silos taller than 60-70 feet, placing extra hoops around the bottom 30 feet of the silo is suggested. Fermentation is complete in 15-20 days. The suggested moisture level for storing high-moisture shelled corn is 28%, with a range of 25%-30%. It should be ground or rolled before being fed.

For earlage, the moisture range of the kernel is 28%-30%, with 28% considered ideal. Because the cob will contain 40%-50% moisture, the moisture content of the earlage will be about 32%. Earlage must be ground before it is stored. The main objective is to break the kernels, so fine grinding is not necessary. Holes in the screens of hammer mills or recutters range in size from 0.5 inch to 1 inch.

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Part III.

Turfgrass

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Current publications on turfgrass management and other turfgrass industry related information can be found on the **Virginia Cooperative Extension publications website** (https://pubs.ext.vt.edu).

Turfgrass Establishment

Pre-Planting Steps Involved in Successful Establishment of Turfgrasses

1. Select the best grass for climate, specific site conditions, its intended use, and maintenance requirements. Consider cold, heat, and drought tolerances for cool- and warm-season species and cultivars. Keep in mind that not all grasses grown in Virginia are available from seed.
2. Submit a soil test sample to the Virginia Tech Soil Testing Laboratory to determine lime and fertilizer needs. Samples should be taken one to two months prior to establishment. Standard tests will provide recommendations for phosphorus, potassium, and lime. Exchangeable calcium and magnesium are also determined in the standard test. For preplant nitrogen applications plant, water-soluble nitrogen can be applied at levels up to 0.7-lb nitrogen per 1,000 sq ft. Slowly available nitrogen can be applied at levels up to 0.9 lb per 1,000 sq ft for cool season or 1.0 lb per 1,000 sq ft for warm season. Control any perennial grass or broadleaf weeds present.
3. Tillage will be necessary where soil compaction is severe, phosphorus or lime needs to be incorporated, or significant surface regrading is required. On other areas, light surface tillage will suffice.
4. Grade the area to establish surface drainage. Save the topsoil by moving it to the side if extensive grading or internal drainage is required.
5. Apply all of the recommended lime and two-thirds of the fertilizers and nitrogen source recommended by the soil test.
6. Till above materials into a depth of 4-6 inches.
7. Finish grade by fine raking.
8. Apply the remaining one-third of the establishment fertilizers and rake into the surface inch of the prepared soil.

Seeding

1. Apply seed at recommended seeding rates **(see table 1, page 67)** in terms of pure live seed (the percentage of pure living seed is calculated by multiplying percent germination by percent purity for each cultivar). Lightly rake the area to incorporate the seed in the surface 1/4-1/2 inch. Be careful not to bury very small-seeded grasses such as Kentucky bluegrass, bermudagrass, zoysiagrass, or centipedegrass. Recommended planting time by region of the state is listed in **table 2 (page 68).**
2. Roll the area with a moderately heavy roller to firm the surface and assure good soil-to-seed contact.
3. Plan for weed control depending on the season of seeding. For fall seeding of cool-season grasses, Tenacity (active ingredient mesotrione) provides excellent control of many important winter annual and perennial weeds, and it can be applied at seeding (DO NOT use on warm-season grasses). For early postemergent control of most summer annual grassy weeds (except for goosegrass), Drive (active ingredient quinclorac) can be used on most cool- and warm-season grasses. **Read pesticide labels very carefully for specific species and/or variety concerns with some herbicides.**

4. Uniformly mulch the area (1–2 bales of weed-free straw per 1,000 sq ft) if frequent and uniform irrigation is unavailable. Don't attempt to remove the mulch as the grass establishes; simply mulch it back into the turf with the mower. Other mulching solutions could include granular-type products made from shredded newsprint or other recycled paper fiber. Some mulch products are suitable to be applied as a hydromulch using a hydroseeder.
5. Keep the seed zone moist but not saturated. New seedings may require several shallow waterings per day to ensure rapid germination. Only the top 1/4–1/2 inch needs to be kept moist. Without frequent daily irrigation, sprigs easily desiccate immediately after planting. Sod and plugs also require frequent, sometimes daily, irrigation in the first three to four weeks after planting.

Table 1. Recommended seeding rates for common turfgrass species, rate per 1,000 square feet.

Turfgrass species	Seeding rate (lbs/1,000 sq ft)
Kentucky bluegrass	2–3
Tall fescue	6–8
Fine fescue	3–5
Perennial ryegrass	3–5
Bermudagrass (hulled)	1–2
Bermudagrass (unhulled)	5–10
Zoysiagrass	1–2
Centipedegrass	0.25–0.50

Vegetative Plantings

Plugging and Sprigging

All of the warm-season grasses (bermudagrass, centipedegrass, zoysiagrass, and St. Augustinegrass) produce creeping stems and can be vegetatively established using either plugs or sprigs (stems often harvested from shredded sod). Soil preparation should be as previously described. The plugs should be fitted tightly into precut holes on 6–12 inch centers and tamped into place. Sprigs can be broadcast and lightly disked or pressed into shallow rows on 6–12 inch centers and covered with soil, with this being an important means of establishing bermudagrass and zoysiagrass in particular. Sprigging rates for bermudagrass and zoysiagrass range from 7 to 10 bushels per 1,000 sq ft and frequent irrigation is required for establishment. Note that zoysiagrass is very slow to establish from sprigs, and higher sprigging rates are recommended when possible. Standard preemergent herbicides can be used for plug and sprig establishments, but their modes of action do tend to reduce rooting of the creeping stems; for this reason they often are not applied.

Sodding

Soil preparation is similar to that described for seeding: a smooth, firm surface is needed. On hot days, moisten the soil to cool it before laying sod. Premium quality, certified sod is easier to transport and install than inferior grades. Good sod is light, does not tear easily, and quickly puts a root system into prepared, well-watered soil. Install sod as soon as it is received; sod is perishable and should not remain in a stack longer than 36 hours.

Table 2. When to plant cool- and warm-season grasses by region in Virginia.

When to plant cool-season grasses[1]				
Area of Virginia	**Seed**	**Sod**		
Northern Piedmont, areas in and west of the Blue Ridge	Aug 15-Sept 15 or March-early April	Any time soil is not frozen		
Southern Piedmont and Eastern Virginia	Sept 1-Oct 15 or Feb and March	Any time soil is not frozen		
When to plant warm-season grasses[2]				
Area of Virginia	**Seed**	**Sod**	**Sprigs**	**Plugs**
Northern Piedmont, areas in and west of the Blue Ridge	May-July 15 (choose appropriate cultivars for climate)	June 1-July 15	June 1-July 1	June 1-July 15
Southern Piedmont and Eastern Virginia				
a. Hulled and eastern bermudagrass	May-July 15	Late May-Aug 15	Late May-July 15	Late May-July 15
b. Hulled bermudagrass	Late fall or winter prior to growing season	Not applicable (N/A)	N/A	N/A

[1] Cool-season grasses include Kentucky bluegrass, fine fescue, perennial ryegrass, tall fescue, and creeping bentgrass
[2] Warm-season grasses include bermudagrass, zoysiagrass, centipedegrass, and St. Augustinegrass.

Establish a straight line lengthwise through the lawn area and lay the sod on either side of the line with the ends staggered as when laying bricks. A sharp masonry trowel is very handy for cutting, forcing the sod tight, and leveling small depressions. Herbicides are generally not necessary for sod installations because the sod itself provides most of the weed control by its competitive nature for space. Roll and water the new lawn immediately; irrigate to moisten the soil below the sod until it is well rooted into the soil.

Sod Versus Other Establishment Methods

Successful**,** weed-free establishment is more difficult with seed, sprigs, or plugs than with sod. Also, the area is exposed to erosion because of the time required for germination and root growth of seed or the lateral growth of creeping stems. Sod use practically eliminates such problems, which is an especially important factor on steep slopes.

Post-Planting Steps To Ensure Successful Establishment

After seed germination, maintain moisture in the soil to a depth of 4-6 inches until plants are well established. Gradually adjust irrigation programs from "lightly and frequently" to a maintenance program that follows a "deeply and infrequently" irrigation strategy.

Initiate a mowing program with a sharp blade that follows the "one-third rule" (never remove more than one-third of the leaf blade at any time) of clipping. Ensure that soil moisture conditions are suitable for foot and equipment traffic to avoid rutting and footprints.

When the sod, sprigs, or plugs are fully rooted or the seed is established, fertilize in accordance with maintenance fertilization recommendations for the grasses (refer to **VCE publication CSES 135P, Lawn Fertilization in Virginia**, available at www.pubs.ext.vt.edu/content/dam/pubs_ext_vt_edu/CSES/CSES-135/CSES-135-pdf.pdf). Begin mowing with a sharp mower as soon as the grass reaches a height one-third greater than the recommended mowing height.

Weed control programs typically are not initiated on recently established grass until the turf has been mowed three to four times. Follow label directions very carefully to safely treat new establishments and to optimize control.

Fertilization and Liming of Established Turfgrass

Phosphorus, potassium, and lime requirements should be determined by soil test. Turf grown on irrigated sandy soils or subjected to frequent and heavy traffic could require higher amounts of nutrients. Turf grown in the shade requires less nitrogen.

Do not apply readily available nitrogen sources in excess of 0.7 lb of actual nitrogen per 1,000 sq ft per active growing month in any single application. For sources that are greater than or equal to 15% slowly available nitrogen, apply no more than 0.9 lb (cool season) or 1.0 lb (warm season) nitrogen per 1,000 sq ft per active growing month, adjusting the fertility program respective to the grass and situation requirements. If possible, water in all fertilizers following application.

Timing and rate of fertilization are influenced by turf species, existing turf conditions, desired level of quality, type of fertilizer, time of year, etc. Established cool-season turfs are fertilized predominantly in the fall and lightly in late spring, while established warm-season turfs are fertilized from late spring through August. Avoid summer fertilization on cool-season grasses if at all possible. Do not apply urea within two weeks of liming.

Phosphorus and potassium levels can be high enough in the soil that there is no need to apply additional amounts of these nutrients. This can be determined by soil test.

Nitrogen fertilizers will state from what source (or carrier) the nitrogen is derived. The nitrogen carrier has a great impact on how you fertilize because different nitrogen carriers make nitrogen available to the turf at different rates. Consequently, the carrier will affect how much nitrogen to apply as well as when to apply it.

Nitrogen fertilizers are generally broken down into two categories: those with water-soluble, readily available nitrogen and those with slowly available nitrogen. Nitrogen fertilizers that are readily available have all of their nitrogen immediately available for plant use. After three to six weeks, this type of nitrogen is used up by the turfgrasses and results in short periods of turfgrass response. Slowly available nitrogen, however, can last from eight to 12 weeks or more.

Some of the nitrogen in slow-release fertilizers can be water-insoluble nitrogen. The percent WIN is usually stated on the fertilizer container. The fraction of nitrogen not listed as WIN should be regarded as readily available nitrogen. To effectively gauge the type of plant response from using slow-release fertilizers, calculate the percent of the total nitrogen in the container that is WIN by the following example:

In this example, 35% of the nitrogen is WIN, while the other 65% of the nitrogen is considered readily available nitrogen. In using such a fertilizer, one could expect to get an immediate response due to the high amount of readily available nitrogen. As a general guideline, if the fertilizer being used has 15% or less WIN or other slowly available N sources, it should be used in the same manner as a readily available nitrogen source in fertilizer programs.

Fertilizer label 16-4-8:	Total nitrogen	16.00%
	5.6% water insoluble nitrogen or WIN-available phosphoric acid (P_2O_5).	
	4.00%	
	Sulfate of potash (K_20)	8.00%

To find % of N that is WIN, use the following calculation:

$$\frac{(5.6\,WIN\ x\ 100)}{(16\,total\ N\ x\ 100)} = 35\%\ \text{WIN.}$$

If the fertilizer has greater than 15% WIN or other slowly available N sources, it should be used in fertilizer programs as a slowly available form of nitrogen.

Typical nitrogen carriers, along with their inherent characteristics, are listed in **table 3 (page 73)**.

Calculating How Much Fertilizer To Purchase

In deciding what type of fertilizer to purchase, it is usually helpful to first look at Virginia Tech's recommendations for fertilizer programs that best fit a particular situation (grass species and location). Recommendations are commonly made on the basis of the number of pounds of actual nitrogen per 1,000 sq ft of lawn area. To convert pounds per 1,000 sq ft to pounds per acre, multiply the pounds of nitrogen per 1,000 sq ft by 43.5 (which is the number of 1,000 sq ft units in 1.0 acre).

The amount of fertilizer to be purchased for any one application will depend on the percent of nitrogen contained in the fertilizer. For example, to apply 1.0 lb N/1,000 sq ft from sulfur-coated urea (32% N), divide the desired application rate by the analyses (1.0 lb N/0.32 N = 3.1 lbs of sulfur-coated urea fertilizer needed to apply 1.0 lb N/1,000 sq ft). The total quantity of fertilizer material needed for an area is calculated by multiplying 3.1 lbs of material by the number of 1,000 sq ft units of lawn area to be fertilized. For example, if a homeowner had 8,500 sq ft of lawn area and wanted to use a 46-0-0 (46% N) fertilizer to apply 0.7 lb of actual nitrogen per 1,000 sq ft of lawn, the homeowner would make the following calculations:

$$\frac{1.25}{00.7} = 1.8 \; per \; 1{,}000 \; sq \; ft.$$

1.8 lbs of fertilizer per 1,000 sq ft x 8.5 units of 1,000 sq ft = 15.3 lbs of fertilizer needed per 8,500 sq ft of lawn.

Applying the Right Amount of Fertilizer

Getting the most out of every fertilizer dollar involves knowing how to accurately apply fertilizer to your lawn. Most lawn fertilizers are applied by the homeowner as dry granules using either a drop-type or spinner-type fertilizer spreader. Each fertilizer spreader will have a dial to adjust the spreader openings that determine how much fertilizer is applied as the spreader travels across the lawn. Changing to a fertilizer of different granule size or weight and varying speed of spreader operation can alter application rates. Therefore, homeowners should be able to calibrate or adjust their fertilizer application.

Calibrating a Drop-Type Spreader

1. Attach a pan, bag, bucket, or other apparatus to the spreader to collect the fertilizer during operation.
2. Fill the spreader.
3. Determine the width of spreader application.
4. Operate the spreader to cover 435.6 sq ft. NOTE: For an 18-inch wide spreader, the distance should be

$$\frac{435.6 \; sq \; ft}{1.5 \; ft} = 290.4 \; ft$$

5. Weigh the amount of fertilizer collected.
6. Multiply the weight collected by 2.3 to calculate fertilizer applied per 1,000 sq ft.
7. If a per-acre delivery rate is desired, multiply the weight collected by 100 to calculate fertilizer applied per acre.
8. Repeat this procedure and continue by trial and error, adjusting the applicator dial each time until the desired application rate is reached.

Calibrating a Spinner-Type Spreader

The procedure and calculations are the same as the drop-type spreader except the width of the fertilizer throw is used as the spreader width. For example, if a spinner spreader has an application width of 5 feet, the operating distance would be

$$\frac{435.6\ sq\ ft}{5\ ft} = 87\ ft$$

This type of applicator gives the best results when half of the desired fertilizer application rate is applied traveling in one direction, while the other half is applied in a direction at a 90-degree (right) angle to the first in a crisscrossing pattern. This ensures more uniform coverage by minimizing the effect of leaving too much space between swaths. However, when using this half plus half crisscrossing method, be sure to calibrate the spreader to apply half of the fertilizer to the 435.6 sq ft area because the lawn area will be covered twice.

Spreader Calibration Without a Collection Device

Method A: The procedure and calculations are the same except that the fertilizer material is repeatedly applied onto wrapping paper or a smooth concrete floor until an area of 435.6 sq ft is covered. The material is then swept up and weighed to determine the application rate per 435.6 sq ft.

Method B: A quantity of fertilizer is weighed and then put in the spreader. The spreader is operated over a 435.6 sq ft lawn area (this fertilizer material cannot be recovered), and the fertilizer remaining in the spreader is then weighed. Subtracting the weight of the remaining fertilizer from the starting weight will equal the fertilizer application rate per 435.6 sq ft.

Method C: This method actually does not involve calibration, but it works particularly well for smaller lawns (10,000 sq feet or less) and applications with spinner-type spreaders that have easy to adjust application levels. Determine the area of the lawn and calculate the amount of fertilizer to the area to be treated. Place that amount of fertilizer in the hopper, select a very low setting on the spreader, and start delivering the product in multiple passes over the lawn in different directions. This method is not the most efficient in terms of time, so it would not be desirable for a lawn care professional being paid by the job, but it is quite effective for treating smaller areas in lieu of the time spent calibrating the spreader.

Table 3. Characteristics or nitrogen fertilizer sources commonly used in turf.

Nitrogen source	% nitrogen	Lbs needed for 0.7 lb of nitrogen[1]	Lbs needed for 0.9 lb of nitrogen	Lbs needed for 1.0 lb of nitrogen	Nitrogen availability	Foliar burn potential
Ammonium sulfate	20.5	3.4	N/A	N/A	Fast	High
Calcium nitrate	15.5	4.5	N/A	N/A	Fast	Very high
Urea	45	1.5	N/A	N/A	Fast	High
Urea formaldehyde	38	1.8	2.4	2.6	Slow[2]	Low
Isobutylidene diurea	31	2.3	2.9	3.2	Slow[3]	Low
Sulfur- or polymer-coated urea	Varies (32 used as standard)	2.2	2.8	3.1	Moderate[4]	Low
Methylene urea	Varies (40 used as standard)	1.8	2.3	2.5	Moderate[5]	Low
Natural organic	Varies (6 used as standard)	11.7	15.0	16.7	Slow[2]	Low

[1] Up to 0.7 lb of water-soluble nitrogen per 1,000 sq ft per active growing month can be applied to either cool-season or warm-season grasses. For products that are 15% or more slowly available nitrogen, up to 0.9 lb or 1.0 lb of nitrogen can be applied per 1,000 sq ft per active growing month to cool-season or warm-season grasses, respectively.
[2] Release is dependent on microbial activity and factors that affect it (e.g., temperature, soil, pH, aeration, moisture, etc.).
[3] Release rate is dependent on moisture availability, particle size, and soil pH.
[4] Release rate is dependent on particle size, soil temperature, soil moisture, mechanical breakage, and thickness of the coating.
[5] Release rate of controlled release component of methylene urea is dependent on microbial activity; small amounts of soluble nitrogen in the product will provide almost immediate response.

Applying at the Proper Time

Proper timing of nitrogen applications is different for warm-season and cool-season turfgrasses because of their different growth cycles. The following four charts show the recommendations for pounds of actual nitrogen per 1,000 sq ft of established lawn area using both quick-release and slow-release nitrogen sources for both warm- and cool-season grasses. The charts can be used to determine the most effective times of application for different levels of turfgrass quality.

Fertilizer Programs for Cool-Season Grasses

The best time to fertilize cool-season grasses, including Kentucky bluegrass, tall fescue, perennial ryegrass, and fine fescue (creeping red fescue, hard fescue, sheep fescue, and chewings fescue), in Virginia is from Aug. 15 through November. Excessive spring application of nitrogen to cool-season grasses in Virginia leads to excessive leaf growth at the expense of stored food reserves and root growth, increasing injury to lawns from summer disease and drought.

Table 4. Recommended nitrogen fertilizer rate and timing for various management programs.

Program 1. Nitrogen application by month using predominately quickly available nitrogen fertilizers (less than 15 % slowly available nitrogen or water-insoluble nitrogen).

	Sept	Oct	Nov	May 15-June 15
Quality desired	(lb N/1,000 sq ft)			
Low	0.0	0.7	0.0	0.0-0.7
Medium	0.7	0.7	0.0	0.0-0.7
High	0.7	0.7	0.7	0.0-0.7

Program 2. Nitrogen application by month using predominately slowly available nitrogen fertilizers (15% or more slowly available nitrogen or water-insoluble nitrogen).

	Aug 15-Sept 15	Oct 1-Nov 1	May 15-June 15
Quality desired	(lb N/1,000 sq ft)		
Low	0.9	0.0	0.0
Medium	0.9	0.0	0.0-0.9
High	0.9	0.9	0.0-0.9

Important Notes About Programs 1 and 2

1. Fine fescue performs best at 1-2 lbs nitrogen per 1,000 sq ft per year.
2. Applications in successive months should be approximately four weeks apart.
3. Natural organic and activated sewage sludge products should be applied early in the application periods in Program 2 to maximize their effect.
4. If nitrogen was not applied the previous fall or to help a new lawn get better established, 0.7 lb nitrogen in Program 1 and up to 0.9 lb nitrogen in Program 2 may be applied per 1,000 sq ft in the May 1-June 15 period.

Fertilizer Programs for Warm-Season Grasses

Warm-season grasses, including bermudagrass, zoysiagrass, St. Augustinegrass, and centipedegrass, perform best when fertilized between April 1 and Aug. 15 in Virginia. Do not initiate spring nitrogen fertilization programs until frost potential has passed.

Table 4. Recommended nitrogen fertilizer rate and timing for various management programs. (cont.)

Program 3. Nitrogen application by month using predominately quickly available nitrogen fertilizers (less than 15% slowly available nitrogen or water-insoluble nitrogen).

	April*	May	June	July-Aug
Quality desired	(lb N/1,000 sq ft)			
Low	0.0	0.7	0.7	0.0
Medium	0.0	0.7	0.7	0.7
High	0.7	0.7	0.7	0.7

*Whenever possible, initiate spring fertilizer applications after turf greening is complete.

Program 4. Nitrogen application by month using predominately slowly available nitrogen fertilizers (15% or more slowly available nitrogen or water-insoluble nitrogen).

	April 15-May 31	June 1-July 15	July 16-Aug 15
Quality desired	(lb N/1,000 sq ft)		
Low	0.0	1.0	0.0
Medium	0.0	1.0	1.0
High	0.9	0.9	0.0-0.9

Important Notes About Programs 3 and 4

1. If overseeded for winter color, add 0.5-1.0 lb of readily available nitrogen per 1,000 sq ft in October and November.
2. Applications in successive months should be approximately four weeks apart.
3. Centipedegrass and mature zoysiagrass perform best at 1-2 lbs nitrogen per 1,000 sq ft per year.
4. Improved winter hardiness on bermudagrass will result from the application of potassium in late August or September.

Turfgrass Management Table Based Upon Use and Location in Virginia

Grass Species & Recommended Use	Adaptation[1]		Fertilization Requirements[2] lbs Nitrogen / 1000 sq ft/yr			Mowing Height[3]	Overseeding Rate[4] lbs/1000 sq ft
	Northern Piedmont & Areas West of The Blue Ridge	Southern Piedmont & Eastern Virginia Areas	Nitrogen (N)	Phosphate (P_2O_5)	Potash (K_2O)		
Bermudagrass 5, 6							
Lawns	NA	A	2-4	0-3	1-3	1 - 2"	2-10
Athletic Fields	A*	A	3-4	0-3	0-3	1/2-1 1/2"	5-10
Fairways	A*	A	3-4	0-3	0-4	1/2-3/4"	5-10
Tees	A*	A	3-4	0-3	0-4	1/2"	5-10
Greens	NA	SA*	1-3	0-3	0-4	3/16" or less	NR
Zoysiagrass 5, 6							
Lawns	A*	A	1-2	0-3	1-3	3/4-1"	NR
Tees	A*	A	1-2	0-3	1-3	1/2-3/4"	NR
Fairways	A*	A	1-2			½-3/4"	NR
Kentucky Bluegrass							
Lawns	A	SA*	2-3.5	0-3	0-3	1 1/2-2 1/2"	+
Athletic Fields	A	SA*	2-3.5	0-3	0-3	1 1/2-2 1/2"	+
Fairways	A	NA	2-3.5	0-3	0-3	3/4-1 1/4"	+
Tees	A	NA	2-3.5	0-3	0-3	3/4-1 1/4"	+
Tall Fescue							
Lawns	A	A	2-3.5	0-3	0-3	2-3"	+
Athletic Fields	A	A	2-3.5	0-3	0-3	1 3/4-2 1/2"	+
Fine-leaf fescues (Red, chewings, hard and sheep fescue)							
Shaded lawns and low maintenance areas	A	SA	1-2	0-3	0-3	1 1/2-3"	
Creeping bentgrass							
Tees	A*	A*	2-3.5	0-3	0-4	1/4"	

Turfgrass Management Table Based Upon Use and Location in Virginia (cont.)

Greens	A*	A*	2-3.5	0-3	0-4	3/16" or less	
Fairways	A*	SA*	2.3.5			1/2"	
Perennial ryegrass [7]							
Lawns	SA	NA	2-3.5	0-3	0-3	1 1/2-2"	+
Athletic Fields	SA	NA	2-3.5	0-3	0-3	3/4"- 2"	+
Fairways	SA	NA	2-3.5	0-3	0-3	3/4-1"	+
Tees	SA	NA	2-3.5	0-3	0-3	3/4"	+
St. Augustinegrass[5]							
Lawns	NA	SA*	2-4	0-3	0-3	2-3	
Centipedegrass[5]							
Lawns	NA	SA	1-2	0-3	0-3	1-2"	
Buffalograss[5]							
Lawns	NA	NA	2-3	0-3	0-3	1.5-2.5"	

A = Adapted.

SA = Semi-adapted (may not persist under normal management). NA = Not adapted (better grass species are available for that use).

NR= Not recommended.

[1] = Turfgrass species may become more adaptive to a climate through increased management (i.e., irrigation, variety selection, fungicide applications, traffic control, proper fertilization, proper mowing, and supplemental cultural practices).

[2] = Fertilization requirement will depend upon geographical locations and management level/use of the turf; use soil test results to guide all other nutrient applications other than nitrogen.

[3] = The ability of a specific turf species to tolerate a particular mowing height is dependent upon the variety and time of the year. Raising the mowing height toward the high end of the range before an anticipated stress period (raise before summer for cool-season grasses, raise before winter for warm-season grasses) will improve stress tolerance. Never remove more than 1/3 of the leaf tissue in any one mowing.

[4] = Single variety or blends of perennial ryegrass varieties are typically most satisfactory for winter overseeding of lawns, athletic fields, fairways, and tees at those rates listed. Annual ryegrass and/or intermediate ryegrass have similar uses but often require more frequent mowing. It is not recommended to overseed Zoysiagrass, St. Augustinegrass and centipedegrass for winter color.

[5] = All varieties of these species go off-color, turning brown at the first frost and remaining dormant until spring.

[6] = The yearly nitrogen requirement will depend upon whether the turf is overseeded in the fall for winter turf. An additional 1 lb of N/1000 sq ft can be applied to overseeded bermudagrass fairways or athletic fields during the active growing periods of the overseeded cool-season turfgrass.

[7] = When used as a mono-stand, it is very often beneficial to use blends of 2 or more varieties.

* = Requires high levels of management and appropriate variety selection.

\+ = May need to be periodically overseeded to maintain adequate density, to repair damaged areas, or to make up for the lack of persistence from year to year.

Description of Cool-Season Grasses Used in Virginia

Kentucky bluegrass is a medium-textured turfgrass best suited to well-drained soils and moderate to high levels of sunlight and management. It can be established from seed or sod. Mixtures or blends of three or four Kentucky bluegrass varieties are recommended in Virginia because they are more likely to provide good quality turf over the wide range of management conditions. Kentucky bluegrass is best suited for full sun or moderate sunlight conditions under high levels of maintenance in the Central and Northern Piedmont and areas in and west of the Blue Ridge Mountains in Virginia.

Tall fescue is well adapted throughout Virginia and has the deepest root system of the cool-season grasses. Improved cultivars called “turf-type” tall fescues have much finer leaf texture and can be mixed with Kentucky bluegrass – a common practice in sod production that expands the genetic diversity of the grasses. The main management problem with tall fescue is the summer occurrence of *Rhizoctonia* brown patch disease.

The **fine fescue** group of very closely related species (hard, chewings, creeping red, and sheep fescues) is best suited for low-maintenance areas or in partial to full shade. They require very little fertility and less mowing, but perform poorly under heavy traffic or poorly drained soil conditions. Hard fescues are best adapted to open sun situations of the group, and overall, fine fescues are best adapted in the Northern Piedmont and areas in and west of the Blue Ridge Mountains in Virginia. Fine fescues sometimes are mixed with Kentucky bluegrass to provide a seed mixture that will perform well in shade and open sun.

Ryegrass is available in two types: annual and perennial. Annual (Italian) ryegrass will provide rapid germination and fast growth but will live only one year. This, along with poor persistence under adverse conditions, makes annual ryegrass only suitable where a temporary turf is desired. However, there are a number of good perennial ryegrasses available for lawn use. Perennial ryegrass lawns perform best at the higher elevations (>1,000 feet) in Virginia. The best use for perennial ryegrasses for Virginia is in a mixture with Kentucky bluegrass where the perennial ryegrass component is less than 15% by weight. A pure ryegrass lawn is generally not recommended since summer quality often declines in July and August due to its lack of drought tolerance and susceptibility to heat stress and fungal diseases.

Description of Warm-Season Grasses Used in Virginia

Bermudagrass is a warm-season turfgrass that is best adapted in Eastern Virginia, but the introduction of cold-tolerant cultivars has expanded the use of this grass pretty much statewide. It does best in open sun and is not shade tolerant. Some varieties do not produce viable seed and are therefore only vegetatively established using sprigs, plugs, or sod. Commonly used varieties that are vegetatively propagated include Tifway, Patriot, Latitude 36, Northbridge, TifTuf, Iron Cutter, and Tahoma 31. Seeded varieties also vary in their cold tolerance, and this is an important consideration in their selection outside the warmest climates of Virginia. Consult the annual VCE publication “Virginia Recommended Turfgrass Varieties” for the latest recommendations on best performing cultivars. Bermudagrass is sometimes overseeded with perennial ryegrass in early autumn to provide winter color while dormant. However, spring transition back to bermudagrass can be hindered by spring-summer conditions that favor perennial ryegrass growth and delay bermudagrass spring regrowth.

Zoysiagrass is a warm-season grass that can be used on lawns, golf course fairways, and areas that do not receive concentrated traffic. There are two major species of zoysiagrass that are used in Virginia, with the wider-bladed *Zoysia japonica* having such cold tolerance that it is adapted statewide, and the finer-bladed *Zoysia matrella* cultivars having somewhat less cold tolerance and being better adapted to the Southern Piedmont and Eastern Virginia. Zoysiagrass is very suited as a low-maintenance turf; it grows slowly and does not recover quickly from severe damage. There are varieties that can only be vegetatively propagated by using sod or plugs. Sprigging zoysiagrass is difficult due to its slow rate of establishment.

St. Augustinegrass and centipedegrass are both lawn grasses that grow best in the Hampton Roads area of Virginia, where they benefit from the coastal climate. Both are vegetatively propagated (stolons, plugs, or sod), while centipedegrass can also be established from seed. St. Augustinegrass requires more management and higher nitrogen levels than does centipedegrass. However, these grasses are not as common to coastal Virginia as they would be in more southern states.

Mixtures Versus Single Species or Variety

The individual species and the conditions under which they are grown determine whether a pure species, variety, or mixture of species or varieties is preferred. Under Virginia conditions, these general rules have given best results.

1. Mixtures or blends of adapted Kentucky bluegrass varieties have been superior to single varieties grown alone.
2. In shady areas, adding an adapted variety of creeping red fescue improves the turf.
3. Tall fescue can be grown alone or in mixtures with Kentucky bluegrass, but in mixtures, 90% or more of the mixture should be tall fescue.
4. Single varieties grown alone are preferred for all warm-season grasses.

When purchasing turfgrass seed, it is extremely important to buy quality seed. Consumer protection programs have been devised to identify quality seed of the varieties recommended by Virginia Cooperative Extension.

Certified Seed

The best guarantee of varietal purity is to purchase CERTIFIED SEED. Such seed will contain fewer weed and other crop seed contaminants and will be free of unneeded inert filler. Certified seed of single grass varieties and certain grass mixtures and blends are available in Virginia. Even with uncertified seed, it is still very important to buy seed by variety name. Varietal purity would not be certain, but there would be an indication that a percentage of the seed is of the variety claimed. When seed is purchased by kind (species) only (e.g., Kentucky bluegrass, red fescue, tall fescue, etc.), the buyer has no indication as to variety adaptation or expected performance. This seed may be sold as Variety Not Stated or VNS. Purchasing turfgrass seed without some assurance that it contains adapted varieties should be avoided except where the quality or persistence of the turfgrass stand is unimportant.

Grass Seed Mixture

Lot # 1234-56

Pure Seed	Variety	Germ	Origin
49.11%	ABC Tall Fescue	90%	OR
34.63%	LMP Tall Fescue	85%	OR
9.95%	TUV Tall Fescue	90%	OR
4.94%	XYZ Kentucky Bluegrass	85%	ID

0.00% Other Crop Seed — 0.00% Weed Seed

1.37% Inert Matter — Test Date 11/19

Noxious Weed Seed Per lb. None Found NT WT 50 lbs.

Seed Company
Any Street
Anywhere, USA 00000

Pure Seed: the percentage of that variety or kind of seed.

Variety/Kind: Indicates the variety or kind in the container.

Germ: the germination percentage for that variety or crop kind 90 out of 100 seed will germinate for a 90%

Origin: the state of country the seed was grown.

Other Crop Seed: the percentage of other crop seeds in the container.

Weed Seed the percentage of weed seed in the container.

Inert Matter: the percentage of stem, leaves, chaff, and matter that will not germinate.

Test Date: the date seed lab report was issued for this lot of seed

Noxious Weed: if present must be listed as the kind and the amount present is seed per pound.

Purchasing Quality Turfgrass Seed

When purchasing turfgrass seed, there are several questions you need to consider. The following list is offered to assist you in making the best choice of grass for the particular location.

1. Most types of turfgrass are perennials and are expected to grow back year after year. When selecting and purchasing grass seeds, consider it a long-term investment. You usually get what you pay for, so consider purchasing a recommended variety that has been tested in Virginia.
2. Deal with a reliable retail store that can answer your questions and provide good information and advice.
3. Factors such as temperature, moisture, and light determine the kinds of grasses that are adapted to a location.

In order to make the best selection, take the time to consider a few basic questions, such as:

1. In what temperature zone or region of the state will the grass be grown? Examples: Eastern, Northern Piedmont, Southern Piedmont, or Western Virginia.
2. Under what moisture conditions will the grass be grown? Examples: irrigated or nonirrigated with light sandy well-drained soil, loamy deep medium-texture soil, or heavy clay soil.
3. Is the area to be planted an open area with full sun, partially shaded, or heavily shaded?
4. What type of use will the area have, and how much traffic and maintenance will it receive? Examples: home lawn with low or high maintenance, commercial business with high visibility, athletic field, or other use.

After gathering this information, consult with a knowledgeable garden center or Extension professional and review the turfgrass options.

Over the past several years, many new turfgrass varieties have been introduced in the Virginia market. The University of Maryland, USDA, and Virginia Tech conduct extensive turfgrass variety trials to identify which varieties perform well in the different regions of the state. Performance data from these trials, along with seed quality, are reviewed and published annually, and the varieties that have the best performance are recommended. The **Virginia Turfgrass Variety Recommendations** list is available through your local Extension office.

The best way to ensure that you are purchasing quality turfgrass seed is to ask for seed that is **blue tag certified.** This ensures that the seed has been inspected by an independent third party and has met established standards of quality.

The Virginia Crop Improvement Association standards for sod quality grass seed of these species are specified in **table 5 (page 82).**

Table 5. Virginia Crop Improvement Association standards for sod-quality grass seed for common turfgrass species in Virginia.

	Minimum purity	Minimum germination	Maximum other crop seed[1]	Maximum weed seed	Lawn & turf noxious weed seed
Kind of seed	(%)				
Kentucky bluegrass	98	85	0.10[2]	0.10	None
Fine fescue	98	85	0.01	0.10	None
Tall fescue	98	85	0.10[3]	0.10	None

[1] Must be free of Canada bluegrass (Poa compressa), cheat and chess (Bromus spp.), chickweed (Cerastium spp. and stellaria media), crabgrass (Digitaria spp.), foxtail (Setaria spp.), goosegrass (Eleusine indica), nimblewill (Muhlenbergia schreberi), nutsedge (Cyperus spp.), panicum (Panicum spp.), ryegrass (Lolium spp.), smooth brome (Bromus inermis

[2] Off-types of Kentucky bluegrass shall not exceed 2% for any one component. Up to 90 Canada bluegrass per pound shall be permitted in Kentucky bluegrass.

[3] Up to 30 ryegrass seed per pound shall be permitted in tall fescue.

Purchasing Quality Sod in Virginia

There are several types of sod being grown in Virginia. The basic types are Kentucky bluegrass blends, tall fescue Kentucky bluegrass mixtures, bermudagrass, and zoysiagrass. Each of these types of sod is best suited to particular uses and geographic areas of Virginia. Some producers grow sod in the Virginia Crop Improvement Association-certified sod program, which means that the sod produced must meet established standards of quality. To view these standards, go to www.virginiacrop.org. VCIA-certified sod is of high quality, meeting rigid standards requiring pre-planting field inspections, prescribed varieties and mixtures, periodic production inspections, and a final preharvest inspection. This program serves as a marketing tool and provides the consumer with guaranteed standards of quality. Consumers purchasing VCIA-certified turf will receive a blue certified turf label as proof of purchase.

VCIA-Certified Turf Label (Blue)

High-quality sod is also available outside of the VCIA-certified sod program. When purchasing this sod, the consumer is encouraged to be aware of factors that are important in determining sod quality. High-quality sod will contain the best varieties and be free of serious disease, insect, or weed problems. It will be dense, have good color, and hold together well.

Virginia Cooperative Extension
Virginia Tech • Virginia State University

Part IV.

Seed Facts

Authored by:
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Seed Inoculation

Legumes have the ability to gather available nitrogen from the air and use it for their growth. Grasses growing in association with legumes, or following legumes in rotation, also benefit. Legumes are able to accomplish this through the presence of nitrogen-fixing bacteria that form colonies on the legume roots.

Most soils contain native strains of nitrogen-fixing bacteria (rhizobia), but they are often not efficient in fixing nitrogen. When a legume is seeded – especially in soil where that legume has not been grown in the previous two or three years – commercial strains of bacteria should be included with the seed to "inoculate" the soil and the plant roots. This ensures that bacteria of a productive strain are present in sufficient quantities to fix nitrogen for the plant.

The rhizobia are usually mixed with black peat that serves as the carrier for the bacteria. This black inoculum is mixed with the seed just prior to seeding. It can be mixed thoroughly with dry seed, but better seed contact is obtained by slightly moistening the seed with sugar water or a commercial sticker before adding the inoculum. Pre-inoculated seed, which is coated with the appropriate rhizobia by the seed company, is also available.

When the seed germinates in the soil, the rhizobia bacteria invade the root hairs of the seedlings and begin to multiply to form nodules. A symbiotic relationship exists between the bacteria in these nodules and the plant. The plant provides food and a supply system for the bacteria. In return, the bacteria convert atmospheric nitrogen into ammonia nitrogen, which the plant uses.

Well-nodulated plants have large nodules that are pink or red inside. Ineffective bacteria produce small nodules that are white, gray, or green inside. Nodules should be present by about four weeks after seed germination. If the plants are not properly nodulated, emergency inoculum can be applied to the soil surface by broadcasting or spraying in rainy weather. Under hot and dry conditions, it is necessary to drill the inoculum into the soil.

There are several different strains of rhizobia. It is important to use the correct strain to inoculate the legume being seeded. Table 1 (page 85) indicates those groups of legumes or individual legumes requiring specific strains.

Table 1. Cross-inoculation of legumes.

	Alfalfa	Black medic	Bur clover	Yellow sweet clover	Alsike clover	Crimson clover	Ladino clover	Red clover	White clover	Austrian winter pea	Canada field pea	Garden pea	Hairy vetch	Birdsfoot trefoil	Crown vetch	Garden bean	Soybean	Cowpea	Kudzu	Lespedeza	Partridge pea	Peanut
Alfalfa	+*	+	+	+																		
Black medic	+	+	+	+																		
Bur clover	+	+	+	+																		
Yellow sweet clover	+	+	+	+																		
Alsike clover					+	+	+	+	+													
Crimson clover					+	+	+	+	+													
Ladino clover					+	+	+	+	+													
Red clover					+	+	+	+	+													
White clover					+	+	+	+	+													
Austrian winter pea										+	+	+	+									
Canada field pea										+	+	+	+									
Garden pea										+	+	+	+									
Hairy vetch										+	+	+	+									
Woollypod vetch										+	+	+	+									
Birdsfoot trefoil														+								
Crown vetch															+							
Garden bean																+						
Soybean																	+					
Cowpea																		+	+	+	+	+
Kudzu																		+	+	+	+	+
Lespedeza																		+	+	+	+	+
Partridge pea																		+	+	+	+	+
Peanut																		+	+	+	+	+
Sunnhemp																		+	+	+	+	+

* Cross marks indicate which legumes are inoculated by bacteria from other legumes. For example, alfalfa is inoculated by bacteria from bur clover, sweet clover, and black medic.

Precautions and Tips in Utilizing Inoculum

1. Buy the inoculant with the proper strain of bacteria for the legumes you will inoculate. Refer to table 1 for information about legume species in the same cross-inoculation group.
2. Use the inoculant before the expiration date for optimum results.
3. Powder inoculants are the most common, reliable, available for all types of legumes, and the least expensive to use. However, powder inoculants require more handling, and good contact with the seed is more difficult to achieve without the use of a sticker agent.
4. If legumes seed become too wet during the inoculation process, allow the seeds to dry in a place with good ventilation and away from direct sunlight.
5. Inoculants are made of living organisms, so they must be treated with care. The main reasons affecting bacterial survival on seed are desiccation, toxicity originated from soluble seed coat exudates, and inappropriate temperatures during long-term storage. Inoculants can be stored in refrigerators at temperatures around 40˚F, in places with good ventilation and away from direct sunlight. Avoid cool, dry places when not in use. Do not allow seed to contact caustic lime or soluble fertilizers before inoculating the seed.
6. When preparing the inoculation mix, do not use acidic or alkaline water with a high chlorine level. Choose an inoculant that will tolerate the level of chlorine in your water. Ideally, water should meet the standards for drinkable water (less than 1 ppm chlorine).
7. Use an insulated cooler with ice packs to transport the inoculation mix from preparation place to the field.
8. Application equipment should be clean, thoroughly rinsed, and properly calibrated. Leftover from any chemical product can be detrimental for bacteria survival.
9. If applied with fungicide and/or insecticides, check the pesticide label to ensure that the particular strain of bacteria used as inoculum is compatible with the product being applied.
10. Select inoculants that contain stability enhancers that will let them remain stable for a longer time following hydration.
11. Keep packaging closed until future use. Limit the amount of oxygen inside the package to the very minimum level.
12. Plant inoculated seeds within no more than three to four hours after seeds were inoculated. A proper soil moisture and good seed to soil contact is indispensable to maximize chances of bacteria survival.

Certified Seed

The use of viable seed of adapted varieties is an essential part of successful crop production. Like livestock, seed are living bodies subject to the influences of weather, disease, and breeding. It is not enough that the seed produce a plant; it must also contain the genes that will enable the plant to resist disease, produce high yields, and utilize high levels of soil fertility.

Certifying Agency

The Virginia Crop Improvement Association has been designated as the official seed-certifying agency in Virginia by the State Certified Seed Board. The association is an incorporated nonprofit organization of seed growers. It works in cooperation with seed growers, seedsmen, research, Extension, and teaching divisions of Virginia Tech, the Virginia Department of Agriculture and Consumer Services, and the U.S. Department of Agriculture.

Purpose of Certification

The purpose of certification is to reproduce – and make available to the public – high-quality seed and propagating material of superior plant varieties grown and distributed as to ensure genetic purity and a minimum of seed-borne diseases. "Seed" includes all propagating material that could be certified.

Classes and Sources of Certified Seed

Four classes of seed shall be recognized in seed certification; namely, (a) Breeder, (b) Foundation, (c) Registered, (d) Certified.

Breeder seed is seed or vegetative propagating material directly controlled by the originating or sponsoring plant breeder or institution that provides the source for the initial increase of foundation seed. Breeder seed is not available for commercial distribution.

Foundation seed is the progeny of breeder or foundation seed stock that is handled so as to most nearly maintain specific genetic identity and purity. Production must be carefully supervised and approved by the certifying agency or the agricultural research station.

Registered seed is the progeny of breeder, foundation, or registered seed that is handled so as to maintain satisfactory genetic identity and purity and a minimum of seed-borne diseases, and that has been approved and certified by an official certifying agency.

Certified seed is normally the progeny of breeder, foundation, or registered seed. However, when foundation or registered classes of a variety are not available, certified seed can be produced from certified seed that was grown under the supervision of the certifying agency and handled so as to maintain genetic identity, purity, and a minimum of seed-borne diseases.

Application for Certification

Application for inspection of a crop for certification can be made on an official association application blank that can be obtained from Extension agents, vocational teachers, or by writing to the Association office. The application must be properly filled out and mailed to the Virginia Crop Improvement Association, 9225 Atlee Branch Lane, Mechanicsville, VA 23116; 804-746-4884; www.virginiacrop.org.

Field Inspection

At least one field inspection is made at a time most appropriate to determine compliance with certification requirements. All inspections are performed by individuals who have been trained for the job.

Sampling of Seed

Before sampling, seed lots should be cleaned and ready for sale, except for labeling. A representative sample should be taken from the entire lot. Following are sample sizes required for some common seed types.

2 ounces – Kentucky bluegrass, redtop, white clover, alsike clover, bentgrass, and other types of seed of similar size.

5 ounces – Orchardgrass, red clover, crimson clover, alfalfa, fescues, lespedezas, ryegrasses, foxtail millet, grass mixtures, and other types of seed of similar size.

2 pounds – Small grains, vetches, corn, peanut, soybean, sorghum, sudangrass, sunflower, and other types of seed of similar size. For a seed count, a sample must be submitted in a moisture-proof container.

Send samples to: State Seed Testing Laboratory, 600 N. 5th Street, Room 232, Richmond, VA 23219.

Sources of Seed

The Virginia Crop Improvement Association distributes spring and fall certified seed directories that list sources of registered and certified seed grown in Virginia. The Foundation Seed Farm, located at 4200 Cople Highway, Montross, VA 22520, is responsible for increasing seed of new varieties and maintaining commercially important varieties that have been developed by public institutions.

Seed Protection

Plant variety protection ensures intellectual property protection to breeders of new varieties of plants. There are four types of intellectual property protection that breeders can obtain **(table 2, page 89)**.

1970 Plant Variety Protection Act – Legislation enacted to promote the development of new varieties by allowing the variety owner to determine who may sell seed of the variety. Farmers may save seed for their own planting need and sell that amount to a neighbor if plans for that variety change. All seed sales must comply with state seed laws. Applies to all varieties protected prior to April 4, 1995.

1994 Amended PVPA – Amendment to the Plant Variety Protection Act that prohibits the sale of any farmer-saved seed without the permission of the variety owner. It also extends protection to tuber-reproduced plants, varieties essentially derived from variety, and harvested material of the variety. Seed protected under the 1994 PVPA must be sold by variety name (except for turf, forage, alfalfa, and clover). Length of protection was increased to 20 years for most kinds of plants, and 25 years for trees, shrubs, and vines. Applies to all varieties protected after April 4, 1995.

Title V – An option for protected varieties that allows for the sale of the seed by variety name only as a class of certified seed. Noncertified sales are prohibited. Seed may be called "certified" only after meeting all requirements and standards of an official seed certifying agency.

Utility and plant patents – A means of protection for certain varieties, especially those developed through genetic engineering or biotechnology. Farmers cannot save, clean/condition, or sell any seed protected under a utility/plant patent.

Table 2. Plant variety protection type and allowable uses.

	1970 PVPA	1994 PVPA	TITLE V	PATENT
Farmer				
Allowed to sell seed	YES*	YES*	YES*	NO
Allowed to sell seed (no advertising) to neighbor if in compliance with state law	YES*	NO	'70 PVPA ONLY	NO
Conditioner				
Condition varieties for farmers	YES*	YES*	YES*	NO
Store seed for farmers	YES*	YES*	YES*	NO
Clean or stock as step in marketing variety	NO	NO	NO	NO
Deliver or load seed to a third party	NO	NO	NO	NO
Advertise farmer-saved seed	NO	NO	NO	NO
Sell or act as broker for farmer-saved seed	NO	NO	NO	NO

* Limited to the amount of seed needed to plant a farmer's own holdings (land owned, leased, or rented).

A quick method for estimating the pounds of seeds broadcast per acre

After planting, place a sheet of 8 1/2" x 11" paper over the planted area and make an outline in the soil. Remove the paper and count the seeds in the marked area. In the first column of **table 3**, find the number of seeds counted. The other columns show pounds of seed per acre. Measure several different areas and take an average. This method could be modified by placing a large cover on the ground before planting to make the small seed more visible.

Table 3. Estimate of seeding rate based on seed count under one sheet of paper.

Seeds per lb for each species	223,500	275,000	1,400,000	540,000	14,500
No. of seeds counted under 8 1/2" x 11" paper	Alfalfa fescue (tall)	Red clover	Kentucky bluegrass	Orchard-grass	Wheat barley
Pounds of seed broadcast per acre					
1	0.29	0.24	0.05	0.12	4.51
2	0.60	0.49	0.10	0.25	9.25
4	1.20	0.98	0.19	0.50	18.51
6	1.80	1.46	0.29	0.75	27.76
8	2.40	1.95	0.38	0.99	37.01
10	3.00	2.44	0.48	1.24	46.27
12	3.60	2.93	0.58	1.49	55.52
14	4.20	3.42	0.67	1.74	64.77
16	4.80	3.90	0.77	1.99	74.03
18	5.40	4.39	0.86	2.24	83.28
20	6.00	4.88	0.96	2.48	92.53
25	7.50	6.10	1.20	3.11	115.67
30	9.01	7.32	1.44	3.73	138.80
40	12.01	9.76	1.92	4.97	185.07
50	15.01	12.20	2.40	6.21	231.34
60	18.01	14.64	2.88	7.45	277.60
70	21.01	17.08	3.35	8.70	323.87
80	24.01	19.52	3.83	9.94	370.14
90	27.02	21.96	4.31	11.18	416.41
100	30.02	24.40	4.79	12.42	462.67

Table 4 allows estimate of seeding rate (seeds per acre) based on the row spacing and distance between seeds in a row.

Table 4. Seed population at planting

	Row spacing (inches)																
	4	6	8	10	14	16	18	20	22	24	26	28	30	32	34	36	38
Seeds/acre	Inches between seeds																
4,000	392	261	196	157	112	98	87	78	71	65	60	56	52	49	46	44	41
6,000	261	174	131	105	75	65	58	52	48	44	40	37	35	33	31	29	28
8,000	196	131	98	78	56	49	44	39	36	33	30	28	26	25	23	22	21
10,000	157	105	78	63	45	39	35	31	29	26	24	22	21	20	18	17	17
12,000	131	87	65	52	37	33	29	26	24	22	20	19	17	16	15	15	14
14,000	112	75	56	45	32	28	25	22	20	19	17	16	15	14	13	12	12
16,000	98	65	49	39	28	25	22	20	18	16	15	14	13	12	12	11	10
18,000	87	58	44	35	25	22	19	17	16	15	13	12	12	11	10	9.7	9.2
20,000	78	52	39	31	22	20	17	16	14	13	12	11	10.5	9.8	9.2	8.7	8.3
22,000	71	48	36	29	20	18	16	14	13	12	11	10	9.5	8.9	8.4	7.9	7.5
24,000	65	44	33	26	19	16	15	13	12	11	10	9.3	8.7	8.2	7.7	7.3	6.9
26,000	60	40	30	24	17	15	13	12	11	10	9.3	8.6	8.0	7.5	7.1	6.7	6.3
28,000	56	37	28	22	16	14	12	11	10	9.3	8.6	8.0	7.5	7.0	6.6	6.2	5.9
30,000	52	35	26	21	15	13	12	10.5	9.5	8.7	8.0	7.5	7.0	6.5	6.1	5.8	5.5
35,000	45	30	22	18	13	11	10	9.0	8.1	7.5	6.9	6.4	6.0	5.6	5.3	5.0	4.7
40,000	39	26	20	16	11	9.8	8.7	7.8	7.1	6.5	6.0	5.6	5.2	4.9	4.6	4.4	4.1
50,000	31	21	16	13	9.0	7.8	7.0	6.3	5.7	5.2	4.8	4.5	4.2	3.9	3.7	3.5	3.3

Table 4. Seed population at planting (cont.)

	Row spacing (inches)																
	4	6	8	10	14	16	18	20	22	24	26	28	30	32	34	36	38
Seeds/acre	Inches between seeds																
60,000	26	17	13	10	7.5	6.5	5.8	5.2	4.8	4.4	4.0	3.7	3.5	3.3	3.1	2.9	2.8
70,000	22	15	11	9.0	6.4	5.6	5.0	4.5	4.1	3.7	3.4	3.2	3.0	2.8	2.6	2.5	2.4
80,000	20	13	10	7.8	5.6	4.9	4.4	3.9	3.6	3.3	3.0	2.8	2.6	2.5	2.3	2.2	2.06
90,000	17	12	8.7	7.0	5.0	4.4	3.9	3.5	3.2	2.9	2.7	2.5	2.3	2.2	2.0	1.94	1.83
100,000	16	10.5	7.8	6.3	4.5	3.9	3.5	3.1	2.9	2.6	2.4	2.2	2.1	2.0	1.84	1.74	1.65
125,000	13	8.4	6.3	5.0	3.6	3.1	2.8	2.5	2.3	2.1	1.9	1.8	1.7	1.57	1.48	1.39	1.32
150,000	10	7.0	5.2	4.2	3.0	2.6	2.3	2.1	1.9	1.7	1.6	1.5	1.4	1.31	1.23	1.16	1.10
200,000	7.8	5.2	3.9	3.1	2.2	2.0	1.7	1.6	1.4	1.3	1.2	1.1	1.0	0.98	0.92	0.87	0.83
250,000	6.3	4.2	3.1	2.5	1.8	1.6	1.4	1.3	1.1	1.05	0.97	0.90	0.84	0.78	0.74	0.70	0.66
300,000	5.2	3.5	2.6	2.1	1.5	1.3	1.2	1.05	0.95	0.87	0.80	0.75	0.70	0.65	0.61	0.58	0.55
500,000	3.1	2.1	1.6	1.3	0.9	0.8	0.7	0.63	0.57	0.52	0.48	0.45	0.42	0.39	0.37	0.35	0.33
1,000,000	1.6	1.0	0.8	0.6	0.45	0.39	0.35	0.31	0.29	0.26	0.24	0.22	0.21	0.20	0.18	0.17	0.17
1,500,000	1.0	0.7	0.5	0.4	0.30	0.26	0.23	0.21	0.19	0.17	0.16	0.15	0.14	0.13	0.12	0.12	0.11

Virginia Cooperative Extension
Virginia Tech • Virginia State University

Part V.

Seeds and Stored Grains

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Managing stored grains and seed requires the use of various techniques to ensure that the quality of the product entering the storage facility does not deteriorate over time. These techniques include the use of sanitation; storing sound, dry grain; managing temperature and aeration; using chemical protectants; sampling regularly; and using fumigation. Bin and storage facilities also play an important role in determining the quality of the stored grain. Storage facilities should be inspected regularly for deterioration of any type.

Proper storage moisture varies depending on type of seed, length of storage, and storage conditions. Seed moisture content changes until equilibrium is established with the surrounding environment. The equilibrium moisture is different for each kind of seed. High-oil-content seeds (soybeans, peanuts, sunflowers) will not absorb as much moisture as seeds with high starch content (wheat, barley, corn, sorghum). Oil does not absorb water; therefore, in a seed with 40% oil, the seed moisture will be concentrated in the other 60%. The time to reach equilibrium will vary from days to months depending on the kind of seed, humidity, and temperature. When there are large differences in seed moisture and the surrounding environment, the initial change is rapid and slows as equilibrium temperature/moisture is approached.

Over 60 species of insects infest stored grains. Lesser grain borers, rice weevils, maize weevils, cadelle beetles, flat grain beetles, rusty grain beetles, sawtoothed grain beetles, foreign grain beetles, mealworm beetles, red flour beetles, confused flour beetles, Indian meal moths, book lice, and grain mites are considered the main pests. Of those listed, Indian meal moths are the most commonly encountered. Damage by stored grain insects can go unnoticed until the grain is removed from the storage facility. Regular monitoring will ensure that the quality of the grain will be maintained at the highest level possible. Scouting should not be limited to the field. A regular monitoring program should be continued until the grain leaves the storage facility.

Microorganisms are another important consideration when storing seeds or grain. The two major microorganisms involved in seed molds are aspergillus and penicillin. As molds develop in stored grains, temperatures rise, resulting in "hot spots." In these spots, temperatures can reach as high as 125°F. Mold growth is retarded as temperatures increase; seed vigor and germination are also reduced with increased temperatures.

Bin Facilities (Bulk Storage)

Bin facilities should be weather-tight, rodent-proof, steel, and on a moisture-proof concrete base. Bins should be equipped with a perforated-floor aeration system and weatherproof roof vent. All bins should be inspected on a regular basis to guard against leaks and deterioration of any kind. Once filled, attempt to seal the bottom and sides of the bin so insects and rodents can only enter from the top of the facility. Do not seal roof aeration exhaust or inlet vents except during fumigation so the top of the bin can be easily sampled and top dressings applied if necessary.

Sanitation

Before adding grain to a storage facility, make sure it is clean and free of old grain, trash, and insects. Be sure the walls, ceiling, sills, ledges, floors, and ventilation system (under perforated floors, ducts, and fan system) are clean. The area outside the bin should also be free of insects, weeds, and grain products. Insects can breed and persist in these areas and can infest new grain when placed in the bin. It is best to clean and treat bins at least two weeks prior to adding new grain.

Most insect infestations in stored grain originate in the immediate area of the storage facility. Area sanitation is important because many of the commonly stored grain pests can fly and may move from one bin to another.

Grain Moisture

As a general rule, grain should be stored at no more than 12% moisture. Insects and fungi do not develop well in grain with a moisture content of 12% or below. For seed to be stored for long periods of time, the maximum safe moisture content is about 2% below the safe storage moisture of the grain. Refer to **table 1 (page 96)** for recommended storage moistures for grains and seed at various storage temperatures. Seed can be stored for three to five years in sealed containers at 65-75°F if dried to 5-8% moisture. For longer storage periods under these conditions, seed should be dried to 2.5-5% moisture before placing it in a sealed container. Seed moisture content can be increased as the temperature is reduced below 60°F. Avoid storing seed in environments that will expose them to high temperatures or humidity. Dry, cold storage is ideal; therefore, a freezer is excellent for seed storage.

Temperature and Aeration

A combination of low seed temperature and low moisture aid in insect control. Insect reproduction is reduced at temperatures below 60°F and as the moisture content of the seed is reduced (**table 2**). These conditions do not provide enough heat and water to meet the needs of the insects. Grains harvested and stored in the hottest part of the year have a greater chance of becoming infested because insects reproduce rapidly at temperatures in the range of 60-90°F. Farm-stored wheat, rye, barley, or oats are more likely to have insect problems than corn or soybeans, which are harvested during the cooler months of the year. Aeration during times of low outside temperature and humidity is suggested to reduce temperature and moisture. In the southern United States, it is recommended to maintain warm temperatures and low humidity until cooler temperatures arrive and then cool the grain to 55-65°F or lower as soon as possible. The amount of air required for good aeration is relatively low, but it should be at least 0.10 cubic foot per minute per bushel.

Table 2. Resistance to low temperatures of various insects that attack stored grain and grain products.

	Days exposure required to kill all stages at*						
Insect	**0-5°F**	**5-10°F**	**10-15°F**	**15-20°F**	**20-25°F**	**25-30°F**	**30-35°F**
Rice weevil	1	1	1	3	6	8	16
Granary weevil	1	3	–	14	33	46	73
Saw-toothed grain beetle	1	1	3	3	7	23	26
Confused flour beetle	1	1	1	1	5	12	17
Red flour beetle	1	1	1	1	5	8	17
Indian-meal moth	1	3	5	8	28	90	–
Mediterranean flour moth	1	3	4	7	24	116	–

Source: *Storage of Cereal Grains and Their Products*, J. A. Anderson and A. W. Alcock. 1954. St. Paul, MN: American Association of Cereal Chemists.

*Several practices should be followed when filling bins to permit even aeration of the grain mass. The upper surface of the grain mass should be level or slightly inverted to permit even aeration. The use of a grain spreader will help prevent the accumulation of fines (broken grain, weed seed, dust, and debris) in the center when filling bins. If not spread evenly, this material will accumulate in the center of the bin, preventing even aeration and providing an excellent environment for insects and fungi to develop (fig. 1, left).

Table 1. Suggested maximum safe moisture storage for grain and seed.

Seed	2 months	6 months	Grain and seed long-term storage	Storage temp should be below °F
	Maximum grain moisture (%)			
Barley	–	13.4	11.9	77
Buckwheat	–	13.9	12.4	77
Corn, grain	14.8	14.0	12.4	77
Corn, grain	15.2	14.2	12.6	60
Corn, grain	17.7	15.5	13.9	40
Corn, ear*	–	20.0	–	50
Oats	–	12.8	11.4	77
Millet	–	10.0	9.0	70
Peanuts, unshelled	11.2	9.6	8.4	70
Peanuts, unshelled	12.0	10.3	8.9	50
Peanuts, shelled	8.8	7.7	6.7	70
Peanuts, shelled	9.1	8.1	7.2	50
Rye	–	13.9	12.3	77
Soybeans	15.8	12.0	9.7	77
Soybeans	16.1	12.4	10.1	60
Soybeans	16.5	12.9	10.4	40
Sunflowers, oil	–	9.6	8.6	77
Sunflowers, non-oil	–	10.0	9.0	77
Sorghum	14.7	13.5	12.4	90
Sorghum	15.2	14.0	13.0	60
Wheat, soft red winter	15.6	13.6	12.1	77
Wheat, soft red winter	15.8	14.0	12.4	70
Wheat, soft red winter	16.0	14.4	13.1	40
Alfalfa	–	–	7.8	73
Bluegrass, Kentucky	–	–	11.3	73
Clover, red	–	–	9.1	73
Clover, white	–	–	8.7	73
Crown vetch	–	–	9.4	73
Tall fescue	–	–	12.1	73
Orchardgrass	–	–	11.0	73
Ryegrass	–	–	12.8	73
Timothy	–	–	12.5	73

Note: Safe storage depends on many factors such as temperature, humidity, kind and variety of seed, quality, damage, microorganisms, length, and kind of storage. Stored grains and seed should be inspected frequently for changes in temperature and moisture as well as pest infestations.

*Ventilated cribs 6-8 feet wide.

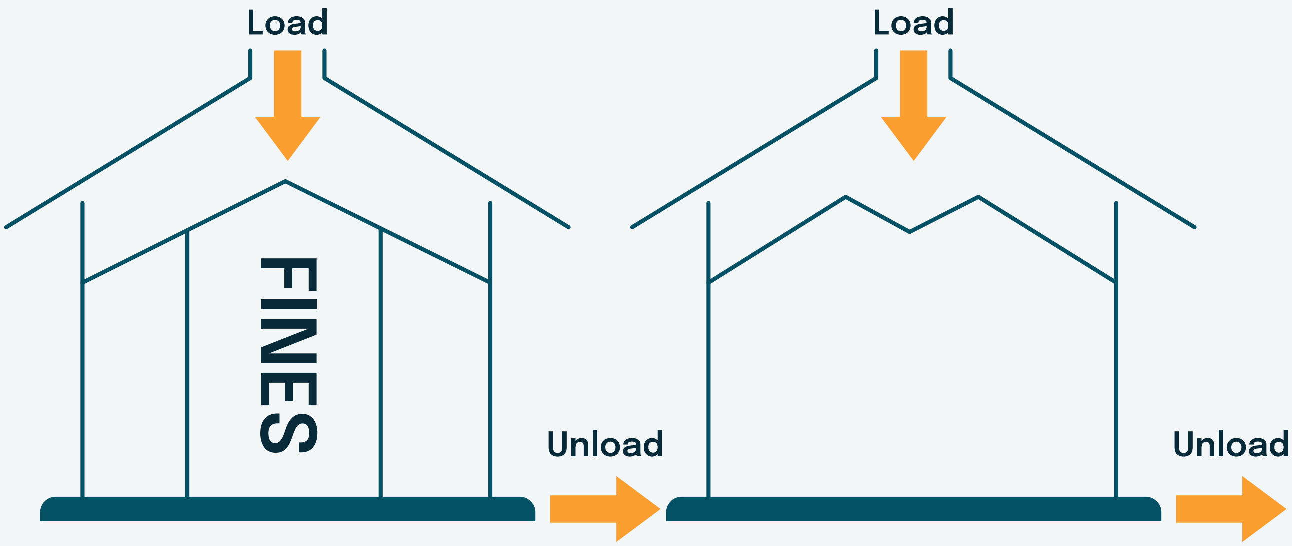

Figure 1. Proper filling of grain bins.

The accumulation of fines in the center of the bin can be greatly reduced by removing a portion of the grain mass after the facility is filled or several times during the loading process. Removing the core from the bottom with the centrally located unloading auger or conveyer will remove the column of fines and invert the peaked grain in the top of the tank (**fig. 1, right**). After this process is completed, the grain can be left alone or leveled. This process, called "coring," will increase aeration efficiency and reduce problems with insects, fungi, and hotspots. For grain stored through the winter, aeration in the fall can deter moisture migration in the bin. Moisture migration is caused by differential temperatures in the grain mass, resulting in a convective flow of air through the grain. The convective flow of air can result in accumulating moisture condensation in the upper center of the grain mass. These factors will contribute to the development of molds and insects. Attempt to maintain grain temperature within 10°F of the average outside air temperature. Depending on conditions, several aeration events may be required to correct temperature differences. Aeration is very important in grain bins containing 2,000 bushels or more.

Bin and Grain Treatments

Empty Bin Sprays

Empty bin sprays are recommended for summer stored grain, difficult-to-clean bins, or when there is a history of insect problems. After bins have been properly cleaned and inspected but prior to adding new grain, spray the empty bin with a labeled insecticide. Spray to run off the inside surface and as much of the outside as possible, including the nearby ground surfaces, aeration ducts, and grain handling equipment. Sprays should be concentrated on cracks, crevices, and areas that are difficult to clean. Applications should be made at least two weeks prior to adding new grain. Allow 24 hours for sprays to dry. These sprays provide a barrier for insects that may be attracted to the storage facilities and also provide control of the insects not removed during the cleaning operation.

Bacillus thuringiensis Grain Products

Bacillus thuringiensis (Bt) is a biological insecticide that has activity on some moth larvae. This insecticide has been genetically engineered into many of the grain crops currently produced in the United States.

In many of these newer engineered crops, the *Bt* gene is expressed in the grain as well as in other parts of the plant, thus providing the grain with protection from larval feeding. Although no research has been conducted to determine the effectiveness of *Bt* grains in storage, protection should be equal to or superior to the *Bt* products available for stored product treatments. The expression of the *Bt* toxin in every grain should provide a level of protection greater than any *Bt* topical, bin, or grain treatment. Until research has been conducted to determine the effectiveness of the *Bt* gene under storage conditions, sample grain regularly. *Bt* products will not control weevils or other beetles.

Chemical Grain Protectants

A grain protectant may be added when the bin is being filled in order to guard against insect damage. Protectants may also be added to the upper surface of the grain in the bin to protect against damage from moths and other insects entering the top of the storage facility. Protectants will not eliminate existing infestations. They are recommended if grain is going to be stored for extended periods or in flat structures, under circumstances that favor pest development, or in facilities with a history of insect damage. The combination of high grain moisture and high temperatures will shorten the residual life of grain protectants. Use only labeled products at the approved rates and check with your miller or buyer before using an insecticide on stored products.

Top Dressing and Pest Strips

It may be necessary to mix an insecticide with the top 4 inches of the grain to deal with an infestation of primarily moths. Moths tend to attack the upper surface of the grain mass. The Indian meal moth is the most common insect to attack stored grain and, unfortunately, it already has resistance to some insecticides.

Resin strips (dichlorvos, or DDVP) may also be hung in the air space in the top of the bin to help control adult moths. For this treatment to be effective, the top of the bin must be temporarily sealed, including the roof vent, because aeration will disrupt this treatment. Remember to open the roof vent before aerating.

Insect Sampling

Bins should be inspected on a regular basis for insects, hot spots, mold growth, or any “off” odor. As a general guideline, bins should be sampled twice per month under warm conditions and once per month under cool conditions. Regular inspections will reduce the chances of pests becoming established. Take all necessary safety precautions. Bins should be easily accessible, and all unloading equipment should be turned off. Be aware of any pesticides applied to the grain, undissipated fumigants, bridged grain, grain dusts, and high temperatures. **Working in teams is the best policy, with at least one person on the outside of the storage facility.**

Samplers should be alert for:

- Off odors.
- Crusting.
- Temperature differences greater than 10°F.
- Visible water vapor.
- Sprouting grain.
- Exterior bin conditions and signs.
- Uneven snow melt or frosting.
- Condensation.
- Discoloration.
- Fecal matter (bird, rodent, and insect).
- Birds (insect feeders).

Use a probe (**fig. 2**) or scoop to collect the samples. Take five to ten 1-pint samples from areas over the grain surface. Using a compartmentalized grain trier (**fig. 3**) will allow the sampler to determine differences in grain moisture, insect populations, temperature, and grain quality at different depths in the grain mass. Label samples so problem areas within the bin can be identified. Sampling at different depths will greatly increase the chances of finding trouble spots before a large area of grain is damaged.

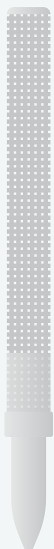

Figure 2. Probe trap.

Figure 3. Grain trier.

Grain temperature should be determined as soon as possible after the sample is taken to achieve the most accurate results. Temperature differences in the range 10-15°F indicate a potential problem. Aeration will usually correct the temperature difference. After corrective measures are taken, further sampling is suggested to ensure the problem has been corrected.

When sampling for insects in cool grain, samples should be warmed. Warming will increase the activity of the insects, allowing the sampler to easily spot the pests and determine if the insects are alive. Individual samples can be placed in labeled plastic bags to guard against contamination. Each sample should be placed on a sieve, which will hold the grain while allowing the pieces (fines), insects, and small debris to pass through. If insects are present, save them for identification, estimate the abundance, and determine the distribution. Pest identification is crucial when selecting a control measure. For example, several species of insects feed on fungi. Their presence indicates a moisture problem. Control of the insects with pesticides can be achieved without correcting the primary problem.

Another method of sampling involves using a grain probe trap (**fig. 2**). This trap consists of a perforated plastic tube with a funnel collector on the bottom. Traps are inserted in the grain mass and marked with colored string that allows them to be retrieved. Traps are retrieved after 24 hours and are more efficient than probing and sieving for beetles, but they do not adequately detect moth larvae.

Trouble spots can also be identified using a metal rod. Insert the rod into the grain and allow it to remain for about 10 minutes. Hot spots can be detected by running your hand down the rod after removing it from the grain. If temperature differences are sensed, further investigate these areas to determine the reason for the difference in grain temperature.

Accurate records should be kept so that changes over time can be detected. Records can be used to refine a management strategy for your individual operation.

Generally, it is suggested to treat grain to control insects

- When wheat, rye, or triticale have one live insect per quart sample.
- When corn, sorghum, barley, oats, or soybeans have one live weevil or five other insects per quart sample.

If these thresholds are exceeded, fumigation is suggested. However, if temperatures are below the manufacturer's suggested levels, fumigation should be delayed. Fumigation effectiveness is greatly reduced under cool conditions. For conditions that do not favor fumigation, the grain mass should be cooled to below 60˚F if possible. At temperatures below 60˚F, insects are mostly inactive. When temperatures permit, fumigation should be considered.

Pests

Primary Grain Insects

Primary grain insects refer to a group of insects that attacks whole, undamaged grain. The immature stages of these insects occur on the inside of the grain where detection is more difficult. The damage from these insects results in a sample grade classification of "insect damaged kernels." Examples of primary insects include the rice weevil, bean weevil, and lesser grain borer.

Secondary Grain Insects

This group refers to a complex of insects that feeds on fragments of grain and cereals. They can also be referred to as bran bugs. They include various grain moths, mites, psocids, and various beetles. Examples of secondary insects include flour beetles, sawtoothed grain beetles, rusty grain beetles, and Indian meal moths.

Grain Storage Space, Capacities, and Weights

Bushels of grain can be determined either on a weight basis or on a volume basis. Grain test weight can be used to convert from one to the other.

Volume Bushels

- 1.0 bushel shelled grain = 1.25 cubic feet
- 1.0 cubic foot = 0.8 bushel shelled grain
- 1.0 bushel ear corn = 2.5 cubic feet
- 1.0 cubic foot = 0.4 bushel ear corn
- 2.0 bushels ear corn = 1.0 bushel shelled corn

Table 3. Bin storage capacity in bushels (approximate).

Corn			Soybeans	
Moisture (%)	Shelled lbs	Ear lbs	Harvest moisture (%)	Lbs grain to make 60 lbs bushel at 14%
10.0	52.6	62.5	10.0	57.6
12.0	53.8	64.7	12.0	58.2
14.0	55.0	66.9	14.0	58.8
16.0	56.0	68.4	16.0	59.4
18.0	57.7	71.3	18.0	60.0
20.0	59.1	74.0	20.0	60.6
22.0	60.6	76.8	22.0	61.2
24.0	62.2	79.8	24.0	61.8
26.0	63.9	82.8	26.0	62.4
28.0	65.7	85.6	28.0	63.0
30.0	67.6	88.5	30.0	63.6
32.0	69.6	91.4	32.0	64.2
34.0	71.7	94.3	34.0	64.8

Weight of Grain Per Bushel at Various Moisture Levels

- Rectangular bins = length x width x height x 0.8 bushel.
- Round bins = diameter^2 x height x 0.628 bushel.

Resources

- 1987. *Management of Stored Grain Insects, Part I: Facts of Life*. Kansas State University Agricultural Experiment Station and Cooperative Extension Service. Publication MF-726. Manhattan: Kansas State University.
- 1989. Management of Stored Grain Insects, Part II: Identification and Sampling of Stored Grain Insects. Kansas State University Agricultural Experiment Station and Cooperative Extension Service. Publication MF-916. Manhattan: Kansas State University.
- Oklahoma State University Cooperative Extension Service, Division of Agricultural Sciences and Natural Resources; USDA Federal Grain Inspection Service; USDA Extension Service; and USDA Animal and Plant Health Inspection Service. 1995 [Revised]. *Stored Product Management*. Oklahoma Cooperative Extension Service Circular No. E-912. Stillwater: Oklahoma State University.
- Sloderbeck, Phillip E.; Bhadriraju Subramanyam; and Randall A. Higgins. 2002. *Management of Stored Grain Insects, Part III: Structural Sprays, Pest Strips, Grain Protectants, and Surface Dressings*. Kansas State University Agricultural Experiment Station and Cooperative Extension Service. Publication MF-917. Manhattan: Kansas State University.

Virginia Cooperative Extension
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Part VI.

Soils of Virginia

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There are more than 880 soil series mapped in Virginia. These soils show great ranges in properties and behavior, and thus in their suitability for different uses. Much of the difference in soils relates to the materials from which they formed; the local topography, hydrology, and soil climate; how long they have been forming; and the degree of human alteration they have received. The diverse nature of the parent materials (the geologic material from which the soil formed) and geologic resources they formed in is seen in the Physiographic and Soil Parent Material Map of Virginia (**fig. 1. page 105**), which divides the soils of the commonwealth into four major divisions. Differences in soils, common topography, rock types, and geology also form the basis of the five physiographic regions that influence hydrology, climate, and patterns in vegetation and land use (**www.dcr.virginia.gov/natural-heritage/natural-communities/document/ncoverviewphys-veg.pdf**). In general, the soils in Virginia are highly weathered outside of the Appalachian Plateau and clayey in the subsoil outside of the Appalachian Plateau, where they are loamy with more rocks, and the Coastal Plain, where they are loamy with almost no rocks and more sand. Almost all soils are moderately permeable and have a pH less than 6.2, unless noted. Acid soils need lime and fertilizer on a regular basis, as predicted by a soil test.

Soil Properties

In the following sections, the reaction (pH), depth class, and natural drainage class are described. The reaction classes (pH values) mentioned are: extremely acid (3.5-4.4), very strongly acid (4.5-5.0), strongly acid (5.1-5.5), moderately acid (5.6-6.0), slightly acid (6.1-6.5), and neutral (6.6-7.0). Alkaline classes are pH 7.1 and higher.

Very shallow soils are less than 10 inches deep to bedrock; shallow soils are less than 20 inches deep; moderately deep soils are 20-40 inches to bedrock; deep soils are 40-60 inches deep; and very deep soils are at least 60 inches deep.

Redoximorphic (redox) features are color patterns associated with prolonged wetness. Redox depletions of iron are grayish in color, and redox concentrations of iron are yellow, orange, or red. Excessively and somewhat excessively drained soils are either sandy throughout, with no restrictions to drainage, or are very shallow to bedrock. Water drains very rapidly in excessively drained soils, while in somewhat excessively drained soils, the water is drained rapidly, producing no redox features. Water is removed readily but not rapidly from well-drained soils, and there are no redox features in the upper 40 inches. Water is drained from moderately well-drained soils somewhat slowly during some times of the year due to a restriction to drainage, or there is a temporary seasonal high water table during the growing season, and redox depletions occur between 20 and 40 inches as a result. Somewhat poorly drained soils have either a moderately deep restriction to drainage or a prolonged seasonal high water table during the growing season, producing redox depletions or a dominant gray color in the upper 20 inches. Poorly drained soils have either a shallow restriction to drainage or a prolonged and shallow seasonal high water table during the growing season, producing a dominant gray color right below the topsoil and often a much darker-than-average topsoil color. Very poorly drained soils have free water near the ground surface for long periods during the growing season and much thicker and darker-than-average topsoil, or they have textures that are organic due to inhibited decomposition of organic matter.

Legend

Appalachian Division

Appalachian Plateau	Sandstone, Shale, Coal Seams	1
Mountains & Uplands	Sandstone, Shale, Conglomerate	2
Limestone Valleys	Limestone, Dolomitic Limestone, Sandstone, Shale	3

Blue Ridge Division

Blue Ridge Mountains	Sandstone, Shale	4
	Crystalline Rocks	5

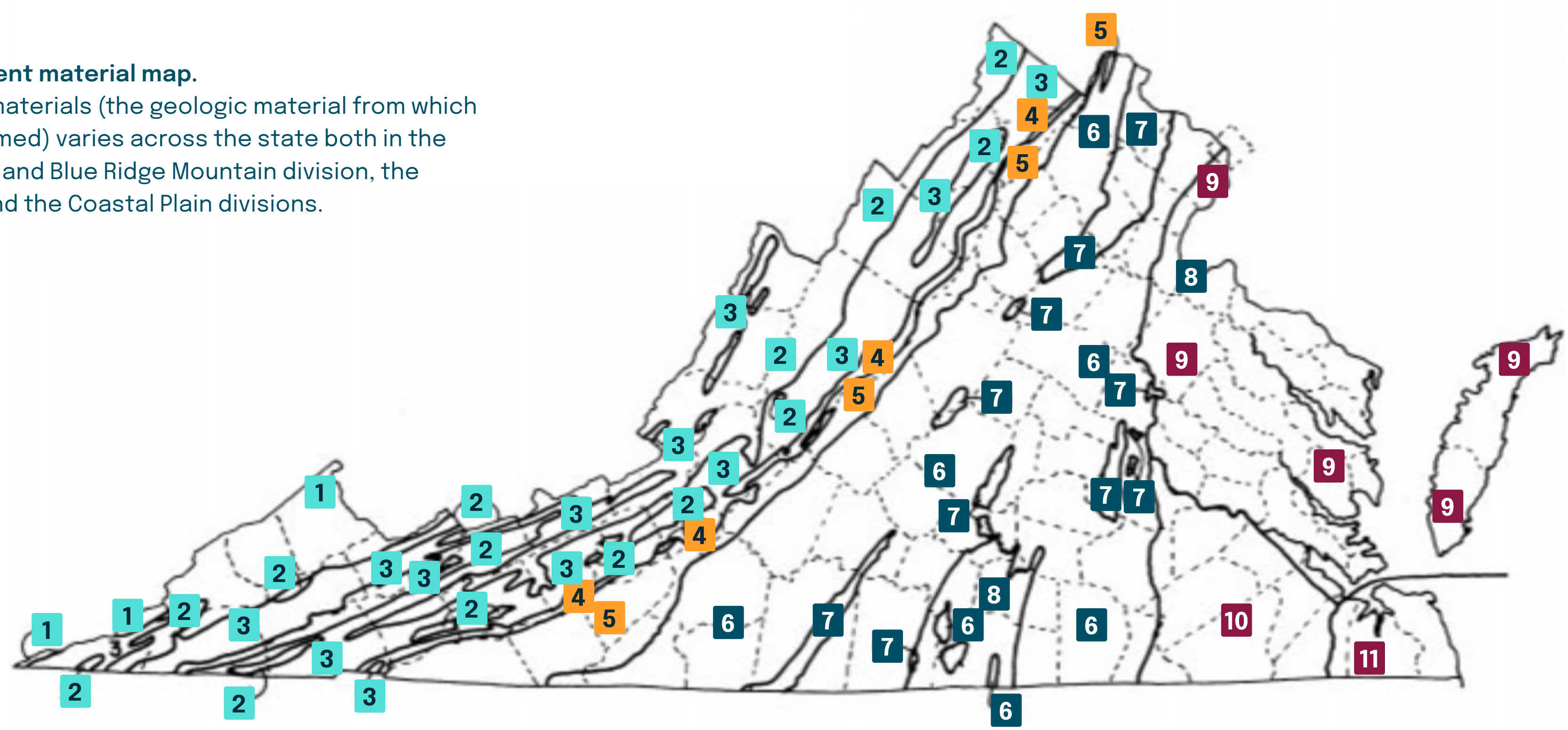
Piedmont Division

Crystalline Rocks	Gneiss, Schist	6
Triassic Areas	Sandstone, Shale	7
Slate Belt	Aaron Slate, Quartz Porphyr, Greenstone	8

Coastal Plain Division

Chesapeake Bay Region	Sands, Clays	9
Middle Coastal Plain	Sands, Clays	10
Flat Woods	Sands, Clays	11

Figure 1. Parent material map.
The parent materials (the geologic material from which the soils formed) varies across the state both in the Appalachian and Blue Ridge Mountain division, the Piedmont, and the Coastal Plain divisions.



Major Soil Divisions

The following sections associate soils with specific properties in each of the four divisions across the Commonwealth.

Appalachian Division

The soils in the southwestern part of Virginia have formed in parent materials deposited beneath ancient seas or on the ancient Coastal Plains bordering those seas. Those deposits became sedimentary rocks after their deep burial and cementation into acid shale, siltstone, sandstone, and conglomerate, or their consolidation (diagenesis) into limestone and dolomite (carbonate rocks). The division is made up of the Appalachian Plateau physiographic region that has flat-lying bedrock (**fig. 1, parent material 1, page 105**) and the Ridge and Valley physiographic region that has folded and faulted bedrock (**fig. 1, parent materials 2 and 3**).

Soils in the Appalachian Plateau are typically shallow to moderately deep on very steep slopes and moderately deep to very deep (5-8 feet) on more gentle slopes. Farming and grazing are limited to gently sloping areas in valleys or on broad summits. The soils are mostly very strongly acid and well drained, but they are not highly developed or weathered due to forming in resistant bedrock types on steep slopes. Most soils are loamy with many rock fragments ranging up to boulder size. These soils are yellowish brown to brown in the subsoil, but many at higher elevations have very dark topsoil. Common series are deep and very deep Cloverlick, Shelocta, and Highsplint formed in colluvium (gravity-transported material) and moderately deep Marrowbone, Mattewan, and Dekalb that formed over siltstone and sandstone and contain many rock fragments.

Soils in valley areas of the Ridge and Valley formed from limestone and dolomite (**fig. 1, parent material 3**). The bedrock is generally deeper than 80 inches on farmed soils, but ranges from shallow to moderately deep in pastures and forest, with some rock outcrops. In the past, most limestone- and dolomite-derived soil areas have been farmed, and they remain some of the most agriculturally important soils of the region due to their moderate natural fertility. They are moderately to strongly acid and well drained. The major land-use problem with these soils is the variable depth to bedrock and the presence of numerous sinkholes that provide pathways for excess nutrients into the groundwater. The surface textures are typically silt loam or loam, with yellowish red to red subsoils that have high clay contents. Common soil series are Groseclose and Frederick. Soils like Carbo and Endcav have yellowish brown to strong brown clayey subsoils that shrink and swell dramatically when they wet and dry, limiting their land use and productivity because of droughtiness and damage to infrastructure.

Deep and very deep soils formed from strongly acid shales on ridges within the valleys (**fig. 1, parent material 3**) have low natural fertility. Most of these well-drained and moderately slowly permeable Lowell and Rayne soils have been cleared and planted to crops or pastures. They have strong brown clayey and silty subsoils. Shallow to moderately deep soils formed from strongly acid siltstones and shales along the mid- to lower flanks of the mountainsides (**fig. 1, parent material 2**). They are typically permeable and well drained. Weikert (shallow) and Berks (moderately deep) are silt loam or loam throughout and contain many shale fragments throughout the soil profile, limiting their water-holding capacity. Gilpin (moderately deep) soils have a silt loam and loam textures and fewer rock fragments.

Soils formed from very acid, strongly cemented sandstones and conglomerates occur along the major ridgelines and upper portion of the mountains. These soils are usually shallow, sandy, and often gravelly or cobbly with many stones and boulders covering the surface. Rock outcrops are common. They remain in native forest as part of the National Forest System because of their inherently low fertility and very low water-holding capacity, numerous large rock fragments, and very steep slopes. Soils that are shallow to bedrock have limited rooting zones for crop and pasture plants. Commonly occurring, very strongly acid soil series on more gentle slopes are the moderately deep, yellowish brown Dekalb soils and the deep Shelocta soils that have silty clay loam subsoils. Moderately deep, strong brown to reddish brown Lily and Calvin soils form at high elevations under native forests and over maroon-red sandstones and shales.

Soils formed in materials transported by gravity (colluvium) and water (alluvium) are common on gentle slopes in lower landscape positions and are important agriculturally. Laidig soils were formed from colluvium and have dense, very slowly permeable subsoil layers called “fragipans” that restrict roots and water, and have moderately deep, seasonal, high water tables. Strongly to moderately acid, loamy Jefferson colluvial soils are well drained and permeable and are used for pasture or forest, or for cropland on more gentle slopes. They have few limitations for use if they are on gentle slopes. Soils formed in alluvium are generally the most productive soils of the region because of high water-holding capacity and moderate natural fertility. Slightly acid to neutral Ross, Weaver, and Timberville are silty and loamy soils on floodplain positions and are subject to stream overflow. Poorly drained, silty soils like Purdy have restricted use because of poor drainage. Very deep, strongly to very strongly acid, clayey, red, well-drained, and highly weathered Shottower soils occur on nearby higher positions such as stream terraces and are well suited to many land uses. They have very low natural fertility.

Blue Ridge Division

The Blue Ridge Mountain division and region ranges from 5 to 25 miles wide. The soils of this division are formed from a combination of crystalline igneous rocks, formed from molten magma that cooled underground, and metamorphosed rocks, formed by heat and/or pressure alteration of other rocks. The bedrock on the western slopes of the division are highly consolidated acid shale, sandstones, conglomerates, and quartzite.

The overriding soil use constraints in the Blue Ridge are steep slopes, stoniness, and shallow depth over bedrock. The soils formed over acid crystalline rocks (**fig. 1, parent material 5, page 105**) are very strongly to moderately acid and well drained. Common, very deep soils that have strong brown to yellowish brown loamy subsoils are Glenelg, Edneyville, Edneytown, and Hayesville, and those with clayey subsoils are Elioak. Loamy Myersville soils formed over more alkaline bedrock but have highly weathered into very strongly acid subsoils. The steep slopes associated with much of the area demand that careful attention be given to any activity, either cultivation or construction, that leaves the soil bare to minimize erosion hazards. Very deep, strongly to very strongly acid, clayey, red, well-drained, and highly weathered Braddock and Unison soils occur on footslopes and stream terraces on the east side of the region, and are well suited to many land uses. They have very low natural fertility.

Many slopes are very steep, but more gently sloping highland areas occur along the Blue Ridge Parkway. To the north of Roanoke, these gently sloping ridges are narrow, thus limiting uses to forestry and recreation within the national forests. To the south of Roanoke, the Blue Ridge Highland area is gently sloping and several miles wide. This area is intensively used for agriculture and is dominated by very deep, well-drained soils suitable for many uses, although high elevation areas have short growing seasons and cold climates. They require careful management for crop or Christmas tree production.

The western flanks of the division (**fig. 1, parent material 5, page 105**) north of Roanoke are covered by soils, such as shallow, strongly acid, yellowish brown Ramsey over sandstone, and deep, excessively drained Drall that formed over sandstone or quartzite rock. Many colluvial soils on broad footslopes that flank the Shenandoah Valley have fragipans (Buchanon, Laidig) and are high in rock fragments, severely limiting their water-holding capacity and rooting depth. Other colluvial soils with loamy subsoils (Jefferson) are suited to a wide variety of land uses.

Piedmont Division

The Piedmont is the largest physiographic division and region in Virginia. It occurs between the Blue Ridge Mountains and the fall line that runs between Arlington, Fredericksburg, Richmond, and Emporia. The fall line is the easternmost place where waterfalls and rock outcrops occur in stream and river bottoms, such as near Belle Isle in Richmond. The Piedmont region is dominated by crystalline igneous and metamorphic rocks (**fig. 1, parent material 6**) surrounding important areas of sedimentary rocks (**fig. 1, parent material 7**). The soils are warmer to the east of a line that runs between Martinsville, Appomattox, and Fredericksburg, and that affects some crop and timber production choices.

The predominant, acidic, crystalline bedrocks are gneiss, schist, and granite, of which quartz, feldspar, and mica are the dominant, primary minerals. Natural fertility is very low in these highly weathered soils. Highly available aluminum and very low phosphorus content limit native plants and crops. Liming is necessary to prevent particularly high aluminum in the subsoil from being an agronomic problem. Historically, much of the Piedmont region was cleared and farmed intensively to cotton and tobacco, causing extreme erosion over much of the region. Before modern soil fertility and managerial practices were adapted to these soils, agricultural production diminished and most farms reverted back to forests. Over two-thirds of this region is wooded today, with many plantation forests in the eastern half. The best soils on gentle slopes are still agriculturally productive through well-managed soil fertility and erosion control plans, while other former croplands are now in pasture.

Soils such as Cecil (Clifford) and Pacolet (Fairview) developed very deep, well-drained, very strongly acid, with sandy loam or loam surfaces and red clayey subsoils. Appling (Nathalie) and Wedowee (Toast) soils are similar except for having yellowish brown to strong brown subsoils. Madison (Poplar Forest) soils are similar to Pacolet but have abundant flakes of mica in the subsoil. The Fe-oxide content is higher in the red soils, controlling their subsoil color. Yellowish brown to strong brown Nason (Buffstat) and red Tatum (Littlejoe) are deep clayey soils formed from moderately weathered, fine-grained schist bedrock. The soil names in parentheses above are equivalent soils that formed on the cooler west side of the Piedmont.

Some soils were formed from igneous and metamorphic rocks with a high base content of calcium and magnesium. Soils formed from such minerals tend to be less acid and more naturally fertile, with less free aluminum in the subsoil. Davidson (dark red), Cullen (red), and Mecklenburg (yellowish red) form very deep, clayey soils that are well drained with low activity (low volume change and chemical activity) clays. However, in some instances the bedrock weathers into expansive clay subsoils with moderate chemical activity and very high capacity to shrink and swell on wetting and drying. These deep to very deep "shrink-swell" soils such as Iredell are slowly to very slowly permeable and moderately well to somewhat poorly drained. They are moderately suited to lawns and gardens if properly managed, but they pose a managerial challenge to farmers and developers.

Scattered throughout the Piedmont are other soil areas formed from sandstone and shale that were once sediments deposited in Triassic-age basins. These ancient (252-201 million years ago) basins (**fig. 1, parent material 7, page 105**) are oriented in a northeast to southwest direction, roughly paralleling the Blue Ridge. The soils north and east of Charlottesville developed over red siltstone and shale bedrock and are moderately deep to very deep. The very strongly acid, reddish brown, silty and clayey soils such as moderately deep Penn and deep Bucks can be quite productive. To the south and east of Charlottesville, many Triassic Basin soils have high clay content and very high aluminum levels. On soils such as the very deep, yellowish red Mayodan, it is difficult to establish high productivity for crops, lawns, or gardens without careful liming and fertilization. The very deep, red, silty, and clayey Georgeville soils formed over slate. Some soils in this region (**fig. 1, parent material 8**), such as moderately well-drained White Store and somewhat poorly drained Creedmore, have expansive clays in the subsoil that cause slow permeability and pose severe problems for farming and urban uses.

Coastal Plain Division

The Coastal Plain begins at the fall line to the west and extends to the bays and ocean on the east. Soils of this region are formed from stream and ocean water deposits that have never been consolidated into bedrock. All soils are very deep because consolidated bedrock is deeply buried by the unconsolidated sediments in all parts of the Coastal Plain. Some of the sediments were deposited when the ocean level was much higher than at present and still occur far west of the fall line in thin and discontinuous deposits. They form a wedge of sandy-textured parent material that is at the surface at the fall line and up to 15,000 feet thick at Virginia Beach. There are 11 marine terraces that are remnants of higher ocean levels. Between periods when the ocean was higher, gravel, sand, silt, and clay sediments were deposited by meandering rivers and streams that originated in the western part of the state. All Coastal Plain soils used for cropland require liming and fertilization, although aluminum toxicity is less of an issue than in the Piedmont. Excess fertilization is a concern on sandy Coastal Plain cropland soils, many of which are in close proximity to water bodies and streams.

Soils closer to the fall line have been exposed and forming and weathering longer than soil at lower elevations and closer to the Chesapeake Bay and Atlantic Ocean. Soils in the Coastal Plain are strongly to very strongly acid and are much more acid on the west side toward the fall line and becoming extremely acid with depth. Most are naturally infertile, with some moderately fertile soils at low elevations and along rivers that drain the western regions of Virginia. Many of the soils have thick sand or loamy sand surface textures, which make them susceptible to wind erosion and summer droughts. Major soils such as Norfolk and Suffolk are well drained with yellowish brown to strong brown loamy subsoils. Bojac soils are similar but have more sand and less clay in the subsoil, which makes them droughty in dry summers. Emporia and Slagle have moderately slow to slow permeability because of platy structure in the subsoil that restricts downward water movement, causing temporary seasonal high water tables in the upper subsoil. The soils on terraces of many rivers that drain the Piedmont and farther west are the well-drained Pamunkey soils, which have slightly to moderately acid subsoils, yellowish red colors, loamy textures, moderate natural fertility, and good structure throughout. Pamunkey is the unofficial state soil of Virginia and often sets records for crop production. Because most landscapes are nearly level to gently sloping, the soils are not as susceptible to erosion as in the other regions. In general, the closer to the coast, the nearer the water table is to the soil surface, the lower the elevation, and the higher the sand content. Many of the streams form sluggish swamps with very poorly drained soils that are high in organic matter.

Soils in the Northern Neck areas (**fig. 1, parent material 9, page 105**) are moderately acid, yellowish brown, very deep, and well-drained loamy soils with large amounts of sand. Eastern Shore and low-elevation soils such as Dragston and Lumbee are somewhat poorly and poorly drained, with grayish brown to light gray loamy-textured subsoils. Many cropland fields have drainage ditches and tile drains to remove excess water. Many streams and rivers dissect the landscape.

The soils and fields of Southside Virginia (**fig. 1, parent material 10**) are broader and more level than in the Northern Neck. These soils and landscapes, commonly coupled with larger field sizes, accommodate more efficient and large-scale farming practices. This region has the highest percentage of row crop agriculture in Virginia as well as a thriving plantation forestry industry. Modern soil liming and nutrient management practices, high-capacity farm implementation, and other advanced electronic tools and production technologies make the soils highly productive for row crops. Some soils have thick, sandy surface textures suitable for growing peanuts.

The growing season in the Tidewater area (**fig. 1, parent material 11**) is long and warm, which makes it well suited for both peanuts, and for cotton, which cannot grow in shorter growing season areas of Virginia. Many soils have water tables near the surface and must be drained for farming. The soils have sandy surfaces and loamy subsoils, with very sandy lower subsoils.

There are significant acres of slightly acid, poorly drained soils with high water tables in low-lying or flat landscapes in the Coastal Plain region. About 22% of the area is wetlands, and almost 75% of the wetland soils in Virginia occur in this region. The high amounts of sulfur in many marsh and swamp soils along bays and estuaries create extremely acid soil conditions if drained. Pungo is a very poorly drained swamp soil made up of highly decomposed organic material. Seasonally saturated mineral flats with poorly drained Roanoke, Rains, Tomotely, Nimmo, and Acredale soils are in plantation woodland or drained cropland, or they exist as jurisdictional wetlands, which are protected from drainage by law. These strongly to very strongly acid, loamy-textured soils are typically gray or brownish gray with dark topsoil and white sand below the subsoil. Unplowed freshwater wetland areas provide the essential mechanisms necessary to slow water movement from uplands to estuaries and bays of Eastern Virginia and to buffer nutrient losses from farm fields, thus serving to maintain high water quality and a sustainable biodiversity for the region.

Soils in Natural Landscapes and Soil Surveys

The discussion above is intended only as a general guide to major land resource areas in Virginia. It must be remembered that drastically different soils can occur within the same landscape. Soils within similar landscapes are somewhat variable in properties; much of this is due to local variations of parent materials. Several soils can occur together in a field of a few acres. Usually, soil bodies are related to landscape positions. The shape of the landscape configuration has a direct effect on soil drainage and soil type. Concave-shaped positions are collectors of water, while convex positions divert water and thus are usually better drained.

Virginia has detailed soil survey maps typically produced at the county level by Virginia Polytechnic Institute and State University in cooperation with the USDA-Natural Resources Conservation Service. These soil survey maps show the geographic locations of different soil bodies on the landscape. The use of the maps with soil descriptions and interpretative guides provides a means of estimating the suitability of an area for a particular land use. Soil surveys are available online, and paper copies may be available in libraries, at the local Virginia Cooperative Extension office, or at USDA-Natural Resources Conservation Service offices. Free online versions of county and statewide maps are available, as well as a digital file for use with geographic information system software.

Soils for Homesites

If a conventional on-site septic tank and drainfield system (conventional system) is planned, the soil must not have restrictions to drainage in the upper 36 inches. The homeowner should be aware of the following soil/site features if a conventional system is to be installed:

1. Surface drainage and permeability.
2. Erodibility.
3. Presence of shrink-swell clays.
4. Relief and soil depth, nutrient status, and pH.

Drainage and Permeability

Surface drainage and internal soil drainage relate to the shedding of water from a site by surface overflow and the removal of excess soil water to give the soil aeration. Well-drained soils are not saturated for significant periods of time, and the depth of a seasonally high water table is usually greater than 40 inches. Well-drained soils are generally the most suitable for building sites and most types of plantings. Poorly drained soils can have water at or near the ground surface during wet periods of the year.

All regions of Virginia have both well-drained and poorly drained soils, as well as soils between these extremes. In some areas of Virginia, such as in the Tidewater region, over 90% of the soils have potential wetness problems. These wet areas present special problems for landscaping, yard drainage, and maintenance of a dry basement.

Permeability is the rate that a soil will transmit water. This rate varies from rapid to very slow within any soil horizon. Often the most limiting rate is reported. Water movement is aided by a network of interconnected pores that extend throughout the soil. Where soil pores are small and total pore space is limited – such as in poorly aggregated subsoils with high clay content or where compacted layers exist – permeability will be slow to very slow. Layers of expansive clays, abrupt changes in texture, compacted layers, and platy structure restrict downward movement or percolation during wet periods and may result in temporarily perched water tables.

In many cases, wetness problems in basements or around footings can be overcome with proper surface drainage by diverting excess water away from problem areas. For new construction, the use of footing drains along with proper grading and surface water control is recommended to reduce the potential for wetness problems. Footing drains installed at construction time are relatively inexpensive, but they are very costly to install later when a problem arises.

Erodibility

The susceptibility of a homesite to soil erosion depends on the kinds of soil as well as on the grading and land forming done by the contractor during development. In many cases, especially on small lots, the natural soils have been completely removed, or at least disturbed, by cutting and filling. The original surface soil on the lot is likely to have been removed from the site or lost during construction, although some recent regulations now require contractors to reapply the topsoil to the finished grade. The erodibility therefore depends on characteristics of the slope and soil material. Vegetation should be established as soon as possible on any bare soil areas. Any kind of plant debris (straw, grass, mulch) or commercial cloth mesh that covers the ground will help reduce soil erosion until permanent vegetation or sod is in place.

Shrink-Swell Clays

Soils with a high content of shrink-swell (expansive) clays will change volume on wetting and drying. These expansive soils can cause severe damage to foundations and footings of buildings and to sidewalks, roads, and other structures. Where such clays are at or near the soil surface, severe root pruning of plant seedlings can occur. When such soils are encountered or expected, an on-site evaluation by a qualified soil scientist is recommended. If construction is planned on such soils, it may be advisable to remove the expansive material from the site. In some instances, special designs – such as rebar reinforcement – may be necessary. In other cases, it may be advisable to seek an alternative site or install an alternative on-site sewage treatment system. Proper planning ahead of construction is far less costly than remediation of a site once expansive soils have caused building, driveway, and other infrastructure damage.

Relief and Soil Depth

Homesites with excessive relief (steep slopes) may impose restrictions on basic construction and force other compromises relative to access and maintenance of public utilities. Locating lawns, gardens, play areas, and septic drainfields is difficult on steep slopes. There must be adequate soil depth for growing the kinds of plants desired. Steep slopes or shallow to bedrock conditions are severe limitations.

Nutrient Status and pH

Lawn, garden, and yard management testing of the soil is recommended every few years by a certified soil analysis laboratory. Acid rainfall causes a continuous acidification of the soil. The soils with low clay content or high amounts of low-activity clays are less buffered against acidification, which could cause aluminum toxicity problems. Plant nutrients and aluminum are most available at neutral pH. Homeowners should apply lime to raise the pH and fertilizer at the rates prescribed by the testing lab by carefully following the rates and instructions on the product. Lowering the pH to aid acid-loving plants and fruits should be done very carefully and cautiously.

Managing On-Site Septic Tank Drainfield Systems

Houses constructed where there are no public sewer systems will have an individual subsurface sewage disposal system. A conventional septic tank drainfield system will usually be within an area of about 50 feet by 100 feet in size, and will possibly have an adjacent reserve area half that size. The purpose of the system is to carry all the wastewater from the house and allow its slow absorption into and percolation through the subsoil. Soil areas used for this purpose in Virginia must pass strict evaluations and testing procedures. In order to pass this test for a conventional system, soils must be well drained, have moderate permeability, be higher in elevation than adjacent drainageways, and not be installed on excessively steep slopes or in drainageways. Alternative systems can be designed and built for less than ideal soil and site conditions. The septic tank drainfield system absorbs hundreds of thousands of gallons of sewage effluent and will last many years if the soil is suitable and the system is correctly installed and properly maintained.

Drainfield Maintenance

A cover of grass should be maintained over the system. It is important to prevent and eliminate any erosion because the drainfield lines are often within 2 feet of the land surface. The species of grass is not as important as the maintenance of a healthy cover. Do not locate trees or shrubs on or near the drainfield because roots could eventually damage and block the distribution lines. Heavy traffic over the drainfield should be avoided.

Cleaning

It is advisable to have the septic tank pumped and cleaned every three to six years. Contact your local health department for recommendations concerning maintenance, cleaning, or any alterations on any part of the septic drainfield system.

Soil Water Use

A yearly water budget diagram offers a way to show where soil water is being utilized (depleted) and where soil water is being recharged. The diagram **(fig. 2, page 114)** shows an average water budget for three climatic recording stations in Eastern Virginia. The left vertical scale is in inches of water. The bars show the difference between precipitation (P) and water usage. Evapotranspiration (ET) is the total of water loss from the soil (evaporation) and the water used or lost from plants (transpiration). A positive number indicates there was an excess of soil water for that month. For months where the average precipitation was less than usage, the number on the left vertical scale is negative. This indicates that the soil must have the capacity to supply stored water in order for plants to continue to grow at the maximum rate.

For summer months (the midpoint of the growing season), there was a deficit for each of the months of June, July, August, and September. The soil has to hold this total amount of water for continued plant growth. The best soils will store about 7 inches of water in the upper 3 feet of soil. This would be enough to make up for the expected water deficit in a climatic setting described by the water budget diagram in **figure 2**.

Soil Water Recharge

In Virginia, the normal climatic pattern from October to May has periods of water excess (where ET is less than P). This excess precipitation over ET will recharge the soil with water, month by month, until the soil is fully recharged. The data indicate this recharge would be complete sometime in January of the following year.

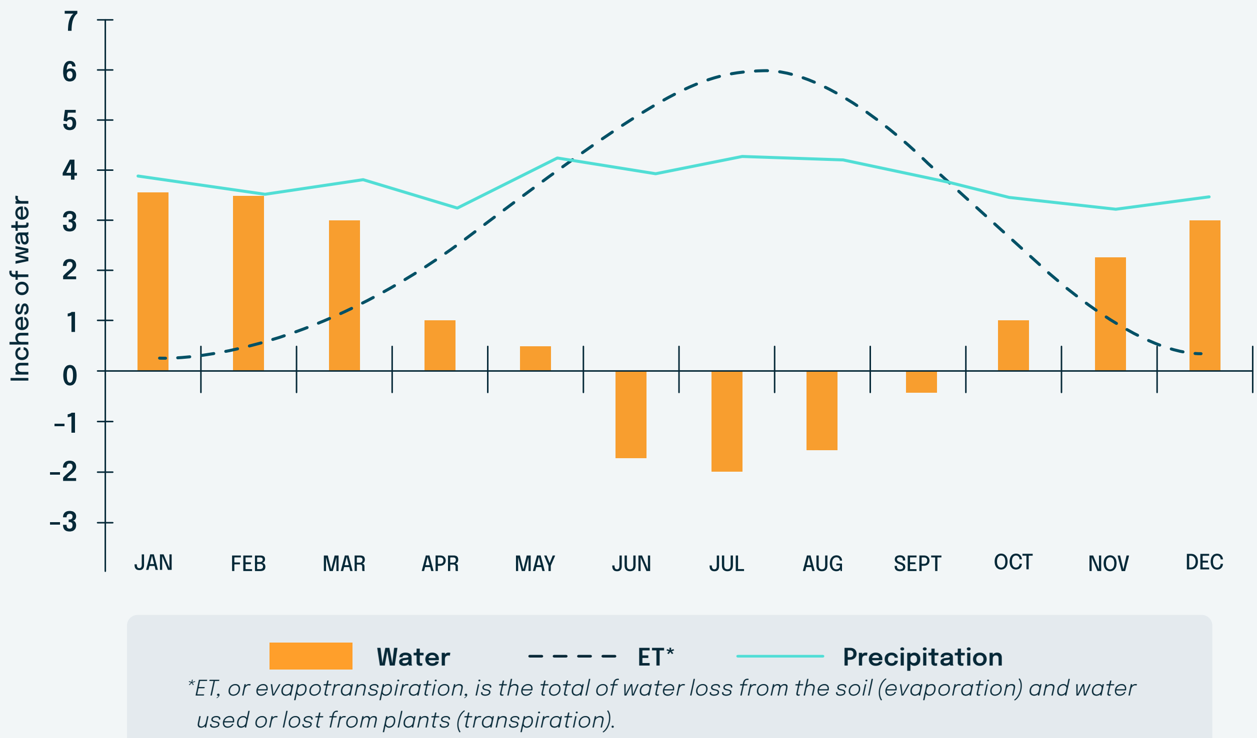


Figure 2. Example annual soil water budget. Evapotranspiration (ET) is the total of water loss from the soil (evaporation) and the water used or lost from plants (transpiration).

Leaching

After recharge is complete, before the growing season starts, the soil will have excess water. At this point, when precipitation events occur, excess water will (1) run off the soil surface, promoting erosion; or (2) push existing soil water through the soil, causing leaching and percolation losses. This is the most likely time for nitrogen and other chemicals to enter groundwater. It will continue until the growing season begins and plant use of water increases. Maximum leaching and maximum runoff will occur on average during this period when the soil is recharged and before plants begin to use it in the early growing season. This leaching potential will continue until about June, when once again, the soil will give up stored water to maintain maximum growth potential for the crop. In order to minimize leaching losses, applications of nitrogen or other soluble fertilizers should be applied as near to planting time as practical and/or added in split applications over the growing season.

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Part VII.

Soil Health Management

Characteristics, Priorities, Principles, and Holistic Systems Thinking

Authored by:

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Farmers, ranchers, market gardeners, and land managers must constantly assess and know their operation, values, and resource concerns in order to balance and achieve their overall objectives. For many people, soil is a starting point and basis for viability, profitability, sustainability, and regenerative agriculture. Soil is a foundational resource to farming, conservation, and health in the 21st century.

Interest in the health of a soil and its quality and function as a holistic system has continued to grow among farmers, ranchers, gardeners, and land managers the past 30 years. Soil health is defined as the continued capacity of soil to function as a vital living ecosystem with integrated chemical, physical, biological, and ecological properties, processes, and boundaries, that sustains plants, animals, and humans (USDA-NRCS 2018; Doran et al. 1994).

This publication reviews and discusses why soil health is critical, the characteristics of influence and consideration, the key soil management priorities, and four core soil health principles that should guide and inform different farm and land management practices as within a system.

Why Soil Health?

Adoption of principles and implementation of soil health practices are management decisions, but they are also tangible expressions of who farmers and land managers are as people and what they believe are critically important social, economic, and ecological values. With soil management, overall context of the farm operation, and values matter. Soil health is critical for the following social, economic, and environmental reasons; however, individuals may have additional personal reasons for building soil health to add to this short list.

- Improved long-term sustainable, regenerative agricultural production.
- Enhanced economic viability.
- Improved environmental, ecological, and climatic resilience.
- Continued loss of prime arable farmland to urban and suburban development.
- Improved biodiversity and wildlife habitat.
- Rapidly increasing world population.
- Increased food supply requirements.

Soil Characteristics of Influence and Fundamental Consideration

Within soil science, there continues to be research and discussion on the natural and human factors influencing soil formation and development, particularly fundamental considerations of how farmers, ranchers, market gardeners, and land managers can directly and indirectly influence soil through their management. Authors Fred Magdoff and Harold Van Es (2021), in their book “Building Soils for Better Crops: Ecological Management for Healthy Soils,” identified seven distinct soil characteristics and attributes that people’s management can affect and influence, particularly in building topsoil and increasing the possible rooting zone for plants. These characteristics provide a baseline for management consideration and overall thinking about soil as an integrated holistic system. As research continues, scientists and the agricultural community are learning more about other characteristics and relationships in the soil environment.

The characteristics of soil, distilled by Magdoff and Van Es (6-7), that influence and distinguish how soil is managed for productive yields and healthful plants for high positive and low negative environmental impacts are as follows:

1. **Fertility** – The ability of a soil to cycle nutrients so the nutrients are available to plants at specific growth stages. Therefore, soil testing is integral to knowing nutrient content, pH, soil organic matter levels, and other soil properties.
2. **Structure** – Farmers and producers often talk about tilth and the mellowness of soil having good aggregate stability, being absorptive, taking less effort to work, not crumbling into a powder, and allowing water and air to infiltrate without being blocky or clod-forming.
3. **Depth** – Crops and plants need an adequate rooting zone to allow for growth and expansion without being unnecessarily impeded by a hardpan and compacted soil.
4. **Drainage and aeration** – Of course, there are a few plants that can tolerate living in perpetual wet conditions, but adequate drainage and aeration is needed for water and air flow and the exchange of carbon dioxide and oxygen as part of evapotranspiration. Soil compaction can influence structure, depth, drainage, and aeration by compressing soil pore spaces; therefore, it is imperative to know and evaluate when a soil is too wet and plastic for foot and equipment traffic.
5. **Minimize pests** – As a living ecosystem, the soil should have a balance of beneficial insects for defense and to suppress infection and limit predation. Planting and rotating diverse crops can break up disease cycles and pest pressures.
6. **Free of potential pollutants and toxins** – A healthy soil would be free of pollutants and toxins but should also have the ability to buffer and detoxify potential pollutants.
7. **Resilience against stresses** – Some soils are more naturally forgiving than others, some soils are less forgiving, and other soils are fairly unforgiving to poor management. However, in setting priorities and adhering to core management principles and sound soil health-building practices, the resilience of soils can be increased to be able to withstand drought, heavy rainfall, and other stresses to the ecosystem for a longer duration.

Five Priorities of Soil Management

Key concepts of soil health and ecological soil management include

- Protecting the soil habitat.
- Managing more by disturbing less.
- Keeping soil covered.
- Diversifying food and carbon sources for soil microorganisms with cropping rotations.
- Integrating diverse plant and animal communities.
- Growing living roots throughout the year.

Additionally, there are priorities and principles for overall management of soil that adhere to these concepts that need to be remembered and followed, no matter the soil type, to build internal strengths into the system. Eliminate erosion: Keeping soil in place and preventing soil movement from the field and landscape is essential to maintaining productivity and building soil health. Soil eroded by rain or wind results in nutrient loss, diminished growing potential, and other off-site environmental impacts such as sedimentation of local roads and waterways. Keeping soil covered and armored can eliminate erosion.

1. **Match land use to landscape:** Land use should consider soil capability and the potential for soil erosion based on soil type, slope class, land cover, crop rotation, potential fallow, and transitions in crop rotations. As the slope of the landscape steepens, the likelihood of erosion and soil loss increases. Similarly, land use decisions should consider distance to streams, creeks, and other sensitive environmental areas that would be impacted by soil erosion and increased sediment loads.

2. **Enhance soil biology:** Good soil biology begins with principles and practices that enhance and promote soil as a habitat and an ecosystem. Soil management inherently means providing habitat, shelter, and food for belowground employees and volunteers. Biology is critical to how the soil food web functions, so microbes, bacteria, and fungi can biologically mediate chemical and physical processes to assist in making nutrients available and giving structure for water and air cycling.

3. **Build soil organic matter:** Soil organic matter is a source of carbon and other essential nutrients made available and exchanged through solid, liquid, and gaseous phases (Lal 2016). Magdoff and Van Es (2021, xiii) state that “building and maintaining good levels of organic matter in our soils are as critical as managing physical conditions, pH, and nutrient levels.” Soil organic matter affects many soil properties and is made up of plant and animal residues, root exudates, and amendments added to the soil. Soil is a living ecosystem that experiences gains and losses of soil organic matter. Farmers, gardeners, and soil managers should minimize losses that can occur when soil is disturbed or left bare, and build organic matter through management of plants, rotation of crops, integration of livestock, and the addition of plant nutrients and soil amendments such as compost, manures, poultry litter, and fertilizers.

4. **Think systems, not shortcuts:** Soil is a living system with biological, chemical, and physical properties. Some properties are inherent to the soil type and how the soil was formed. However, management or neglect can affect all soil properties, so a holistic systems-based approach is needed for long-term health and vitality. Thinking of soil as an ecosystem with various parts and players can help soil managers understand all soil change processes are integrated and interactive. Shortcuts in decision-making may be shortsighted, only addressing symptoms of poor management, and short-changing the system in the long run (Karlen and Rice 2015).

Four Core Soil Health Principles

1. **Keep soil covered:** It’s the first step in protecting it from erosion but also buffers soil temperature, slows rainfall runoff, aids rainfall infiltration, and limits evapotranspiration of crucial moisture.

2. **Minimize soil disturbance,** both physical and chemical. Being proactive to reduce physical and chemical disturbance can heal and protect properties of the soil and ultimately enhance the habitat and home of the biological component of soil life. Physical and chemical disturbance can adversely affect the home of microbes and their living environment (Karlen et al. 1994).

3. **Maximize living roots:** Having roots growing and living throughout the year fuels biological activity, aids nutrient cycling, and contributes to improved soil structure because roots provide food, water,

oxygen, and shelter for soil microbes. The more diverse and complex the cropping and cover crop system, the more diverse the root structure will be to support a diverse microbial community.

4. **Energize with diversity:** Use different crop species, crop rotations, and livestock integration where possible for specific purposes to enhance chemical, physical, and biological aspects of the soil. Diverse crop species and rotations can maximize plant surface area and groundcover to better fully capture sunlight. Also, do not underestimate the positive synergies and impact that a diverse population of beneficial insects and pollinators can have on the whole system.

Holistic Systems Thinking

Soil has biological, chemical, physical, and ecological properties as part of living ecosystem affected by natural factors and human influences. As previously mentioned, some of these properties are inherent to the soil type and how the soil was formed through time. All soil properties can be positively and negatively affected. Some effects may be experienced relatively rapidly and others may occur long-term. Soil health management, therefore, requires a holistic systems-based approach for long-term health and vitality. A sole focus on current symptoms may ultimately be shortsighted and short-change the system in the long run. Thinking of soil as an ecosystem with various players, employees, and volunteers working at different scales in soil, liquid and gaseous phases can help soil managers understand all soil change processes need to be thoughtfully considered because the processes are integrated, interactive, interdependent, and dynamic.

References

Doran, J. W., T. B. Parkin, J. W. Doran, D. C. Coleman, D. F. Bezdicek, and B. A. Stewart. 1994. "Defining and Assessing Soil Quality." *In Defining Soil Quality for a Sustainable Environment*, edited by J. W. Doran, D. C. Coleman, D. F. Bezdicek, and B. A. Stewart. Soil Science Society of America Special Publication 35:3-21. Madison, WI: SSSA.

Karlen, D. I., N. C. Wollenhaupt, D. C. Erbach, E. C. Berry, J. B. Swan, N. S. Eash, and J. L. Jordahl. 1994. "Long-Term Tillage Effects on Soil Quality." *Soil & Tillage Research* 32:313-27.

Karlen, D. L., and C. W. Rice. 2015. "Soil Degradation: Will Humankind Ever Learn?" *Sustainability* 7 (9): 12490-501. https://doi.org/10.3390/su70912490.

Lal, R. 2016. "Soil Health and Carbon Management." *Food and Energy Security* 5 (4): 212-22. https://doi.org/10.1002/fes3.96.

Magdoff, F., and H. Van Es. 2021. *Building Soils for Better Crops: Ecological Management for Healthy Soils*. 4th ed. Sustainable Agriculture Research and Education (SARE) Handbook Series 10. College Park, MD: SARE.

USDA-NRCS (U.S. Department of Agriculture. National Resources ConservationService, Virginia). 2018. "Soil Health in Virginia: The Next Frontier of Conservation." www.nrcs.usda.gov/wps/portal/nrcs/detailfull/va/soils/health/?cid=stelprdb1248422.

Virginia Cooperative Extension
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Part VIII.

Soil Testing and Plant Analysis

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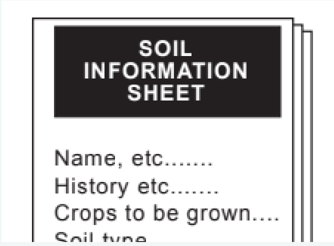
Soil testing and plant analysis are important agronomic tools for determining crop nutrient needs. Soil testing evaluates the fertility of the soil to determine the basic amounts of fertilizer and lime to apply. Plant analysis, on the other hand, is used as a monitoring tool to determine if the fertilization and liming program, as determined by the soil test, is providing the nutrients at the necessary levels for top yields. Plant analysis is the ultimate test (i.e., is the plant obtaining ample nutrients for good growth and development from the soil?). If not, nutrients can be added during the existing growing season to improve yields, or the fertilization program can be modified for next year's crop. The following sections discuss how to use soil testing and plant analysis to evaluate crop nutrient needs.

Soil Testing

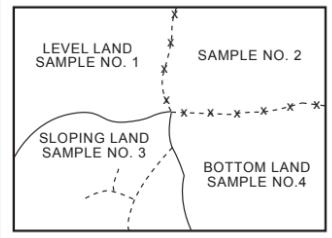
Sampling Instructions

Collecting the sample is one of the most important steps in the soil testing program. When one considers that a 2-pound soil sample must adequately represent 10 million or more pounds of soil in the area being sampled, the importance of doing a good job of sampling becomes apparent. Here are instructions for collecting a good representative soil sample.

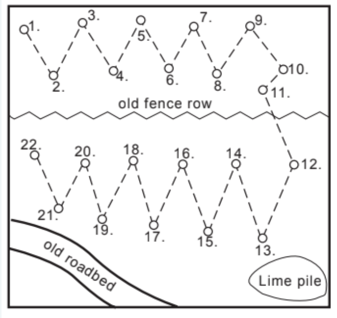
Sampling Soil



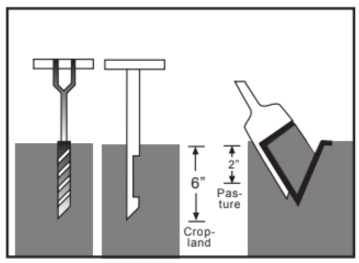
1. **Get Soil Sample Information Sheets and soil boxes.**
These can be obtained from your local Extension office or from the Virginia Tech Soil Testing Lab. Follow the directions they provide.



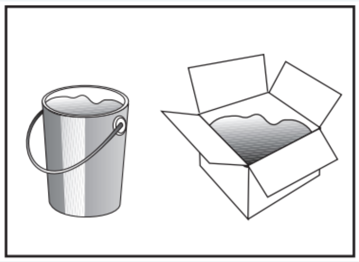
2. **Divide farm into areas or fields.**
If the field is uniform, one composite sample will do. But most fields will have been treated differently, or the slope, drainage, or soil type will make it desirable to divide the field into small areas of 5-10 acres each.



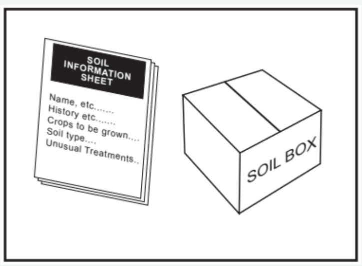
3. **Obtain a good sample of soil.**
The soil test can be no better than the sample. Take the sample from 20 or more places in the field. Zigzag across the field or area as shown in the diagram. When taking the sample, avoid unusual places such as old fencerows, old roadbeds, eroded spots, where lime or manure have been piled, or in the fertilizer band of row crops.



4. **Use proper sampling tools.**
   Sampling can be made with a soil auger, soil tube, or spade. The desired depth for cropland is plow depth (6-8 inches or more), and 2-4 inches for pastureland, or no-till crop fields. Place sample in clean container.



5. **Mix well in a clean plastic pail.**
   From the 20 or more stops you have made, you now have 1 gallon or more of soil. Mix it thoroughly, then send about 1/2 pint of the mixed soil to the lab for analysis.



6. **Fill out a Soil Sample Information Sheet for each sample.**
   It is essential that your name, address, and sample number be clearly written on the sheet you send with each sample. As a guide in making recommendations for each of your numbered areas, it is important that the history of fertilization, liming, and any unusual treatments is stated.

7. **Mail to Soil Testing Laboratory.**
   Place the Soil Sample Information Sheet inside the top flap of the soil box and mail to the Virginia Tech Soil Testing Laboratory, 145 Smyth Hall (MC 0465), 185 Ag Quad Lane, Blacksburg, VA 24061

Soil Sampling for Precision Farming

Precision farming, also known as site-specific management, typically employs intensive soil sampling to map fertility in a field. Fertilizer and lime can then be applied at variable rates, according to the needs of the particular areas in the field. To begin, fields are first divided into grids, with typical grid size being 2.5 acres. For small fields, a 1-acre grid size will give a more precise representation of the fertility across the field, but for larger fields, this is usually not economically feasible.

The grid is established using a GPS. A radio receiver, connected to a portable computer and mounted on an ATV, is used to receive satellite coordinate signals to map the field and locate the grid points. Soil samples are then collected at each grid point, with six to eight subsamples being taken in a 10-foot circle around the ATV and mixed together for a composite sample. After lab analysis, soil test information from the field can then be fed into a computer mounted in a variable-rate fertilizer/lime spreader with GPS receiver, and material can be applied according to the needs of the various areas in the field.

"Smart sampling" techniques can also be employed to sample a field. This can be done in lieu of the above standard (uniform) grid sampling or as a follow-up to an initial grid sampling of the entire field. Smart sampling consists of sampling those areas of the field that are obviously different, such as with respect to topography (hilltops, low areas), or – if a combine yield monitor has been used – high-yielding and low-yielding areas in the field. If yield data are not available, one oftentimes has a good idea of the high-yielding and low-yielding areas in their field. These should be sampled separately. If the field has been mapped, it can be divided by soil series (i.e., soil mapping unit). Grid points should be located or grouped in those areas with unique visible or measurable differences.

Using the Soil Test Report - The Soil Test Report will contain the laboratory test results plus fertilizer and lime recommendations. Additional information regarding time and method of fertilizer and lime application will also be provided in the form of a Soil Test Note or Notes that will accompany the report. When several samples have been collected from the same field, the soil test reports should be compared to determine the best rates of fertilizer and lime to use for the field. Large differences in the reports could call for fertilizer and/or lime at two or more different rates. Advice on how to best fertilize a given field can be obtained from your local Extension agent or fertilizer dealer.

Plant Analysis

Sampling Instructions

1. Avoid submitting sample tissue that is contaminated with dust or soil. If tissue is dusty or dirty, remove as much of it as you can by shaking, brushing, or washing the tissue in gently flowing water.
2. Do not sample disease-, insect-, or mechanically damaged plant tissue.
3. Place the plant tissue in a clean paper bag. **Do not use plastic bags.** If the sample is wet or succulent, let it air-dry in the open for one day before sending it to the laboratory. Identify each sample by number and crop name.
4. When using tissue analysis in the diagnosis of crop productions problems, take one sample from the problem area in the field and one from an area where plants appear normal.
5. When sampling, both the time (growth stage) and plant part collected are important. Be sure to sample at the recommended time and collect the proper plant part.
6. If you do not have specific sampling instructions for the crop you wish to have analyzed, a good rule of thumb is to sample mature leaves that are representative of the current season's growth during the midperiod of the growth cycle or just prior to seed set.
7. Submit samples to recommended labs for testing. **Virginia Tech does not run tissue analysis.**

Interpreting the Laboratory Results

The Plant Analysis Report will contain the tissue test results plus the optimum nutrient ranges for the crop sample. Note whether levels are deficient, borderline, or adequate for good crop growth. Also make comparisons in soil nutrient levels between problem versus normal areas, noting any differences and whether they are small or large. Depending on what nutrient or nutrients are deficient and the stage of growth of the crop, it may or may not be worthwhile making additional fertilizer applications for the present crop. If trace element deficiency is noted and it is early enough in the growing season, a foliar application of the trace element can be applied to correct the problem. Following harvest, a more lasting soil application can be made for the next crop in the rotation.

If low magnesium and phosphorus plant tissue levels are observed, and the corresponding Soil Test Report indicates that the pH is low, it may not be possible to correct the problem for the present crop. Lime needs to be in the root zone to correct the problem, and this can be a difficult thing to do if it is not possible to till the lime into the soil. However, remedial action can and should be taken to ensure that the problem does not arise in future crops. The actual treatment needed will depend on the nature and severity of the problem and the economics involved. In most cases, it is usually worth the cost and effort to correct the problem.

Table 1. Sampling instructions for field crops.

Crop	Time	Plant Part to Sample	No. of Plants to Sample
Alfalfa	Early bloom	Top 4-6" of plant	30
Bermudagrass	Optimum time for maximum quality hay	Upper half of plant	50
Corn	Prior to 4th leaf stage	Whole plant, cutting at ground level	30
	Prior to tasseling	Entire leaf immediately below whorl, removing at stalk	20
	At silk when silks are still green	Entire ear leaf, removing at stalk	20
Cotton	At full bloom	Youngest recently mature leaves on main stem, collecting 2 leaves per plant	25
Peanut	At bloom stage	Last fully mature leaves at top of the plant, collecting 3 leaves per plant	25
Small Grains	Prior to jointing	Whole plant above ground, remove dead leaves	50
	Jointing to heading	Uppermost fully developed leaf	50
Soybeans	Prior to or at initial bloom	Uppermost fully developed trifoliate leaf set (composed of 3 leaflets) per plant. Remove leaf stem (petiole)	25
Tobacco	Prior to or at bloom	Entire 4th leaf from the top of the plant	15

Table 2. Sampling instructions for fruits, nuts, vegetables, and turf.

Crop	Time	Plant Part to Sample	No. of Plants to Sample
Fruit, nut			
Apple	8 to 10 weeks after full bloom	Leaves from spurs or near base of current season's growth, taking 4 to 8 leaves per tree	25 trees
Blueberry	Mid-summer	Mature leaves from mid-portion of current season's growth, taking 4 to 8 leaves per bush	25 bushes
Cherry	Mid-summer	Mature leaves near base of current season's terminal growth, taking 4 to 8 leaves per tree	25 trees
Grape	4 to 8 weeks after peak bloom	Petioles only (discard leaves) from mature leaves or nodes just beyond fruiting clusters	50 petioles
Peach	12 to 14 weeks after bloom	Mature leaves from mid-portion or near base of current season's terminal growth, taking 4 to 8 leaves per tree	25 trees
Pear	Mid-summer	Mature leaves from spurs, taking 4 to 8 leaves per tree	25 trees
Pecan	July 7 to August 7	Middle pair of leaflets from middle leaf of terminals around periphery of tree	25 trees
Vegetable			
Asparagus	Midgrowth	Mature fern from 18-36" up	10
Beet	Midgrowth	Young mature leaf, 3 leaves/plant	25
Broccoli	Heading	Young mature leaf, 2 leaves/plant	
Brussels sprout	Midgrowth	Young mature leaf, 3 leaves/plant	25
Cabbage	Head half grown	Young wrapper leaf, 2 leaves/plant	30
Cantaloupe	Prior to or at initial fruit set	Mature leaf near growing tip, 3 leaves/plant	25
Cauliflower	Buttoning	Mature leaf with stem removed	30
Collards	Midgrowth	Young mature leaf, 3 leaves/plant	25
Cucumber	Prior to or at initial fruit set	Mature leaf near growing tip, 3 leaves/plant	25
Green beans	Prior to or at early bloom	Uppermost mature leaves, 3 leaves/plant	20
Kale	Midgrowth	Young mature leaf, 3 leaves/plant	30
Onion	Midgrowth	Young mature leaf, 2 leaves/plant	30
Peas	Bud to full bloom	Entire top growth	15

Table 2. Sampling instructions for fruits, nuts, vegetables, and turf. (cont.)			
Crop	Time	Plant Part to Sample	No. of Plants to Sample
Peppers, bell	Midgrowth	Young mature leaf, 3 leaves/plant	30
Potatoes, Irish	Tubers half grown	Young mature leaf, 3 leaves/plant	25
Spinach	Midgrowth	Young mature leaf, 2 leaves/plant	25
Sweet corn	At silking when silks are green	Entire ear leaf, removing at stalk	20
Sweet potato	Midgrowth	4th leaf from a primary vine, counting down from growing tip	30
Tomato,	Early fruiting	3rd and 4th leaf from growing tip mech. harvest	50
Turnip greens	Midseason	Young mature leaf, 3 leaves/plant	25
Watermelon	Prior to or at initial fruit set	Mature leaf near growing tip, 3 leaves/plant	25
Turf			
Kentucky bluegrass	Normal growing season mowing	Clippings 7 to 14 days after last	1 pint

Table 3. Nutrient removal by crops.											
Crop	Plant Part	Acre yield	N	P as P_2O_5	K as K_2O	Ca	Mg	S	Cu	Mn	Zn
Row Crops											
Barley	grain	80 bu	70	30	20	2	4	6	0.06	0.06	0.12
Barley	straw	2 ton	30	10	60	16	4	8	0.02	0.64	0.10
	Total		**100**	**40**	**80**	**18**	**8**	**14**	**0.08**	**0.70**	**0.22**
Corn	grain	150 bu	135	53	40	2	8	10	0.06	0.09	0.15
Corn	stover	4.5 tons	100	37	145	26	20	14	0.05	1.50	0.30
	Total		**235**	**90**	**185**	**28**	**28**	**24**	**0.11**	**1.59**	**0.45**
Cotton	seed & lint	1500 lbs	40	20	15	2	4	3	0.06	0.11	0.32
Cotton	stalks, leaves	2000 lbs	35	10	35	28	8	15	–	–	–
	Total		**75**	**30**	**50**	**30**	**12**	**18**	**-**	**-**	**-**
Oats	grain	80 bu	50	20	15	2	3	5	0.03	0.12	0.05
Oats	straw	2 tons	25	15	80	8	8	9	0.03	–	0.29
	Total		**75**	**35**	**95**	**10**	**11**	**14**	**0.06**	**-**	**0.34**

Table 3. Nutrient removal by crops. (cont.)											
Crop	Plant Part	Acre yield	N	P as P_2O_5	K as K_2O	Ca	Mg	S	Cu	Mn	Zn
Peanuts	nuts	1.25 tons	90	10	15	1	3	6	0.02	0.01	–
Peanuts	vines	4500 lbs	105	25	95	–	–	–	–	–	–
	Total		**195**	**35**	**110**	**–**	**–**	**–**	**–**	**–**	**–**
Sorghum	grain	60 bu	50	25	15	4	5	5	0.01	0.04	0.04
Sorghum	stover	3 tons	65	20	95	29	18	–	–	–	–
	Total		**115**	**45**	**110**	**33**	**23**	**–**	**–**	**–**	**–**
Soybeans	grain	40 bu	150	35	57	7	7	4	0.04	0.05	0.04
Soybeans	straw		30	10	25	–	–	–	–	–	–
	Total		**180**	**45**	**80**	**–**	**–**	**–**	**–**	**–**	**–**
Tobacco	leaves	2000 lbs	75	15	120	75	18	14	0.03	0.55	0.07
Tobacco	stalks		35	15	50	–	–	–	–	–	–
	Total		**110**	**30**	**170**	**–**	**–**	**–**	**–**	**–**	**–**
Wheat	grain	80bu	100	45	49	2	16	8	0.06	0.18	0.28
Wheat	dtraw	2.0 tons	34	9	113	12	8	12	0.02	0.32	0.10
	Total		**134**	**54**	**170**	**14**	**24**	**20**	**0.08**	**0.50**	**0.38**
Hay											
Alfalfa		4 tons	180	40	180	112	12	19	0.06	0.44	0.42
Bluegrass		2 tons	60	20	60	16	7	5	0.02	0.30	0.08
Coastal bermudagrass		8 tons	300	70	270	59	24	35	0.21	–	–
Red clover		2.5 tons	100	25	100	69	17	7	0.04	0.54	0.36
Soybean		2 tons	90	20	50	40	18	10	0.04	0.46	0.15
Timothy		2.5 tons	60	25	95	18	6	5	0.03	0.31	0.20
Fruits, Vegetables											
Apples		500 bu	30	10	45	8	5	10	0.03	0.03	0.03
Cabbage		20 tons	130	35	130	20	8	44	0.04	0.10	0.08
Grapes	fruit	5 tons	15	10	25	–	–	–	–	–	–
Grapes	leaves & wood		20	5	20	–	–	–	–	–	–
	Total		**35**	**15**	**45**	**–**	**–**	**–**	**–**	**–**	**–**

Table 3. Nutrient removal by crops. (cont.)											
Crop	Plant Part	Acre yield	N	P as P_2O_5	K as K_2O	Ca	Mg	S	Cu	Mn	Zn
Muskmel-on	fruit	7 tons	30	11	60	–	–	–	–	–	–
Muskmel-on	vines	1.5 tons	20	5	30	–	–	–	–	–	–
	Total		**50**	**15**	**90**	**-**	**-**	**-**	**-**	**-**	**-**
Peaches		600bu	35	20	65	4	8	2	–	–	0.01
Potatoes	tubers	400 bu	80	30	150	3	6	6	0.04	0.09	0.05
Sweet potatoes	roots	300 bu	45	15	75	4	9	6	0.03	0.06	0.03
Tomatoes	fruit	20 tons	120	40	160	7	11	14	0.07	0.13	0.16

Table 4. Plant nutrient sufficiency ranges for field, forage, fruit, and nut crops.*

Crop**	N	P	K	Ca	Mg	Mn	Fe	B	Cu	Zn	Mo
Field, Forage			%					%			
Alfalfa	4.50-5.00	0.35	2.20	0.80	0.40	25	30	15	7	15	0.5
Bermudagrass	2.00-3.00	0.20-0.50	1.50-2.50	0.25-0.75	0.15-0.50	50-250	50-300	5-20	6-20	20-50	-
Corn-up to 12" tall	3.50-5.00	0.30-0.50	3.00-4.00	0.30-0.70	0.20-0.60	30-300	50-250	4-25	3-20	20-60	0.2
Corn-ear leaf at silk or leaf below whorl	3.00-3.50	0.25-0.45	2.00-2.75	0.25-0.80	0.20-0.50	30-200	50-300	3-20	3-20	20-60	0.2
Cotton	3.50-4.50	0.30-0.50	2.00-3.00	2.25-3.00	0.50-0.90	50-350	50-250	20-60	8-20	20-60	–
Peanut	3.50-4.50	0.25-0.50	2.00-3.00	1.25-2.00	0.30-0.80	50-350	50-300	25-60	-	20-50	0.5
Small grains	4.00-5.00	0.20-0.40	1.50-3.00	0.20-0.50	0.15-0.50	25-100	25-100	3-20	5-25	20-70	–
Soybeans	4.25-5.00	0.30-0.50	1.75-2.50	0.50-1.50	0.25-0.80	20-200	50-300	25-60	6-30	20-50	0.5
Tobacco	3.50-4.25	0.25-0.50	2.50-3.20	1.50-3.50	0.20-0.65	30-250	50-200	20-50	15-60	20-80	–
Fruit, Nut											
Apple	2.00-3.00	0.15-0.50	1.25-3.00	1.00-2.00	0.20-0.50	20-200	50-400	20-60	5-20	15-50	–
Blueberry	1.80-2.00	0.10-0.20	0.40-0.60	0.30-0.75	0.20-0.30	20-200	60-150	10-50	10-20	10-50	–
Cherry	2.00-3.00	0.15-0.50	1.25-2.50	1.50-2.50	0.20-0.50	20-200	50-400	20-60	5-20	15-50	–
Grape	0.80-1.00	0.20-0.50	1.50-2.50	1.75	0.40-0.80	30-200	30	40-60	5-20	20-50	–
Peach	2.75-3.50	0.25-0.50	1.20-2.50	1.50-2.50	0.20-0.50	20-200	60-400	20-100	5-20	15-50	–
Pear	2.20-3.00	0.15-0.50	1.00-3.00	1.00-2.00	0.20-0.50	20-200	50-400	20-60	5-20	15-50	–
Pecan	2.50-3.90	0.12-0.30	1.00-1.50	0.70-1.50	0.30-0.60	100-800	50-300	20-45	10-30	50-100	–

*In general, if leaf composition is less than the lower value, yields may be reduced and deficiency symptoms may be visible. When leaf composition values are greater than the upper value, in some cases yields may be reduced and toxicity symptoms may be visible. It should be noted that temperature, moisture, and other factors also influence plant nutrient levels and sometimes make the interpretation of results difficult. Where possible, tissue analysis results should be compared between problem and normal growth areas and also compared with soil test results before a diagnosis is made. Information on crop management (planting time, depth, etc.) should also be included in the diagnosis.

**Sufficiency ranges are only applicable to the plant part and time of sampling specified in Tables 1 and 2. These values do not apply to other plant parts or times of sampling.

Table 5. Plant nutrient sufficiency ranges for vegetable crops and turf.

Crop*	N	P	K	Ca	Mg	Mn	Fe	B	Cu	Zn
Vegetable			%					%		
Asparagus	2.4-3.8	0.30-0.35	1.5-2.4	0.40-0.50	0.15-0.20	10-160	-	50-100	-	20-60
Beet	3.5-5.0	0.20-0.30	2.0-4.0	2.5-3.5	0.30-0.80	70-200	-	60-80	-	15-30
Broccoli	3.2-5.5	0.30-0.70	2.0-4.0	1.2-2.5	0.23-0.40	25-150	100-300	30-100	1-5	45-95
Brussels sprout	2.2-4.2	0.26-0.45	2.4-3.4	0.3-2.2	0.23-0.40	-	-	30-40	-	-
Cabbage	3.0-4.0	0.30-0.50	3.0-4.0	1.5-3.5	0.25-0.45	-	30-60	30-60	-	20-30
Cantaloupe	2.0-3.0	0.25-0.40	1.8-2.5	5.0-7.0	1.0-1.5	-	-	30-80	-	30-50
Cauliflower	3.0-4.5	0.54-0.72	3.0-3.7	0.72-0.79	0.24-0.26	-	-	-	-	43-59
Collards	4.0-5.0	0.30-0.60	3.0-4.0	3.0-4.0	-	-	-	50-80	-	-
Cucumber	-	-	-	-	-	-	-	50-80	-	20-40
Green beans	3.0-6.0	0.25-0.50	1.8-2.5	0.8-3.0	0.25-0.70	30-300	300-450	40-60	15-30	30-60
Kale	4.0-5.0	0.30-0.60	3.0-4.0	3.0-4.0	-	-	-	50-80	-	-
Onion	1.5-2.5	0.25-0.40	-	-	-	-	-	30-45	-	10-15
Peas	3.1-3.6	0.30-0.35	2.2-2.8	1.2-1.5	0.27-0.35	-	-	20-60	-	-
Peppers, bell	3.0-4.5	0.30-0.70	4.0-5.4	0.4-0.6	1.0-1.7	-	-	40-100	10-20	-
Potatoes, Irish	3.0-5.0	0.20-0.40	4.0-8.0	2.0-4.0	0.5-0.8	30-50	70-150	30-40	-	20-40
Spinach	4.0-6.0	0.30-0.50	3.0-4.0	0.6-1.0	1.6-1.8	30-60	220-245	40-60	5-7	50-75
Sweet corn-ear leaf at silk	2.6-3.5	0.20-0.30	1.8-2.5	0.15-0.30	0.20-0.30	-	-	20-30	-	-
Sweet potato	3.2-4.2	0.20-0.30	2.9-4.3	0.75-0.95	0.40-0.80	40-100	-	-	-	-
Tomato, mech. harvest	3.0-6.0	0.50-0.80	2.5-4.0	0.6-0.9	60-100	-	40-80	4-8	15-30	
Turnip greens	3.5-4.5	0.35-0.60	-	3.0-5.0	-	60-80	-	30-60	-	-
Watermelon	2.0-3.0	0.20-0.30	2.5-3.5	2.5-3.5	0.6-0.8	-	-	-	4-8	-
Turf										
KY bluegrass	2.2-3.8	0.30-0.55	1.8-3.0	0.75-1.35	0.25-0.50	150-400	100-200	10-30	10-20	35-45

*Nutrient ranges apply only to the plant part and time of sampling specified in Table 2. These values do not apply to other plant parts or times of sampling.

Table 6. General crop nutrient deficiency symptoms.

Nutrient	Deficiency Symptoms
Nitrogen (N)	Restricted growth of tops and roots; growth upright and spindly; leaves pale and yellowish-green in early stages, more yellow and even orange or red in later stages; deficiency shows up first on lower leaves.
Phosphorus (P)	Restricted growth of tops and roots; growth is upright and spindly; leaves bluish-green in early stages with green color sometimes darker than plants supplied with adequate phosphorus; more purplish in later stages with occasional browning of leaf margins; defoliation is premature, starting at the older leaves.
Potassium (K)	Browning of leaf tips; marginal scorching of leaf edges; development of brown or light colored spots in some species which is usually more numerous near the margins; deficiency shows up first on lower foliage.
Calcium (Ca)	Deficiency occurs mainly in younger leaves near the growing point; younger leaves distorted with tips hooked back and margins curled backward or forward; leaf margins may be irregular and display brown scorching or spotting.
Magnesium (Mg)	Interveinal chlorosis with chlorotic areas separated by green tissue in earlier stages giving a beaded streaking effect; deficiency occurs first on lower foliage.
Sulfur (S)	Younger foliage is pale yellowish-green, similar to nitrogen deficiency; shoot growth somewhat restricted.
Zinc (Zn)	Interveinal chlorosis followed by die back of chlorotic areas.
Manganese (Mn)	Light green to yellow leaves with distinctly green veins; in severe cases, brown spots appear on the leaves and the leaves are shed; usually begins with younger leaves.
Boron (B)	Growing points severely affected; stems and leaves may show considerable distortion; upper leaves are often yellowish red and may be scorched or curled.
Copper (Cu)	Younger leaves become pale green with some marginal chlorosis.
Iron (Fe)	Interveinal chlorosis of younger leaves.
Molybdenum (Mo)	Leaves become chlorotic, developing rolled or cupped margins; plants deficient in this element often become nitrogen deficient.
Chlorine (Cl)	Deficiency not observed under field conditions.

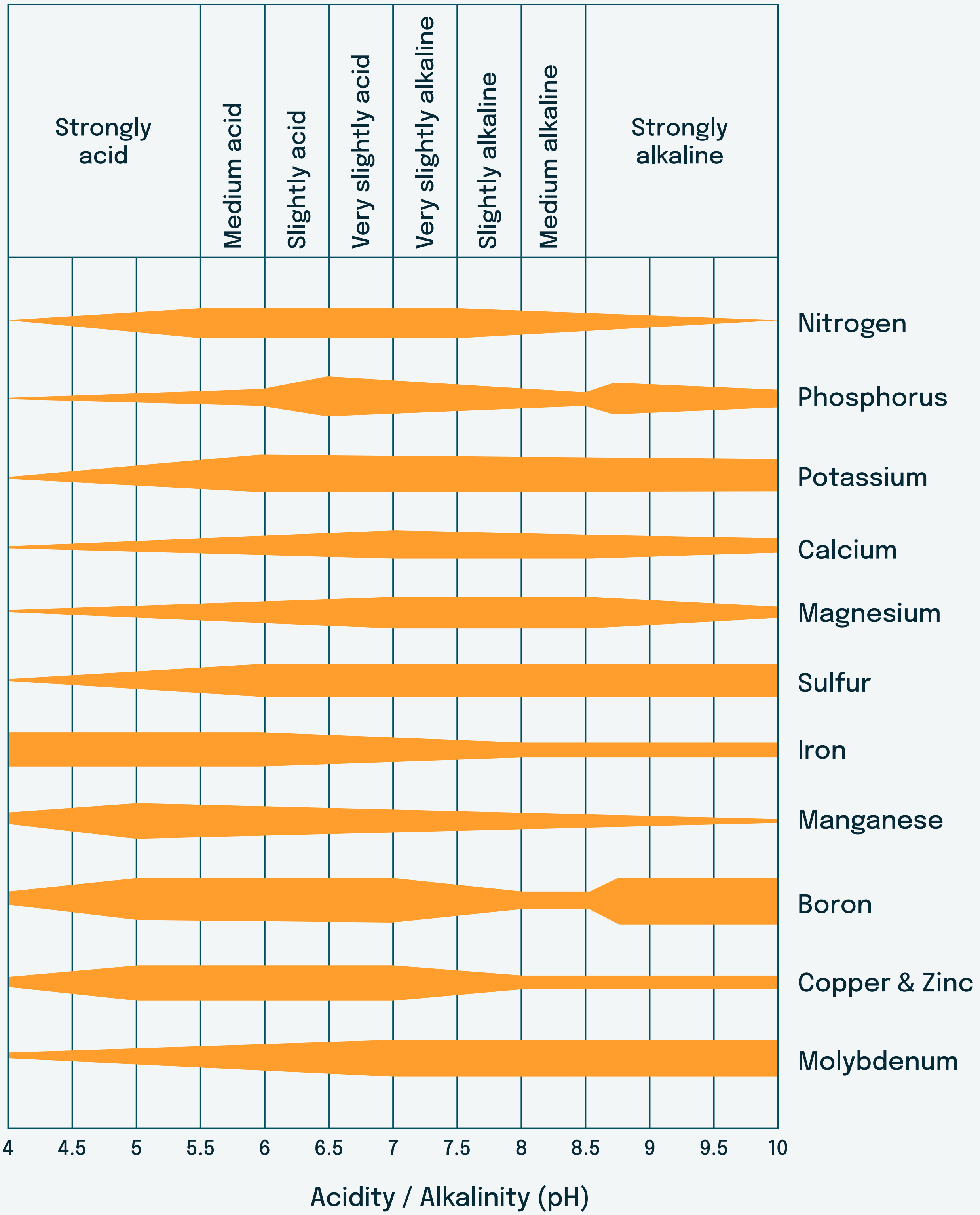


Figure 1. Relationship between soil pH and the availability of minerals that are essential for plant growth.

Soil Testing Lab Conversion Factors

Periodically, Virginia Cooperative Extension receives requests for information on the interpretation of soil test results from laboratories that use procedures that differ from ours. Very simply, different procedures usually extract different amounts of nutrients from the soil. However, any good soil testing procedure, when properly correlated with plant growth, can be used as a basis for making fertilizer recommendations. In the Virginia Tech Soil Testing Laboratory, we use the Mehlich 1 (0.05N HCl + 0.025N H_2SO_4) soil test procedure to extract both phosphorus and potassium because we have done considerable research to correlate the test results obtained by this method with plant growth. Other procedures, however, could extract more or less nutrients than the Mehlich 1 procedure does, and therefore, values obtained by these other methods cannot be used directly to make fertilizer recommendations. **They must first be converted to equivalent Virginia Tech test levels.**

The following are **conversion factors** for converting private and other state lab phosphorus and potassium test results to Virginia Tech test values. The conversion factors are approximate values only, and they vary depending on soil type, type of clay, past fertilization, etc. However, they should put one in the ballpark with respect to Virginia Tech test levels.

1. **Converting Bray P_1 (weak) phosphorus to Virginia Tech Mehlich 1 phosphorus.**

pH < 5.6	Weak Bray P, ppm x 0.6 = Virginia Tech P, ppm	Weak Bray P, ppm x 1.2 = Virginia Tech P, lb/A
pH 5.6-6.2	Weak Bray P, ppm x 0.7 = Virginia Tech P, ppm	Weak Bray P, ppm x 1.4 = Virginia Tech P, lb/A
pH 6.3-6.9	Weak Bray P, ppm x 0.8 = Virginia Tech P, ppm	Weak Bray P, ppm x 1.6 = Virginia Tech P, lb/A
pH > 6.9	Weak Bray P, ppm x 1.2 = Virginia Tech P, ppm	Weak Bray P, ppm x 2.4 = Virginia Tech P, lb/A

2. **Converting ammonium acetate potassium to Virginia Tech Mehlich 1 potassium.**

Ammonium acetate K, ppm x 0.67 = Virginia Tech K, ppm
Ammonium acetate K, ppm x 1.33 = Virginia Tech K, lb/A

3. **Converting Mehlich 3 phosphorus to Virginia Tech Mehlich 1 phosphorus.**

   Preliminary research indicates that, for Mid-Atlantic soils, the Mehlich 3 phosphorus procedure extracts approximately the same amount of phosphorus as the Bray P_1 (Weak Bray) procedure. Therefore, use the same conversion factor as given for Bray P_1 to convert Mehlich 3 phosphorus to Virginia Tech phosphorus.

4. **Converting Mehlich 3 potassium to Virginia Tech Mehlich 1 potassium.**

   Preliminary research indicates that, for Mid-Atlantic soils, the Mehlich 3 potassium procedure extracts approximately the same amount of potassium as the ammonium acetate procedure. Therefore, use the same conversion factor as given for ammonium acetate to convert Mehlich 3 potassium to Virginia Tech potassium.

5. Calibration of phosphorus (P) and potassium (K) tests, Virginia Tech Soil Testing Laboratory.

Soil Test P	lb/A	P-ppm
L-	0-3	0-2
L	4-8	2-4
L+	9-11	5-6
M-	12-20	6-10
M	21-30	11-15
M+	31-35	16-18
H-	36-55	18-28`
H	56-85	28-43
H+	86-110	43-55
VH	110+	55+

Soil Test K	lb/A	P-ppm
L-	0-15	0-8
L	16-55	8-28
L+	56-75	28-38
M-	76-100	38-50
M	101-150	51-75
M+	151-175	76-88
H-	176-210	88-105
H	211-280	106-140
H+	281-310	141-155
VH	310+	155+

6. Other useful conversion factors are available in Part IX on pages 138-140 and in Part X on page 142.

Conversion factors				
P	×	2.3	=	P_2O_5
P_2O_5	×	0.44	=	P
K	×	1.2	=	K_2O
K_2O	×	0.83	=	K
ppm	×	2.0	=	lbs/A
lbs/A	×	0.5	=	ppm

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Part IX.

Conversion Factors Needed for Common Fertilizer Calculations

Authored by:

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The world is a big place, and farmers, industry, government, and others likely use different units of measure, oxidation states, and measurements when calculating and reporting nutrient use for farming systems. The following table outlines some of the most common conversions needed for nutrient management. For instance, to convert K to K_2O, you would multiply your K number by 1.2051. So a fertilizer being reported as 49.8% K is also commonly reported as 49.8% × 1.2051 = 60% K_2O. Therefore, you are equally correct to report muriate of potash (KCl) fertilizer as 49.8% K or 60% K_2O as long as you have the correct unit represented. However, note that fertilizer law generally states that oxidation states should be reported for certain nutrients (e.g., K_2O must be used on Virginia fertilizer labels).

Table 1. Common fertilizer conversions needed for nutrient management calculations

Column 1: Conversion	Multiply by	Column 2: Multiplication vValue
Nutrient sources		
P to P_2O_5	Multiply P by	2.2910
P_2O_5 to P	Multiply P_2O_5 by	0.4365
K to K_2O	Multiply K by	1.2051
K_2O to K	Multiply K_2O by	0.8301
KCl to K	Multiple KCl by	0.5244
KCl to Cl	Multiply KCl by	0.4756
K_2SO_4 to K	Multiply K_2SO_4 by	0.4487
Mg to MgO	Multiply Mg by	1.6578
MgO to Mg	Multiply MgO by	0.6032
$MgCO_3$ to MgO	Multiply $MgCO_3$ by	0.4782
MgO to $MgCO_3$	Multiply MgO by	2.0913
$MgSO_4$ to Mg	Multiply $MgSO_4$ by	0.2020
$MgCO_3$ to $CaCO_3$	Multiply $MgCO_3$ by	1.1867
CaO to Ca	Multiply CaO by	0.7147
Ca to CaO	Multiply Ca by	1.3992
$CaCO_3$ to $MgCO_3$	Multiply $CaCO_3$ by	0.8426
$CaCO_3$ to CaO	Multiply $CaCO_3$ by	0.5603
K_2SO_4 to S	Multiply K_2SO_4 by	0.1840
Column 1: Conversion	**Multiply by**	**Column 2: Multiplication vValue**
$CaSO_4$ to Ca	Multiply $CaSO_4$ by	0.2938
$CaSO_4$ to S	Multiply $CaSO_4$ by	0.2350
SO_4 to S	Multiply SO_4 by	0.3339

Table 1. Common fertilizer conversions needed for nutrient management calculations (cont.)		
S to SO_4	Multiply S by	2.9963
NaCl to Cl	Multiply NaCl by	0.6066
N to NH_3	Multiply N by	1.2158
N to KNO_3	Multiply N by	7.2162
NH_3 to N	Multiply NH_3 by	0.8225
N to $(NH_4)_2SO_4$	Multiply N by	4.7160
$(NH_4)_2SO_4$ to N	Multiply $(NH_4)_2SO_4$ by	0.2120
$(NH_4)_2SO_4$ to S	Multiply $(NH_4)_2SO_4$ by	0.2427
N to NH_4NO_3	Multiply N by	2.8571
NH_4NO_3 to N	Multiply NH_4NO_3 by	0.3500
Concentration		
Parts per million (ppm) to pounds per acre (lb/acre)	Multiply ppm by	2.0
Pounds per acre (lb/acre) to parts per million (ppm)	Multiply lb/acre by	0.5
Percentage to gram per kilogram	Multiply percent by	10
Gram per kilogram to percentage	Multiply gram per kilogram by	0.1
Length		
Mile to kilometer	Multiply mile by	1.609
Kilometer to mile	Multiply kilometer by	0.621
Foot to meter	Multiply foot by	0.304
Meter to foot	Multiply meter by	3.28
Column 1: Conversion	**Multiply by**	**Column 2: Multiplication vValue**
Area		
Acre to hectare	Multiply acre by	0.405
Hectare to acre	Multiply hectare by	2.47
Square foot to square meter	Multiply square foot by	0.0929
Square meter to square foot	Multiply square meter by	10.76
Volume		
Gallon to liter	Multiply gallon by	3.78

Table 1. Common fertilizer conversions needed for nutrient management calculations (cont.)		
Liter to gallon	Multiply liter by	0.265
Quart to liter	Multiply quart by	0.946
Liter to quart	Multiply liter by	1.057
Mass		
Pound to gram	Multiply pound by	454
Gram to pound	Multiply gram by	0.00220
Pound to kilogram	Multiply pound by	0.454
Kilogram to pound	Multiply kilogram by	2.205
U.S. ton to tonne	Multiply U.S. ton by	0.907
Tonne to U.S. ton	Multiply tonne by	1.102
Yield and rate		
Pound per acre to kilogram per hectare	Multiply pound per acre by	1.12
Kilogram per hectare to pound per acre	Multiply kilogram per hectare to	0.893
Bushel per acre (bu/acre) for 60-pound bushel to kilogram per hectare	Multiply bu/acre by	67.19
Column 1: Conversion	**Multiply by**	**Column 2: Multiplication vValue**
Bushel per acre (bu/acre) for 56-pound bushel to kilogram per hectare	Multiply bu/acre by	62.71
Bushel per acre (bu/acre) for 48-pound bushel to kilogram per hectare	Multiply bu/acre by	53.75
Gallon per acre to liter per hectare	Multiply gallon per acre by	9.35
Liter per hectare to gallon per acre	Multiply liter per hectare by	0.107
Temperature		
Fahrenheit (°F) to Celsius (°C)	Multiply Fahrenheit by	5/9 × (°F – 32)
Celsius (°C) to Fahrenheit (°F)	Multiply Celsius by	(9/5 × °C) + 32

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Part X.

Lime: Common Soil Additives To Raise Soil pH in Virginia

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Rory Maguire, Professor and Nutrient Management Extension Specialist, Virginia Tech

Agricultural limestone is used to neutralize soil acidity (H+ cations) in Virginia agriculturalproduction systems, which raises soil pH. Optimal soil pH for most grain, oilseed, fiber, and vegetable crops ranges from 6.2 to 6.5. The quality of agricultural lime is determined by its purity and fineness of grind (mesh size). Purity impacts the amount of agricultural lime required per acre to adjust soil pH to a given level. Mesh size impacts the rate of reaction of lime in neutralizing soil acidity, as described below. A comprehensive fact sheet that explains lime and how it works is available through Virginia Cooperative Extension publication SPES-158P (originally publication 452-510; Mullins, Alley, and Phillips 2019).

The calcium carbonate equivalent of agricultural lime is directly related to its purity. Pure calcite is 100% calcium carbonate ($CaCO_3$) and has a CCE value of 100%, whereas pure dolomite ($CaCO_3 \cdot MgCO_3$) has a CCE of 108%. Therefore, pure dolomite can neutralize 8% more acid than pure calcite. The CCE and chemical composition of several common liming materials are shown in **table 1**.

Equivalent amounts of different liming materials can be determined by using the effective neutralizing value. For example, if 2 tons of calcitic lime with a CCE of 100% is recommended, and marl with a CCE of 75% is to be used, the CCE of calcitic lime (100%) divided by the CCE of marl (75%) times the recommended rate per acre of calcitic lime (2 tons/acre) equals 2.66 tons of total marl lime needed. This is the amount of marl that would need to be applied to equal the acid-neutralizing potential of 2 tons of calcitic lime. The lime recommendations of soil testing laboratories are generally based on liming materials that have a 100 CCE.

Table 1. Common lime sources used in Virginia.

See VCE publication 452-510 (SPES-158P) (Mullins, Alley, and Phillips 2019) for a more detailed discussion of lime sources, calculations, use, and precautions. As always, use product labeling for exact formulations and content.

Lime material	Chemical formula	CCE (%)	Approximate fertilizer nutrients* (%)
Calcium carbonate (pure)	$CaCO_3$	100	40% Ca
Calcitic lime	$CaCO_3$	80-100	30-40% Ca, 3% Mg
Dolomitic lime	$CaCO_3 \cdot MgCO_3$	85-108	20-25% Ca, 6-14% Mg
Byproducts and biosolids	Variable	Variable	Variable
Burned or quick lime	CaO	150-175	71% Ca
Cement kiln dusts	Ca oxides	40-100	29-46% Ca, 1-3% S
Gypsum (does not lime)	$CaSO_4$	0	22% Ca, 17% S
Ground oyster shells	$CaCO_3$	90-100	34% Ca
Hydrated or slaked lime	$Ca(OH)_2$	110-135	54% Ca
Marl	$CaCO_3$	70-90	28% Ca
Poultry litter	Ca, Mg, and K oxides	0.3-4	1-5% Ca, 0.5-2% Mg, and others
Poultry litter ash	Ca, Mg, and K oxides	12-31	12-18% Ca, 3-6% Mg, and others
Power plant ashes	Ca, Mg, and K oxides	25-50	Variable
Slags	$CaSiO_3$	60-90	Variable
Wood ashes	Ca, Mg, and K oxides	26-59	7-33% Ca, 2-7% K, and others

* These are naturally occurring minerals or byproducts; therefore, exact nutrient concentrations vary by individual source. Approximate values were obtained from Adaska and Taubert (2008); Baker Lime (2021); John (2016); Griffin (2006); Middleton (2015); Mullins, Alley, and Phillips (2019); New Enterprise Stone & Lime Co. (2021); and Rockydale Quarries Corporation (2021).

Liming Materials Marketed in Virginia

Companies marketing agricultural liming materials in Virginia must be registered with the Virginia Department of Agriculture and Consumer Services in Richmond (**www.vdacs.virginia.gov**). Further, the liming materials sold must pass the specifications stipulated in the Virginia Agricultural Liming Materials Law, Chapter 37 in the Code of Virginia (2021).

Both ground and pulverized limestone are sold in Virginia, and they have different particle sizes based on mesh screen analysis. Mesh size is a measure of the number of openings in 1 square inch of screen. A 20-mesh screen contains 400 openings per square inch, whereas a 100-mesh screen contains 10,000 openings. Crushed limestone material passing a 100-mesh screen is finer and reacts with soil acidity more rapidly than 20-mesh material. Pulverized limestone is, therefore, more reactive than ground limestone. However, reactivity rate does not increase greatly for particle sizes smaller than 100 mesh.

The two main kinds of limestone used in Virginia are calcitic and dolomitic. Sometimes soil test reports will include recommendations for "AG" or agricultural lime. This means that either calcitic or dolomitic limestone can be used, depending on local availability and pricing. In Virginia, agricultural limestone that contains 85% or more of the total neutralizing value in the calcium carbonate form is classified as calcitic; limestone that contains 15% or more of the total carbonate content as magnesium carbonate is classified as dolomitic. Both are excellent liming materials; however, dolomitic lime should be used on soils that test low in magnesium in order to increase magnesium soil testing values.

When buying lime, be aware of the cost per unit of calcium carbonate equivalency. Neutralization potential increases with the increase in calcium carbonate equivalency value. In reality, agricultural lime users are buying acid-neutralizing potential that is associated with both calcium carbonate equivalence and fineness of grind. Be sure to compare actual product labels to better understand the neutralizing value of the particular products available in your area.

References

Adaska, W. S., and D. H. Taubert. 2008. "Beneficial Uses of Cement Kiln Dust." Presentation at the IEEE/PCA 50th Cement Industry Technical Conference, Miami. May 19-22.

Baker Lime. 2021. "Baker Lime Products and Specifications." Accessed Jan. 9. https://www.bakerlime.com/resource-center/product-spec-sheets/

Code of Virginia. 2021. "Agriculture Liming Materials." Chapter 37 in Title 3.2, Agriculture, Animal Care, and Food. Accessed Jan. 9. https://law.lis.virginia.gov/vacode/title3.2/chapter37/.

Griffin, T. S. 2006. *Using Wood Ash on Your Farm*. University of Main Extension bulletin 2279. Orono: University of Maine. https://extension.umaine.edu/publications/2279e/#nutrients.

John, A. T. 2016. "Chemical Composition of the Edible Oyster Shell *Crassostrea Madrasensis* (Preston 1916)." *Journal of Marine Biology and Aquaculture* 2 (2): 1-4. doi: https://doi.org/10.15436/2381-0750.16.972.

Middleton, A. J. 2015. "Nutrient Availability from Poultry Litter Co-Products." Master's thesis. Virginia Tech. http://vtechworks.lib.vt.edu/handle/10919/55126.

Mullins, G. L., M. M. Alley, and S. B. Phillips. 2019. *Sources of Lime for Acid Soils in Virginia*. Reviewed by Rory Maguire. Virginia Cooperative Extension publication SPES-158P. Blacksburg: VCE. www.pubs.ext.vt.edu/content/dam/pubs_ext_vt_edu/452/452-510/SPES-158.pdf.

New Enterprise Stone & Lime Co. Inc. 2021. "Product Specification Sheets." Accessed Jan. 9. www.nesl.com/products/agricultural-lime/product-specification-sheets-aglime/.

Rockydale Quarries Corporation. 2021. "Products & Services – Agricultural Lime: Dolomitic Agricultural Limestone." Accessed Jan. 9. http://rockydalequarries.com/ProductsServices/AgriculturalLime/tabid/91/Default.html.

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Part XI.

Fertilizing With Manures

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Animal manures contain valuable crop nutrients and can have liming value too. With high costs for fertilizers, using animal manures to supply the major crop nutrients nitrogen (N), phosphorus (P), and potassium (K) may represent an economic saving. However, animal manures present some challenges compared to inorganic nutrient sources. The Soil Testing Laboratory at Virginia Tech analyzes soil samples and provides crop N, P, and K recommendations based on sample analysis and crop yield expectations. Inorganic fertilizers can be blended to give the required N, P, and K required by crops, while manures have a set N, P, and K concentration. Because the N to P ratio in manures normally does not reflect crop requirements, you need to decide whether to apply manures on an N or a P basis. Applying manures on an N basis means supplying sufficient N to meet crop needs, but this method generally overapplies P relative to crop requirement. This may be of benefit in P-deficient soils, but it is not needed and could cause environmental problems in higher P soils. Applying manures to meet crop P requirements generally leads to underapplying N, so additional N must be applied from other sources, normally from inorganic fertilizer.

There are also practical considerations to using animal manures, such as having the appropriate machinery to handle it because volumes and textures are substantially different from inorganic fertilizers. Dairy manure contains about 95% water, so it must be pumped, and transporting it long distances is expensive. Poultry manure is only about 25% water, and there are transportation subsidies in some areas, making transportation much more economically attractive. Intensification of animal production over the past decades has led to a situation where some animal farms produce more manure nutrients than the farms' crops need. Concerns about the impact of these excess nutrients have driven nutrient management regulations, which currently affect mainly large producers but are subject to change. Therefore, if you wish to use manure as a nutrient source, check current regulations with your local Virginia Cooperative Extension or Department of Conservation and Recreation office.

Factors To Consider in Applying Manures

Nutrient Concentration in Manures

Average concentrations of nutrients in manures are given in table 1. However, nutrient concentrations in manures can vary substantially for many reasons, such as source, animal diet, and moisture content. For example, when poultry litter is taken out of poultry houses, sometimes just the surface crust that is predominantly manure is taken, and sometimes all the litter is taken that contains a higher proportion of bedding material. For dairy cattle, diets vary greatly by farm in forage and concentrates and also storage and handling. During storage, manure can also lose substantial amounts of N.

Therefore, the basis of accurate manure nutrient management is having an accurate sample analysis. The first step is to get a representative sample of the manure you will be using. For lagoons this involves agitating the tank, while dry manures should be sampled from several representative places, avoiding the surface of piles. Taking samples during spreading is best but not always possible due to time constraints between sampling and obtaining results. If you are receiving manure from a regulated farm, you should receive a manure analysis from the supplier. The importance of manure sampling and analysis cannot be overstated. For example, manure testing in Virginia by the DCR (2014) shows that concentrations of phosphate phosphorus (P_2O_5) in broiler litter have dropped from around 62 pounds per ton in the early 1990s to 52 pounds per ton now due to a combination of reduced insurance feeding of P_2O_5 and the use of the enzyme phytase that helps broilers digest dietary P.

Table 1. Average analysis for manure tested from October 2001 through October 2004 in Virginia.					
Manure Type	TKN*	NH_4	P_2O_5	K_2O	% Moisture
Liquid dairy slurry, lbs/1000gal	19.2	8.9	9.1	17.4	94.6
Semi-solid dairy, lbs/ton	15.3	3.5	7.6	14.3	67.4
Semi-solid beef, lbs/ton	18.0	2.4	9.9	19.0	63.1
Dry chicken broiler litter, lbs/ton	64.9	11.5	52.2	53.4	27.8
Dry chicken layer/breeder, lbs/ton	47.9	8.5	60.8	43.7	29.5
Dry turkey litter, lbs/ton	62.0	13.1	50.2	38.3	28.6
Dry turkey breeder, lbs/ton	58.8	12.6	61.2	36.2	25.5
Liquid swine lagoon, lbs/1000gal	7.2	5.7	2.8	12.2	99.4
Liquid swine pit, lbs/1000gal	23.6	15.3	16.7	15.7	97.5

*TKN is Total Kjeldahl Nitrogen, a measure of total N in a manure

Plant Availability of Nutrients in Manures

Application rates of P and K are based on the total P and K analysis of the manures; however N is much more complicated. When a manure is surface-applied, it can rapidly lose N through ammonia volatilization, mostly in the first two days following application (**table 2**). Incorporation of manure by tillage immediately after surface application or direct injection of manures into the soil can greatly decrease these losses. Organic nitrogen in manures is transformed into plant-available forms through microbial breakdown and will only be partially plant-available, and this plant-available portion varies by manure type (**table 3, page 148**). Therefore, when you submit a manure for testing or are interpreting a manure analysis, you must consider the method of manure application before you can know how much N will be plant-available. Labs that analyze manure will generally calculate the plant-available N (PAN) in manure.

Table 2. Plant availability of ammonium nitrogen in manures.				
Method of application	Semisolid manure	Liquid manure slurry	Lagoon liquid	Dry litter
Injection	-	0.95	0.95	-
Broadcast with immediate incorporation	0.75	0.75	0.90	0.90
Incorporated after 2 days	0.65	0.65	0.80	0.80
Incorporated after 4 days	0.40	0.40	0.60	0.65
Incorporated after 7 days or no incorporation	0.25	0.25	0.45	0.50
Irrigated without incorporation	-	0.20	0.50	-

Table 3. Plant availability of organic nitrogen in manures.			
Manure type	Single crop	Winter topdress/Spring residual	Perennial grass
Dairy manure	0.35	0.20/0.15	0.35
Poultry litter	0.60	0.30/0.30	0.60
Swine manure	0.50	0.25/0.25	0.50

Sample calculation: Consider surface-applying dairy manure with no incorporation in the spring for corn, and the manure has total nitrogen (TKN) of 20 lb/1,000 gal and NH_4 of 9 lb/1,000 gal.

1. Calculate organic N = 20 – 9 = 11 lb organic N/1,000 gal.
2. Calculate NH_4 availability = 9 × 0.25 (table 2) = 2.25 lb/1,000 gal.
3. Calculate organic N availability = 11 × 0.35 (table 3) = 3.85 lb/1,000 gal.
4. Total plant-available N = 2.25 + 3.85 = 6.1 lb/1,000 gal.

Balancing and Calculating Manure and Fertilizer Application Rates

Although manures contain N, P, K, lime, and micronutrients, they are generally applied to meet crop N or P requirements. Manures usually have an imbalance of N and P relative to crop requirements, so applying manures to meet crop N needs results in overapplying P relative to crop uptake. Therefore, applying manure to meet crop N requirements every year will build up P in the soil above concentrations necessary for optimum yields over a period of several years, and soil test P levels may rise to levels where losses of P in runoff and erosion are of environmental concern. This can be avoided by monitoring soil test P and not applying manure every year or by applying lower rates based on crop P requirements, with either strategy generally requiring inorganic N fertilizer. As a rule of thumb, applying manure to meet crop N needs applies about the same amount of P taken up by crops in three years. So applying manure on an N basis one year in three, with inorganic fertilizer containing no P for the other two years, would be close to balance for P. This obviously varies slightly with crops grown, yields, and manure type and analysis. Whatever strategy you use, you must add organic (manure) and inorganic (fertilizer) nutrients together to calculate the total nutrients applied for each year along with soil testing in succeeding years to determine the residual effects of applications.

Sample calculation: Consider applying poultry litter to a corn crop that requires 150 lb of N/acre (known from yield expectation) and 50 lb of P_2O_5/acre (known from soil test). The litter contains 45 lb PAN/ton for a surface application and 55 lb P_2O_5/ton (known from manure analysis).

1. Applying on a nitrogen basis: 150 lb N/acre ÷ 45 lb PAN/ton = 3.3 ton/acre.
2. Applying on a phosphorus basis: 50 lb P_2O_5/acre ÷ 55 lb P_2O_5/ton = 0.9 ton/acre.

Note that applying to meet crop N requirements is a much greater rate. It is also difficult to accurately apply 0.9 ton/acre, another reason for the suggestion of applying one year in three, as discussed above.

Timing of Manure Applications

As for inorganic fertilizers, it is best to apply manures close to the time of nutrient uptake by crops because this minimizes unwanted nutrient losses. This particularly applies to N, which can be lost through leaching, denitrification in waterlogged soils, or ammonia volatilization. For spring crops, manure is therefore normally applied in the spring prior to planting. For forages, manure should be applied at the start of the periods of maximum growth: spring and late summer/fall for cold-season grasses and summer for warm-season grasses.

References

DCR (Virginia Department of Conservation and Recreation). 2014. *Virginia Nutrient Management Standards and Criteria*. Rev. July 2014. Richmond, VA: DCR. www.dcr.virginia.gov/document/standardsandcriteria.pdf.

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Part XII.

Land Application of Biosolids

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Biosolids are solid, semisolid, or liquid materials – the result of domestic sewage treatment – that have been sufficiently processed to permit these materials to be land-applied safely. The term was introduced by the wastewater treatment industry in the early 1990s. It has since been adopted by the U.S. Environmental Protection Agency (USEPA) to distinguish high-quality, treated sewage sludge from raw sewage sludge and from sewage sludge containing large amounts of pollutants.

Benefits of Land Application of Biosolids

Biosolids can be considered a waste to be disposed of or a beneficial soil amendment. As an alternative to disposal by landfilling or incineration, land application seeks to beneficially recycle the soil property-enhancing constituents in biosolids. Biosolids are approximately 50% mineral and 50% organic matter. The mineral matter includes essential plant nutrients, and the organic matter is a source of slow-release nutrients and soil conditioners. Land application returns those materials to the soil where they can contribute to improved crop production.

Farmers can benefit from biosolids application by reducing fertilizer costs. The main fertilizer benefits are through the supply of nitrogen (N), phosphorus (P), and lime (from lime-stabilized biosolids). Biosolids also ensure against unforeseen nutrient shortages by supplying essential plant nutrients that are rarely purchased by farmers because crop responses to their application are unpredictable. These include elements such as sulfur (S), manganese (Mn), zinc (Zn), copper (Cu), iron (Fe), molybdenum (Mo), nickel (Ni), and boron (B). In addition to biosolids' nutrient-supplying and liming benefits, the byproduct can improve soil quality by enriching soil organic matter (**www.virginiabiosolids.com/wp-content/uploads/2018/10/VBC_Benefits.pdf**) and enhance crop yield and quality by biostimulation (**www.virginiabiosolids.com/wp-content/uploads/2018/10/VBC_Biostimulant.pdf**).

Land application is usually less expensive than alternative methods of disposal. Consequently, wastewater treatment facilities and the public they serve benefit through cost savings. The recycling of nutrients and organic matter can be attractive to citizens concerned with environmental protection and resource conservation. See the following websites for more detailed information on land-applying biosolids for:

- **Row crops, forage, and hay lands**
  www.virginiabiosolids.com/wp-content/uploads/2019/02/Biosolids-Use-for-Row-Crop.pdf.
- **Forestry**
  www.virginiabiosolids.com/wp-content/uploads/2019/01/VBC_Biosolids-Use-in-Forestry.pdf.
- **Land reclamation**
  www.virginiabiosolids.com/wp-content/uploads/2019/04/VBC_Land-Reclamation.pdf.
- **Urban landscapes**
  www.virginiabiosolids.com/wp-content/uploads/2019/04/VBC_Urban-Landscapes.pdf.

Production and Characteristics of Biosolids

Understanding how biosolids are produced can elucidate the basis for their composition. The composition of biosolids defines their quality and potential use. The following sections describe biosolids production methods and characteristics.

How Are Biosolids Produced?

Biosolids are produced through physical, biological, and chemical treatment of domestic wastewater (**fig. 1**). Treatment to generate a beneficial product must sanitize wastewater solids to control disease-causing organisms and reduce characteristics that could attract disease vectors (e.g., rodents, flies). The type and extent of processes used to treat wastewater affect the degree of pathogen reduction achieved and the potential for odor generation. Common stabilization processes and their effects on biosolids' properties and land application practices are summarized in **table 1 (page 154)**. More **detailed descriptions of treatment practices and objectives** can be found at www.virginiabiosolids.com/wp-content/uploads/2018/10/VBC_Wastewater.pdf.

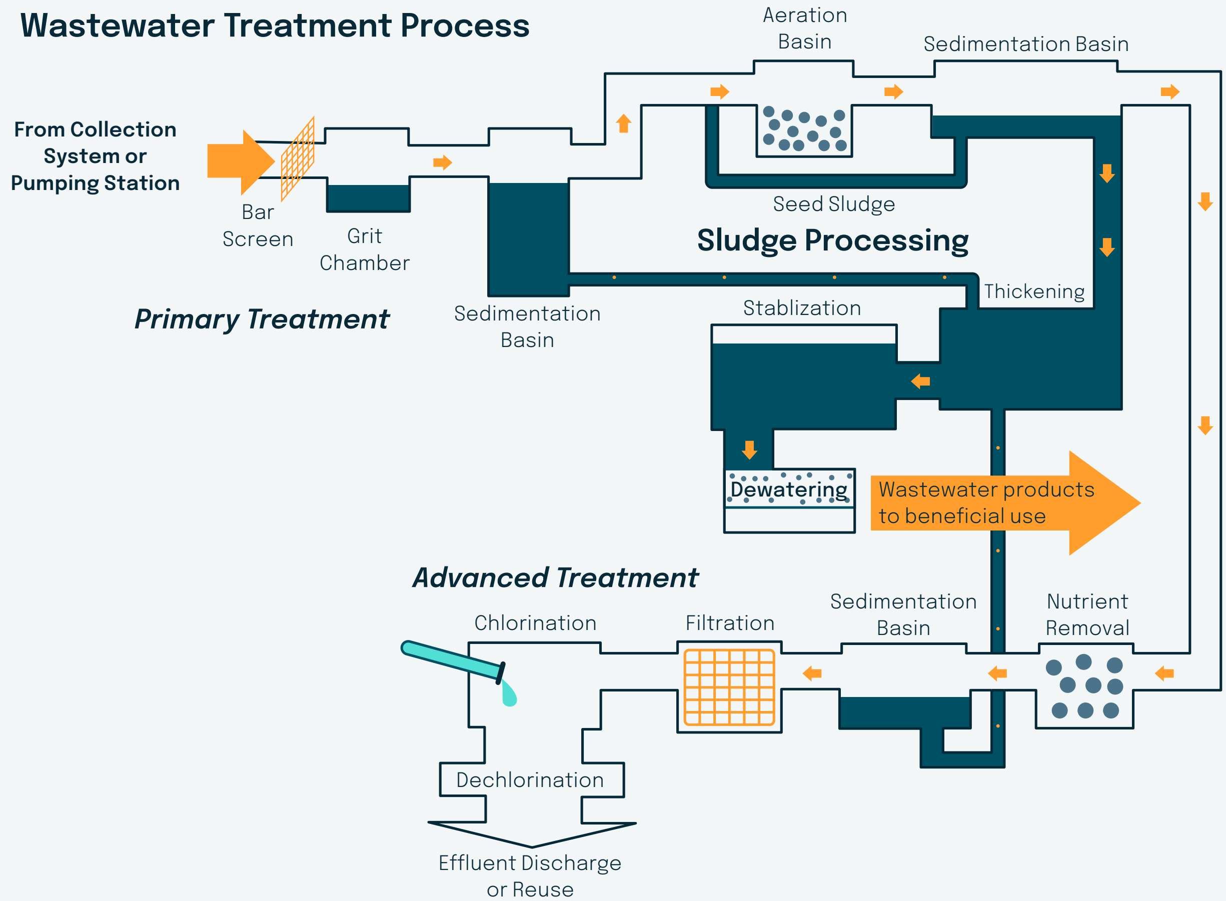

Figure 1. Schematic diagram of a wastewater treatment facility (USEPA 1995).

Table 1. Description of various wastewater stabilization processes and their effects on land application practices. (Adapted from USEPA [1984].)

Process/method	Process definition	Effect on biosolids	Effect on land application process
Digestion (anaerobic and/or aerobic)	Biological stabilization through conversion of organic matter to carbon dioxide, water, and methane.	Reduces biological oxygen demand, pathogen density, and attractiveness of the material to vectors (disease-spreading organisms).	Reduces the quantity of biosolids and the concentration of organic matter.
Alkaline stabilization	Chemical stabilization through the addition of alkaline materials (e.g., lime, kiln dust).	Raises pH > 12 and provides liming capability. Temporarily decreases biological activity. Reduces pathogen density and attractiveness of the material to vectors.	High pH (i.e., >12) results in loss of nitrogen as ammonia. Could limit application rate on sandy soils whose pH is already adequate.
Heat drying	Thermal drying of biosolids.	Destroys pathogens, eliminates nearly all moisture (solids > 95%).	Increases nutrient density.
Composting	Aerobic, thermophilic, biological stabilization in a windrow, aerated static pile or vessel.	Destroys pathogens, generates humus-like material, increases density of beneficial microbes, and reduces nitrogen content and availability.	Excellent soil conditioning properties. Contains less plant-available nitrogen than other biosolids.

Characterizing Biosolids

The suitability of biosolids for land application can be determined by their biological, chemical, and physical attributes. Biosolids' composition depends on wastewater constituents and treatment processes. The resulting properties will determine application method and rate, and the degree of regulatory control required. Several of the more important properties of biosolids are described below.

Total solids include suspended and dissolved solids and are usually expressed as the concentration present in biosolids. The content of total solids depends on the type of wastewater process and the biosolids' treatment prior to land application. Typical solids contents of various biosolids' processes are liquid (2%-10%), dewatered (25%-30%), composted (50%-60%), and (air- or thermally) dried (60%-95%).

Volatile solids provide an estimate of the readily decomposable organic matter in biosolids and are usually expressed as a percentage of total solids. Volatile solids content is an important determinant of potential odor problems at land application sites. Treatment processes such as anaerobic digestion, aerobic digestion, and composting reduce volatile solids content and thus the potential for odor.

Soil pH and calcium carbonate equivalent are measures of the degree of acidity or alkalinity of a substance. CCE is the relative liming efficiency of the biosolids that is expressed as a percentage of calcium carbonate (calcitic limestone) liming capability. The pH of biosolids can be raised with alkaline materials to reduce pathogen content and the attraction of disease-spreading organisms (vectors).

High pH (greater than 12) kills virtually all pathogens. Alkaline addition also increases the gaseous loss (volatilization) of the ammonia (NH3) form of nitrogen, thus reducing the N-fertilizer value of biosolids.

Essential nutrients are elements required for plant growth that contribute to the economic value of biosolids. These include N, P, K, Ca, Mg, Na, S, B, Cu, Fe, Mn, Mo, Ni, and Zn. Concentrations of nutrients in biosolids can vary significantly (**table 2, page 156**); thus, the actual material being considered for land application should be analyzed. For **more information on essential nutrients**, see www.virginiabiosolids.com/wp-content/uploads/2018/10/VBC_NutrientContent.pdf.

Trace elements are found in low concentrations in biosolids. The trace elements of interest in biosolids are those commonly referred to as "heavy metals." Some of these trace elements (e.g., Cu, Mo, Zn) are nutrients needed for plant growth in low concentrations, but all of these elements can be toxic to humans, animals, or plants at excessive concentrations. Possible hazards associated with an accumulation of trace elements in the soil include their potential to cause phytotoxicity (i.e., injury to plants) or to increase the concentration of potentially hazardous substances in the food chain. Federal and state regulations have established standards for the following nine trace elements: arsenic (As), cadmium (Cd), copper, lead (Pb), mercury (Hg), molybdenum, nickel, selenium (Se), and zinc. For **more information on inorganic trace elements**, see www.virginiabiosolids.com/wp-content/uploads/2018/10/VBC_TraceElements.pdf.

Trace organic chemicals are complex compounds that include man-made chemicals from pharmaceutical and personal care products, flame retardants, detergents, other household products, and pesticides. Many of these compounds are toxic or carcinogenic to organisms exposed to high concentrations over time, but most are found at such low concentrations in biosolids that the USEPA concluded that the compounds do not pose significant human health or environmental threats. No organic pollutants are included in the current federal biosolids regulations due to the determination of low risk; however, toxicological research on many such compounds is ongoing. For **more information on trace organic chemicals**, see www.virginiabiosolids.com/wp-content/uploads/2018/10/VBC_TraceOrganic.pdf.

Pathogens are disease-causing microorganisms that include bacteria, viruses, protozoa, and parasites. Pathogens can present a public health hazard if they are transferred to food crops grown on land to which biosolids are applied, contained in runoff to surface waters from land application sites, or transported away from the site by vectors such as insects, rodents, and birds. For this reason, federal and state regulations specify pathogen and vector attraction reduction requirements that must be met by biosolids applied to land. For **more information on pathogens**, see www.virginiabiosolids.com/wp-content/uploads/2019/01/VBC_Pathogens-Biosolids-2.pdf.

Typical Nutrient Levels in Biosolids

There have been few comprehensive surveys of nutrient levels in biosolids during the past 25 years. One such recent study conducted by Stehouwer, Wolf, and Doty (2000) demonstrated that the macronutrient (N, P, and K) concentration of biosolids has changed very little from the late 1970s to the mid-1990s. The data in **table 2 (page 156)** represent the means and variability of more than 240 samples collected and analyzed from 12 publicly owned treatment works (POTWs) in Pennsylvania between 1993 and 1997. The POTWs generated between 110 and 60,500 tons of biosolids annually and implemented aerobic digestion (three POTWs), anaerobic digestion (four POTWs), or alkaline addition (five POTWs) as the stabilization treatment process.

Table 2. Means and standard deviation of nutrient concentrations[a] in biosolids collected and analyzed in Pennsylvania between 1993 and 1997 (Stehouwer, Wolf, and Doty 2000).

Nutrient	Total N[b]	NH_4-N	Organic N	Total P	Total K
	%				
Mean	4.74	0.57	4.13	2.27	0.31
SD[c]	1.08	0.30	1.03	0.89	0.27

[a] Concentrations on a dried solids basis.

[b] Determined as total Kjeldahl nitrogen.

[c] Standard deviation of the mean.

Regulations

Land application of biosolids involves some risks, which are addressed through federal and state regulations. Because small amounts of pollutants and pathogens are added to soil in biosolids, human and animal health, soil quality, plant growth, and water quality could be adversely affected if land application is not conducted in an environmentally sound manner. Nitrogen and phosphorus in biosolids, as for any fertilizer source, can contaminate groundwater and surface water if the material is overapplied or improperly applied. Whether handled by disposal or beneficial use, biosolids incur certain risks.

The Federal Part 503 Rule

As required by the Clean Water Act Amendments of 1987, the USEPA developed the regulation Standards for the Use or Disposal of Sewage Sludge (CFR 2021; Title 40, Code of Federal Regulations, Chapter 1, Part 503). This is commonly known as the **Part 503 Rule**. The Part 503 Rule establishes minimum requirements when biosolids are applied to land to condition the soil or fertilize crops or other vegetation grown in the soil. The Clean Water Act required that this regulation protect public health and the environment from any reasonably anticipated adverse effects of pollutants and pathogens in biosolids.

Federal regulations require that state regulations be at least as stringent as the Part 503 Rule. The underlying premise of both the federal and state regulations is that biosolids should be used in a manner that limits risks to human health and the environment. The regulations prohibit land application of low-quality sewage sludge and encourage the application of biosolids that are of sufficient quality that they will not adversely affect human health or the environment. Determination of biosolids' quality is based on trace element (pollutant) concentrations and pathogen and vector attraction reduction. **Additional information on the regulatory process** can be found at www.virginiabiosolids.com/wp-content/uploads/2018/10/VBC_WhoRegulates.pdf.

Pollutants and Concentration Limits

The Part 503 Rule identifies how biosolids can be used based on the concentrations of arsenic, cadmium, copper, lead, mercury, molybdenum, nickel, selenium, and zinc **(table 3)**.

Table 3. Regulatory limits (adapted from USEPA [1995]) and mean concentrations measured in biosolids from the National Sewage Sludge Survey (USEPA [1990]) and a survey of 12 publicly owned treatment works in Pennsylvania between 1993 and 1997 (Stehouwer, Wolf, and Doty 2000).

Pollutant	CCL[a,b] (ppm[f])	PCL[a,c] (ppm[f])	CPLR[a,d] (lb/A)	Mean[a,g] (ppm[f])	Mean[a,h] (ppm[f])
Arsenic (As)	75	41	36	10	5
Cadmium (Cd)	85	39	35	7	3
Copper (Cu)	4,300	1,500	1,340	741	476
Lead (Pb)	840	300	270	134	82
Mercury (Hg)	57	17	16	5	2
Molybdenum (Mo)	75	—[e]	—[e]	9	13
Nickel (Ni)	420	420	375	43	23
Selenium (Se)	100	100	89	5	4
Zinc (Zn)	7,500	2,800	2,500	1,202	693

[a] Dry weight basis.

[b] CCL (ceiling concentration limits) = maximum concentration permitted for land application.

[c] PCL (pollutant concentration limits) = maximum concentration for biosolids whose trace element pollutant additions do not require tracking (i.e., calculation of CPLR).

[d] CPLR (cumulative pollutant loading rate) = total amount of pollutant that can be applied to a site in its lifetime by all bulk biosolids applications meeting CCL.

[e] The Feb. 25, 1994, Part 503 Rule amendment deleted Mo PCL for sewage sludge applied to agricultural land but retained Mo CCL.

[f] ppm = parts per million.

[g] Data from U.S. EPA (1990).

[h] Data from Stehouwer, Wolf, and Doty (2000).

The following pollutant limits describe biosolids fitness for use.

Ceiling concentration limits are the maximum concentrations of the nine trace elements allowed in biosolids to be land applied. Sewage sludge exceeding the ceiling concentration limit for even one of the regulated pollutants is not classified as biosolids and therefore cannot be land applied.

Pollutant concentration limits are the most stringent pollutant limits included in Part 503 for land application. Biosolids meeting pollutant concentration limits are subject to fewer requirements than biosolids meeting ceiling concentration limits. Results of the USEPA's 1990 National Sewage Sludge Survey (USEPA 1990) demonstrated that the mean concentrations of the nine regulated pollutants are considerably lower than the most stringent Part 503 Rule pollutant limits.

The cumulative pollutant-loading rate is the total amount of a pollutant that can be applied to a site in its lifetime by all bulk biosolids applications meeting ceiling, but not pollutant, concentration limits. No additional biosolids meeting ceiling concentration limits can be applied to a site after the maximum cumulative pollutant-loading rate is reached at that site for any one of the nine regulated trace elements. Only biosolids that meet the more stringent pollutant concentration limits may be applied to a site once a cumulative pollutant-loading rate is reached at that site.

In 1987, the USEPA established pretreatment specifications (40 CFR Part 403) that required industries to limit the concentrations of pollutants, including trace elements and organic chemicals, in wastewater discharged to a treatment facility. An improvement in the quality of biosolids over the years has largely been due to pretreatment and pollution prevention programs (Shimp et al. 1994).

Part 503 does not regulate organic chemicals in biosolids because the chemicals of potential concern (1) have been banned or restricted for use in the United States, (2) are no longer manufactured in the U.S., (3) are present at low concentrations based on data from the USEPA's 1990 National Sewage Sludge Survey (USEPA 1990), or (4) because the limit for an organic pollutant identified in the Part 503 risk assessment is not expected to be exceeded in biosolids that are land applied (USEPA 1992a). The National Research Council concluded, in their review of the science the Part 503 Rule was based on, that additional testing of certain organic compounds should be conducted (National Research Council 2002). These included poly-brominated diphenyl ethers, nonyl phenols, pharmaceuticals, and other potential carcinogenic and endocrine-pathway-disrupting personal care products. Further research demonstrated that the typical concentrations of these chemical compounds found in biosolids pose minor risk that requires no regulation (www.virginiabiosolids.com/wp-content/uploads/2018/10/VBC_TraceOrganic.pdf).

Pathogen Reduction Categories

Federal and state regulations require the reduction of potential pathogens and vector attraction properties. Biosolids intended for land application are normally treated by chemical or biological processes that greatly reduce the number of pathogens and odor potential in sewage sludge. Two levels of pathogen reduction, Class A and Class B, are specified in the regulations.

The goal of **Class B** requirements is to ensure that pathogens (including Salmonella sp., bacteria, enteric viruses, and viable helminth ova) have been reduced to **levels that are unlikely to cause a threat to public health and the environment under specified use conditions**. Processes that significantly reduce pathogens such as anaerobic or aerobic digestion, drying, heating, and high pH or their equivalent are most commonly used to ensure that biosolids meet Class B requirements. Because Class B biosolids contain some pathogens, certain site restrictions are required. These are imposed to minimize the potential for human and animal contact with the biosolids until environmental factors (temperature, moisture, light, microbial competition) reduce the pathogens to below detectable levels. The site restriction requirements in combination with Class B treatment is expected to provide a level of protection equivalent to Class A treatment. All biosolids that are land applied must, as a minimum, meet Class B pathogen reduction standards.

The goal of **Class A** requirements is to reduce the pathogens to **below detectable levels**. Class A biosolids can be land-applied without any pathogen-related site restrictions. The biosolids treatment methods termed Processes to Further Reduce Pathogens, such as those involving high temperature, high pH with alkaline addition, drying, composting, or their equivalent are most commonly used to ensure that biosolids meet Class A requirements. Biosolids that meet the Part 503 pollutant concentration limits, Class A pathogen reduction, and a vector attraction reduction option that reduces organic matter are classified as Exceptional Quality or EQ biosolids.

Vector Attraction Reduction

The objective of vector attraction reduction is to prevent disease vectors, such as rodents, birds, and insects, from transporting pathogens away from the land application site. There are 10 options available to ensure that land-applied biosolids meet vector attraction reduction requirements. These options fall into either of the following two general approaches: (1) reducing the attractiveness of the biosolids to vectors with specified organic matter decomposition processes (e.g., digestion, alkaline addition) and (2) preventing vectors from coming into contact with the biosolids (e.g., biosolids injection or incorporation below the soil surface within specified time periods).

Nitrogen, Phosphorus, and Lime Application Rate

Federal regulations specify that biosolids may only be applied to agricultural land at or less than the rate required to supply the nitrogen needs of the crop to be grown. This agronomic rate is "designed (1) [t] o provide the amount of N needed by the food crop, feed crop, fiber crop, or vegetation grown on the land; and (2) [t]o minimize the amount of N in the biosolids that passes below the root zone of the crop or vegetation grown on the land to the ground water." (40 CFR 503.11 [b])

Agronomic rate can also be based on crop phosphorus needs if it is determined that excessive soil phosphorus poses a threat to water quality.

Although not technically a nutrient, lime can also be used as a basis for agronomic biosolids application rate. Biosolids rate may be limited by the calcium carbonate equivalent if the application of alkaline-stabilized biosolids on an Nor P basis raises soil pH to a level that can induce a trace element deficiency. By signing the land application agreement with a biosolids contractor, the farmer is obligated to make every reasonable attempt to produce a crop on sites receiving biosolids that matches the agronomic rate applied.

Site Suitability

Federal, state, and local regulations, ordinances, or guidelines place limits on land application based on site physical characteristics that influence potential transport of nitrogen, phosphorus, and pathogens. These include topography; soil permeability, infiltration, and drainage patterns; depth to groundwater; and proximity to surface water. The requirement for buffer areas separating the application site from surface water, rock outcrops, roadways, residences, and other critical areas is designed to prevent biosolids constituents from being transported into environmentally sensitive areas **(fig. 2, page 160)**.

Potentially unsuitable areas for biosolids application include:

- Areas bordered by ponds, lakes, rivers, and streams without appropriate buffer zones.
- Wetlands and marshes.
- Steep areas with sharp relief.
- Undesirable geology (karst, fractured bedrock) if not covered by a sufficiently thick layer of soil.
- Undesirable soil conditions (rocky, shallow).
- Areas of historical or archeological significance.
- Other environmentally sensitive areas, such as floodplains.

Figure 2. Aerial view of a biosolids-amended farm showing light green, slightly N-deficient buffer areas that received no biosolids to protect sensitive landforms.

Managing Biosolids for Agricultural Use

Determining appropriate biosolids application rate requires knowledge of crops and soils to which the product will be applied. The following sections describe how to calculate biosolids application rate based on crop selection and soil properties.

Selecting Suitable Crops for Fertilization With Biosolids

Corn and grasses used for hay and forages have the highest annual nitrogen requirements of crops routinely fertilized with biosolids. Thus, cropping systems that include these crops are in high demand for biosolids recycling. Soybean also has high nitrogen assimilative capacity, but is not typically fertilized with biosolids because the crop can “fix” its needed nitrogen from atmospheric nitrogen gas.

Crops grown for their flowering parts, such as cotton, may produce undesirable amounts of vegetative growth if they continue to accumulate nitrogen late in the season; thus, slow-release nitrogen sources such as biosolids are not desirable fertilizer sources for such crops. Biosolids can, however, be used without concern on other crops in rotation with cotton. The tobacco industry has expressly forbidden the use of biosolids for fertilizing tobacco because the crop readily accumulates heavy metals such as cadmium.

Biosolids can be applied to vegetable crops, but green leafy vegetables accumulate higher concentrations of metals than do the grain of agronomic crops. Some scientists have cautioned against using biosolids on vegetable crops because they provide a direct pathway of potentially harmful trace elements from the soil to humans, while others (Chaney 1994) have demonstrated that soil and plant barriers prevent trace elements in biosolids of current quality from posing such risks. Regardless of one's interpretation of the trace element bioavailability evidence, grain and forage crops are better choices for biosolids application than vegetables due to other issues (for example, the time required by regulation between Class B biosolids application and permitted harvesting of crops that can be consumed by humans).

Determining Biosolids Application Rates

Biosolids supply some of all of the essential plant nutrients and soil property-enhancing organic matter. Land application rates, however, are primarily based on the ability of biosolids to supply nitrogen, phosphorus, and (in the case of alkaline-stabilized materials) lime. The general approach for determining biosolids application rates on agricultural land is summarized in the following steps.

1. Determine **nutrient needs** for crop yield expected for the soil on which the crop will be grown, and soil test nutrient and pH levels to account for residual nutrient availability.
2. Calculate **biosolids agronomic rates** based on either:
    - Crop N needs (normally) or soil test P levels (if excess P is a problem).
    - Soil lime requirement (when lime-supplying biosolids are used and will raise soil pH above the desirable range if they are applied on an N basis).
3. Calculate **supplemental fertilizer needs** by subtracting the amount of plant-available N, P, and K supplied by biosolids from the crop's N, P, and K needs.

Determining Nutrient Needs

Fertilizer recommendations are based on the nutrient-supplying capability of the soil and the additional nutrients needed by crops to achieve their potential yield. Soil testing is required prior to the application of biosolids to determine the suitability of soil pH and the availability of phosphorus and potassium. Soil testing can disclose whether limestone, phosphorus, or potassium is required for optimum crop productivity. Nitrogen application rates are based on crop needs for expected yields for a specific soil.

Determining Agronomic Rates

Biosolids are normally applied at rates to provide either the N needed or the rate that can be assimilated by the crop. This is known as the **agronomic N rate**. Fertilizer nitrogen is not normally applied to legumes, which can obtain the nutrient from the atmosphere; however, nitrogen assimilative capacity is used to establish agronomic N rates for legumes because they will use biosolids furnished nitrogen. The relative concentrations of nutrients in biosolids are rarely present in the proportions required by the target crop; thus, supplemental fertilization (for example, with K) may be needed to promote optimum vegetative growth and yield.

Biosolids should be applied at rates that supply no more than the agronomic N rate for the specific crop and soil type. Expected crop yields for different soils and nutrient rates for calculating biosolids' application rates have been established by the Virginia Department of Conservation and Recreation in the Virginia Nutrient Management Standards and Criteria handbook (DCR 2014).

Why is the application rate for biosolids usually based on crop nitrogen needs?

Nitrogen is required by crops in greater amounts than any other nutrient; thus, the crop's requirement for most other nutrients is normally met when the agronomic N rate is applied. Biosolids rate is further limited to N-supplying capacity because N (as nitrate) is the nutrient most likely to be lost to surface and groundwater if applied at greater than agronomic rates.

The following cautions regarding the determination of agronomic N rates should be considered: The amount of plant-available N can be underestimated or overestimated because the nitrogen composition of biosolids that is used to establish the average N concentration can vary significantly during the period of time that samples are collected and analyzed to establish the agronomic N rate.

The equations used to calculate plant-available N are not site- or source-specific, and the actual amounts of plant-available N may vary from the target rates.

These problems occur with other types of organic wastes, such as manures and yard waste composts, and are not unique to biosolids.

What is PAN, and how is it determined?

Only a portion of the total nitrogen present in biosolids is available for plant uptake. This **plant-available nitrogen or PAN** is the actual amount of nitrogen in the biosolids that is available to crops during a specified period. Equations for calculating PAN are relatively straightforward, but selecting precise site-and source-specific availability coefficients and reasonable input values is more challenging. Site-specific data, when available, should always be used in preference to "book" values.

Determining Availability of Ammonium in Biosolids

Nitrogen in biosolids can be found in the ammonium (NH_4+) or nitrate (NO_3) forms found in commercial inorganic fertilizers or in organically bound forms, such as amino acids and proteins. The amount of nitrogen that will be available to plants varies for each of its chemical forms. Nitrate is readily plant-available but is not found in high concentrations in most biosolids. Ammonium is also available to plants, but it can be lost to the atmosphere (via volatilization) as ammonia (NH_3) gas when biosolids are applied to land without prompt incorporation into the soil. The available (i.e., nonvolatilizable) fraction of NH_4+-N can be estimated based on the time of incorporation after application. Examples of nitrogen availability coefficients from the nonvolatized fraction of NH_3 used in Virginia are presented in **table 4 (page 163)**.

Table 4. Examples of estimated plant-available percentage of ammonia from biosolids (adapted from Virginia Department of Environmental Quality Biosolids Use Regulations; https://www.virginiabiosolids.com/wp-content/uploads/2013/09/Biosolids_Regulations_VPA_9VAC25-32_20130705.pdf).

Management practice	Biosolids with pH <10	Biosolids with pH ≥10
	available % NH_3	
Injection below surface	100	100
Surface application with:		
Incorporation within 24 hours	85	75
Incorporation within 1-7 days	70	50
Incorporation after 7 days	50	25

Determining Availability of Organic Nitrogen in Biosolids

Organic nitrogen must be transformed to ammonium (NH_4^+) via mineralization, and further, to nitrate (NO_3^-) via nitrification by soil microorganisms before this form of nitrogen is available for plants to use. Organic nitrogen is thus a slow-release form of nitrogen. The amount of plant-available N from organic N is estimated by using factors established by research (e.g., Gilmour et al. 2003), such as those presented in **table 5**. The largest portion of organic nitrogen in biosolids is converted to PAN during the first year after application to the soil.

For example, the percentages of organic nitrogen that will become available for non-irrigated corn uptake (E_{min}) from land-applied biosolids that have been treated by digestion, alkaline addition, or heating are

- 30% during the first year after application.
- 10% of the remaining organic N during each of the second and third years.
- 5% of the remaining organic N during the fourth year.

Table 5. Biosolids organic N mineralization factors recommended by Gilmour et al. (2000, 2003) for annual (K_{min}) and growing season (E_{min}) periods in Virginia under dryland and irrigated conditions. E_{min} is the effective mineralization factor for the growing season portion of the year. N-use efficiency for this period was determined to be 71%.

Table 5. Biosolids organic N mineralization factors recommended by Gilmour et al. (2000, 2003) for annual (K_{min}) and growing season (E_{min}) periods in Virginia under dryland and irrigated conditions.

E_{min} is the effective mineralization factor for the growing season portion of the year. N-use efficiency for this period was determined to be 71%.

	Nonirrigated				Irrigated			
	Year 1	Year 2	Year 3	Year 4	Year 1	Year 2	Year 3	Year 4
	K_{min}							
Annual	0.42	0.14	0.14	0.07	0.50	0.21	0.14	0.07
	E_{min}							
Growing season	0.30	0.10	0.10	0.05	0.35	0.15	0.10	0.05

The values in **tables 4 and 5 (page 163)** might not be the most appropriate for all biosolids applied to any soil, but such "book" values are normally used when site-specific data are not available. The amounts of available ammonium (NH_4^+) plus the available portion of the organic nitrogen are used to calculate the rate of biosolids needed to supply a given amount of plant-available nitrogen. Equations for calculating PAN are relatively straightforward, but selecting precise site- and source-specific availability coefficients is an imprecise exercise. Site-specific data should be used if it is available.

Will agronomic nitrogen rates of biosolids meet all crop nutrient needs?

Agronomic nitrogen rates of biosolids do not necessarily meet all crop nutrient requirements. For example, potassium is often recommended for agronomic crops grown in Virginia soils, but the nutrient is present in low concentrations in biosolids. Supplemental potassium fertilization based on soil testing may be required for optimum plant growth where biosolids are applied.

Can problems occur by applying biosolids at agronomic nitrogen rates?

Biosolids normally supply similar amounts of plant-available nitrogen and phosphorus, but crops require one-fifth to one-half as much phosphorus as nitrogen. Applying biosolids whose phosphorus is largely contained in forms that are readily soluble/plant available at rates to supply the nitrogen needs of crops will eventually supply more phosphorus than necessary. Many soils in the Chesapeake Bay region contain very high levels of phosphorus due to long-term manure application or repeated fertilization with commercial phosphorus fertilizer. Long-term application of N-based biosolids rates can increase the potential for phosphorus contamination of surface water where soil phosphorus levels are already high. To reduce the potential of phosphorus runoff or leaching in such cases, it is advisable to apply the biosolids at rates to meet the phosphorus, rather than the nitrogen, needs of the crop. The need to apply biosolids on a phosphorus basis can be verified with the use of a site-specific assessment tool, such as the P Index, which incorporates phosphorus transport risk in addition to soil quantity factors. Applying biosolids on a phosphorus basis would likely require a farmer to purchase fertilizer nitrogen to supplement crop needs.

How are plant availabilities of phosphorus and potassium from biosolids determined?

The U.S. Environmental Protection Agency (USEPA 1995) estimates that 50% of the phosphorus and 100% of the potassium applied in biosolids are available for plant uptake in the year of application. More recent research data has established that the availability of phosphorus in biosolids varies widely according to its composition of P-binding constituents (esp. aluminum, iron, and calcium) and the treatment processes that the wastewater was subjected to. The adoption of best management practices and improved testing procedures are recommended to protect water quality (**www.wef.org/globalassets/assets-wef/3---resources/topics/a-n/biosolids/technical-resources/1-page-p-fact-sheet-v25-jul-2016.pdf**). Biosolids' phosphorus source coefficients for use in the P Index can be calculated from water-extractable P (**www.extension.psu.edu/programs/nutrient-management/planning-resources/other-planning-resources/p-source-coefficient**).

The quantities of available phosphorus and potassium applied to soil with the biosolids may be credited against fertilizer recommendations in the year of application. Any phosphorus and potassium in excess of plant needs will contribute to soil fertility levels that can regularly be monitored via soil testing when determining fertilizer recommendations in succeeding years.

Using Soil pH and Calcium Carbonate Equivalent as the Basis for Determining Biosolids Rate

Soil pH influences the availability and toxicity of naturally occurring metals and metals applied to soil in biosolids. Most crops grow well in Virginia soils at pH levels between 5.8 and 6.5. Based on previous U.S. EPA guidance, some states require that soils treated with biosolids be maintained at a pH of 6.5 or higher to reduce metal uptake by crops. Federal regulations do not require a minimum soil pH because pH was factored into the Part 503 risk assessment on which the regulation was based (USEPA 1992b). It is advisable to maintain the pH of agricultural soils where biosolids have been applied in the optimum range for crop growth (i.e., 5.8 to 6.5) to avoid phytotoxicity due to naturally occurring soil or biosolids-supplemented metals.

The calcium carbonate equivalent of the alkaline-stabilized biosolids can be used to determine application rates. The pH of coarse-textured (i.e., sandy) soils can rise rapidly when limed. Deficiencies of manganese in wheat and soybean and zinc in corn have sometimes been caused by excessive liming (pH > 6.8) of coarse-textured, Coastal Plain soils. Application of lime-stabilized biosolids at agronomic nitrogen rates to such soils that already have high pH values can induce such deficiencies. Crop yield reductions can result if the deficiency is not corrected, and the nitrogen not utilized by the crop can potentially leach into groundwater. Thus, alkaline-stabilized biosolids should not be applied at rates that raise the soil pH in Coastal Plain soils above 6.5, and in all other soils above 6.8.

Magnesium deficiencies have been reported in row crops where repeated applications of calcitic (high Ca, low Mg) limestone has reduced soil Mg concentrations. Such soils can be identified by soil testing and should not receive further additions of “calcium-only” liming materials, including Ca-based, lime-stabilized biosolids.

Calculating Annual Agronomic Nitrogen Rate

Calculations for quantifying annual agronomic nitrogen rates are described in **Table 6**.

Table 6. Stepwise calculation of nitrogen-based biosolids application rates.

Step	Action
1	Determine N recommendation for the crop based on the expected yield level for the soil. Use state or private soil testing laboratory fertilizer nutrient recommendations or similar tool (DCR 2014).
2	Subtract anticipated N credits (i.e., other sources of N) from the recommended N rate, such as: • Residual N from a previous legume crop. • N that has already been applied or will be applied for the crop by fertilizer, manure, or other sources that will be readily available to plants. • Residual N remaining from application of previous byproduct (e.g., manure, biosolids).
3	Calculate the adjusted biosolids N rate by subtracting N available from existing and planned sources from the total N requirement of crop.
4	Calculate the PAN/dry ton of biosolids for the first year of application using the following equation (1): $PAN = NO_3\text{-}N + K_{vol}(NH_4^{+}\text{-}N) + K_{min}(Org\text{-}N)$ **(1)** where: **PAN** = lbs plant-available N/dry ton biosolids. **NO_3-N** = lbs nitrate N/dry ton biosolids. **K_{vol}** = volatilization factor or plant-available fraction of NH_4-N (table 4). **NH_4-N** = lbs ammonium N/dry ton biosolids. **K_{min}** = mineralization factor or plant-available fraction of Org-N (table 5). **Org-N** = lbs organic N/dry ton biosolids (estimated by subtracting NH_4-N from total Kjeldahl N).
5	Calculate the amount of biosolids required to supply the crop's N needs using the following equation: **Dry tons biosolids required/acre = adjusted biosolids N rate (in lbs/A) ÷ PAN/dry ton biosolids.** Then divide the tons of dry biosolids by the percentage of solids to convert to the wet weight of biosolids required.

Calculating Annual Agronomic Phosphorus Rate

Applying biosolids to meet the phosphorus rather than the nitrogen needs of the crop is a conservative approach for determining annual biosolid application rates. A more scientifically balanced approach, which accounts for both phosphorus availability and transport, is the use of a tool such as the P Index (as described in Part XI. Fertilizing With Manure). Supplemental nitrogen fertilization will be needed to optimize crop yields (except for N-fixing legumes) if biosolids application rates are based on a crop's phosphorus needs.

The agronomic phosphorus rate of biosolids for land application can be determined by using the following equation (2):

$$\textbf{Agronomic P rate} = P_{req} \div \text{Available } P_2O_5/\text{dry ton,} \quad (2)$$

where:

P_{req} = the P fertilizer recommendation for the harvested crop or the quantity of P removed by the crop.

Available P_2O_5 = K_p[a] (total P_2O_5/dry ton biosolids).

Total P_2O_5/dry ton = %P in biosolids x 20[b] x 2.3[c].

[a] K_p = P availability factor = 0.5 (USEPA 1995).

[b] 20 is the factor to convert % to lbs/ton.

[c] 2.3 is the factor to convert lbs P to lbs P_2O_5.

Calculating Agronomic Lime Requirement

Application rates for lime-stabilized or lime-conditioned biosolids can be computed by determining the biosolids' calcium carbonate equivalent. The CCE provides a direct comparison of the liming value of the biosolids with calcium carbonate limestone, which is the basis for soil testing liming requirements. Biosolids conditioned or stabilized with lime typically have CCEs between 10% and 50% on a dry weight basis. The agronomic lime rate for a biosolid can be determined by using the following equation (3):

$$\textbf{Dry tons biosolids/A} = \text{tons of CCE required/A} \div \text{biosolids CCE/100} \quad (3)$$

Example: Determining nitrogen, phosphorus, and lime agronomic rates for a specific situation.

The following exercise is an example of calculating biosolids application rates based on N, P and lime needs.

A lime-stabilized biosolid has a pH > 10, a calcium carbonate equivalent of 40%, a nitrate-nitrogen (NO_3-N) concentration of 1,000 ppm (0.1%), an ammonium-nitrogen (NH_4-N) concentration of 2,000 ppm (0.2%), a total Kjeldahl (TKN) concentration of 27,000 ppm (2.7%), and a total phosphorus concentration of 21,000 ppm (2.1%) – all on a dry weight basis (% dry solids = 17.6%). Corn for grain is to be grown on a Kempsville sandy loam soil that has a pH of 6.2, "high" calcium, magnesium, and potassium soil test ratings and a "medium" phosphorus soil test rating. The biosolids will be surface-applied and disked into the soil within 24 hours.

Determining N, P, and Lime-Based Agronomic Rates

Determine N recommendation for the crop based on the expected yield level for the soil. The estimated yield potential of corn grown on a Kempsville soil is 120 bu/A (DCR 2014), which requires 132 lbs N/A (assumption: 1.1 lbs N per bu of corn).

1. **Calculate the N-based agronomic rate using (1),**
   a. Calculate the components of PAN in the biosolid:

      NO3-N = 1,000 ppm x 0.002 = 2 lbs/ton.

      NH4-N = 2,000 ppm x 0.002 = 4 lbs/ton.

      TKN = 27,000 ppm x 0.002 = 54 lbs/ton.

      Org-N = 54-(2 + 4) = 48 lbs/ton.

   b. Calculate PAN:

      PAN = 2 + 0.75 (4 lbs/ton) + 0.3 (48 lbs/ton) = 2 + 3 + 14.4 = 19.4 lbs/ton.

   c. Divide the adjusted fertilizer N rate (132 lbs N/dry ton) by the PAN/dry ton biosolids (19.4 lbs N/dry ton) to obtain the agronomic N rate (6.8 dry tons/A).

2. **Calculate the P-based agronomic rate using (2).**
   a. Calculate the total amount of P_2O_5 in a ton of biosolids:

      P_2O_5/dry ton = 2.1 x 20 x 2.3 = 96.6 lbs.

   b. Calculate the amount of plant-available P_2O_5 in a ton of biosolids (using the USEPA availability factor of 0.5):

      Plant-available P_2O_5/dry ton = 0.5 x 96.6 = 48.3 lbs.

   c. Calculate the agronomic P rate. The soil test rating of "medium" in Virginia requires 40-80 lbs P_2O_5/A (DCR 2014).

      The agronomic P rate = 60 lbs P_2O_5/A ÷ 48.3 lbs P_2O_5/dry ton = 1.24 dry tons/A (i.e., about 1/5 of the agronomic N rate for the same biosolids).

3. **Calculate the lime-based agronomic rate.**

   The coarse-textured Kempsville soil requires 0.75 ton limestone/acre to raise the pH to 6.5 (DCR 2014). Use **(3)** to determine the rate of lime-stabilized biosolids needed to provide 0.75 ton CCE/A:

   Lime-based biosolids rate = tons of CCE required/A ÷ biosolids CCE/100 (0.75 ton CCE/A) ÷ 40%/100 = 1.88 dry tons/A.

4. **Compare the rates calculated in steps 1, 2, and 3.**

   The N-based, P-based, and lime-based agronomic rates for the example above are 6.8, 1.24, and 1.88 dry tons/A, respectively. Dividing each of these rates by the fraction of solids in the biosolids (0.176) gives the wet weights of biosolids that must be applied to meet N-based (38.6 wet tons/A), P-based (7.04 wet tons/A), and lime-based (10.7 wet tons/A) application rates.

The P rate appears to be most limiting; however, transport risks as assessed by the P Index should also be considered before deciding on the "correct" agronomic rate. Finally, the capability of the equipment to spread very low rates and the economics of applying low rates may prevent biosolids from being applied at all.

Land Application Methods

The most appropriate application method for agricultural land depends on the physical characteristics of the biosolids and the soil, as well as the types of crops grown. Biosolids are generally land applied using one of the following methods.

- Sprayed or spread on the soil surface and left on the surface for pastures, range, and forestland.
- Incorporated into the soil after being surface-applied or injected directly below the surface for producing row crops or other vegetation.
- Applied to land with or without subsequent soil incorporation (both liquid and dewatered [or "cake"] biosolids).

Applying Liquid Biosolids

Liquid biosolids can be applied by surface spreading or subsurface injection. Surface methods include spreading by tractor-drawn tank wagons, special applicator vehicles equipped with flotation tires, or irrigation systems. Surface application with incorporation is normally limited to soils with less than a 7% slope. Biosolids are commonly incorporated by plowing or disking after the liquid has been applied to the soil surface and allowed to partially dry, unless minimum or no-till systems are being used.

Spray irrigation systems generally should not be used to apply biosolids to forage or row crops during the growing season, although a light application to the stubble of a forage crop following a harvest is acceptable. The adherence of biosolids to plant vegetation can have a detrimental effect on crop yields by reducing photosynthesis, and it provides a more direct pathway for pollutant consumption by grazing animals. In addition, spray irrigation increases the potential for odor problems and reduces the aesthetics at the application site.

Liquid biosolids can also be injected below the soil surface using tractor-drawn tank wagons with injection shanks and tank trucks fitted with flotation tires and injection shanks. Both types of equipment minimize odor problems and reduce ammonia volatilization by immediate mixing of soil and biosolids. Injection can be used either before planting or after harvesting crops, but it is likely to be unacceptable for forages and sod production. Some injection shanks can damage the sod or forage stand and leave deep injection furrows in the field.

Subsurface injection will minimize runoff from all soils and can be used on slopes up to 15%. Injection should be made perpendicular to slopes to avoid having liquid biosolids run downhill along injection slits and pond at the bottom of the slopes. As with surface application, drier soil will be able to absorb more liquid, thereby minimizing downslope movement. Liquid biosolids have largely given way to drier, dewatered products.

Applying Dewatered Biosolids

Dewatered biosolids can be applied to cropland by equipment similar to that used for applying limestone and animal manure (**figs. 3a, 3b**). Typically, dewatered biosolids will be surface-applied and incorporated by plowing or another form of tillage. Incorporation is not used when applying dewatered biosolids to forages or to crops being grown no-till. Biosolids application methods such as incorporation and injection can be used to meet Part 503 vector attraction reduction requirements.

Figure 3a. Dewatered biosolids are spread onto conventionally tilled land.

Figure 3b. Dewatered biosolids being spread onto pastureland.

Timing of Biosolids Application

The timing of biosolids application must be scheduled around the tillage, planting, and harvesting operations and will be influenced by crop, climate, and soil properties. Traffic on wet soils during or immediately following heavy rainfalls can cause compaction and leave ruts in the soil, making crop production difficult and reducing crop yields. Muddy soils also make vehicle operation difficult and can create public nuisances by carrying mud out of the field and onto roadways.

Applications should also be made when crops will soon be able to use the plant-available nitrogen contained in the biosolids. Failure to do so could result in potential nitrate contamination of groundwater due to leaching of this water-soluble form of nitrogen. It is advisable that biosolids applied to land between autumn and spring have a vegetative cover (i.e., permanent pasture, winter cover crop, winter annual grain crop) to reduce erosion of sediment-bound biosolids; runoff of N, P, and pathogens; and leaching of nitrate.

Split applications may be required for rates of liquid biosolids (depending on the solids content) in excess of 2-3 dry tons/acre. Split application involves more than one application, each at a relatively low rate, to attain a higher total rate when the soil cannot assimilate the volume of the higher rate at one time.

Biosolids Storage

In-field storage of biosolids at or near the application site is often needed. Storage facilities are required to hold biosolids during periods of inclement weather, equipment breakdown, frozen or snow-covered ground, or when land is unavailable due to growth of a crop. Liquid biosolids can be stored in digesters, tanks, lagoons, or drying beds, and dewatered biosolids can be stockpiled. Recommended guidelines for such storage have been specified by the Environmental Protection Agency (USEPA 2000).

Disadvantages of Land Application

Large land areas may be needed for agricultural use of biosolids because application rates are relatively low. Transportation and application scheduling that is compatible with agricultural planting, harvesting, and possible adverse weather conditions require careful management.

Biosolids are typically delivered to the application site by tractor-trailers containing approximately 20 tons (**fig. 4**), stockpiled at the staging area, and loaded into manure-type spreaders (**fig. 5**). At a solids content of 15%-25%, 20 tons of wet biosolids is approximately 3-5 dry tons per trailer, or about the amount of biosolids that is normally spread onto 1 acre of land for crops such as corn or hayland. Therefore, there will be considerable truck volume over the course of several weeks for large sites of several hundred acres. Increased traffic on local roads, odors, and dust are potential impacts on the local community that should be addressed by notifying neighbors in public informational meetings or public hearings. Working out delivery schedules that are least likely to be disruptive will minimize the problems caused by biosolids transportation.

Figure 4. Biosolids being stockpiled at staging area.

Figure 5. Dewatered biosolids being loaded into manure-type spreader for application.

Biosolids, even when properly treated, will have odors. Under unfavorable weather conditions, the odors may be objectionable, even to rural communities accustomed to the use of animal manure. Odors may be reduced by stabilization process, application method, storage type, climatological conditions, and site selection, as described below.

Stabilization reduces the biological activity and odor of biosolids. The products of digestion, heat treatment, and composting tend to result in the least objectionable odors. Lime-stabilized biosolids can generate odors if the liming agent has not been well-distributed throughout the product or, for surface-applied unincorporated biosolids, after the pH of the biosolids decreases.

Application method affects the odor potential at the site. Immediate soil incorporation or direct soil injection will reduce the potential for odor problems.

Biosolids storage can occur at the treatment plant, the site of application, or a temporary facility. Storage at the treatment plant (if isolated from the public) is the preferred method. Off-site storage requires proper site selection and management to minimize the potential for odor problems.

Weather conditions (i.e., temperature, relative humidity, wind) will affect odor severity when biosolids are surface-applied. Spreading in the morning when air is warming and rising will help dilute the odor in the immediate vicinity.

The selection of the application site is important to the success of the operation. Ideally, the site should be located away from residential areas.

Objectionable odors will sometimes be present despite adequate stabilization processes and favorable weather conditions. Complaints can be expected if adjacent property owners are subjected to persistent odors. A well-managed system with the proper equipment and stabilized biosolids will substantially reduce the potential for unacceptable odors.

References

Chaney, R. L. 1994. "Trace Metal Movement: Soil-Plant Systems and Bioavailability of Biosolids-Applied Metals." *In Sewage Sludge: Land Utilization and the Environment*, edited by C. E. Clapp, W. E. Larson, and R. H. Dowdy, 27-31. Madison, WI: ASA, CSSA, SSSA Books.

DCR (Virginia Department of Conservation and Recreation). Division of Soil and Water Conservation. 2014. *Virginia Nutrient Management Standards and Criteria. Richmond*, VA: DCR.

CFR (Code of Federal Regulations). 2021 (last revised). 40 CFR 503.11(b).

Gilmour, J. T., C. G. Cogger, L. W. Jacobs, S. A. Wilson, G. K. Evanylo, and D. M Sullivan. 2000. *Estimating Plant-Available Nitrogen in Biosolids*. Project 97-REM-3. Alexandria, VA: Water Environment Research Foundation.

Gilmour, J. T., C. G. Cogger, L. W. Jacobs, G. K. Evanylo, and D. M Sullivan. 2003. "Decomposition and Plant-Available Nitrogen in Biosolids: Laboratory Studies, Field Studies, and Computer Simulation." *Journal of Environmental Quality* 32:1498-1507.

National Research Council. 2002. Biosolids Applied to Land: Advancing Standards and Practices. Washington, DC: National Academies Press.

Shimp, G., K. Hunt, S. McMillian, and G. Hunter. 1994. "Pretreatment Raises Biosolids Quality." *Environmental Protection* 5 (6).

Stehouwer, R. C., A. M. Wolf, and W. T. Doty. 2000. "Chemical Monitoring of Sewage Sludge in Pennsylvania: Variability and Application Uncertainty." *Journal of Environmental Quality* 29 (5): 1686-95.

USEPA. 1984. *Environmental Regulations and Technology: Use and Disposal of Municipal Wastewater Sludge*. EPA/625/10-84/003. Washington, DC: USEPA.

USEPA. 1990. "National Sewage Sludge Survey: Availability of Information and Data, and Anticipated Impacts on Proposed Regulations." *Federal Register* 55 (218).

USEPA. 1992a. *Technical Support Document for Land Application of Sewage Sludge,* Vol. I. EPA/822/R-93/900/9. Washington, DC: USEPA.

USEPA. 1992b. *Technical Support Document for Land Application of Sewage Sludge,* Vol. I. EPA/822/R-93/001a. Washington, DC: USEPA.

USEPA. Office of Research and Development. 1995. *Process Design Manual: Land Application of Sewage Sludge and Domestic Septage*. EPA/625/R-95/001. Washington, DC: USEPA.

USEPA. Office of Wastewater Management. 2000. *Guide to Field Storage of Biosolids*. EPA/832-B-00-007. Washington, DC: USEPA.

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Part XIII.

Weeds and Weed Management

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Weeds and Their Impacts

There are numerous definitions of a weed. The following are some common definitions:

- A plant that is out of place and not intentionally cultivated.
- A plant that grows where it is not wanted or welcomed.
- A plant whose virtues have not yet been discovered.
- A plant that is competitive, persistent, pernicious, and interferes negatively with human activity.

No matter which definition is used, weeds are plants whose undesirable qualities outweigh their good points – at least according to humans. Human activities create weed problems because no plant is a weed in nature. Though we may try to manipulate nature for our own good, nature is persistent. Through manipulation we control certain weeds, while other, more serious weeds thrive due to favorable growing conditions. Weeds are naturally strong competitors, and those weeds that can best compete always tend to dominate.

Both humans and nature are involved in plant breeding programs. The main difference between the two programs is that humans breed plants for yield and/or aesthetic qualities, while nature breeds plants for survival.

Classification of Weeds

Almost all plants are categorized by some sort of plant classification system and given a scientific name to identify them anywhere in the world. Keep in mind that the scientific name (i.e., genus and species) is universal, but the common name of a weed can differ from region to region. For example, velvetleaf is also known as buttonweed and butter print; common lambsquarters can be referred to as pigweed, goosefoot, fat-hen, or baconweed; and wild carrot is known as Queen Anne's lace. Weeds are also classified by other means. In general, they can be classified by their structure and appearance (e.g., dicots [broadleaves] and monocots [grasses and sedges]), habitat, or physiology. A common categorization system groups them according to their life cycle (how long they live). The three major life cycle groups are annuals, biennials, and perennials.

Annuals

Annuals are generally divided further into summer annual and winter annual weeds. Summer annuals germinate in the spring, mature, produce seed, and die in one growing season. Large crabgrass, giant foxtail, smooth pigweed, common lambsquarters, common ragweed, velvetleaf, hairy galinsoga, and common purslane are examples of troublesome summer annuals.

Winter annual weeds germinate in late summer or fall, mature, produce seed, and then die the following spring or summer. Examples of winter annuals include common chickweed, henbit, shepherdspurse, and downy brome.

Biennials

Biennial weeds grow from seed at any time during the growing season. They normally produce a rosette of leaves close to the soil surface the first year, and then flower, mature, and die during the second year. A true biennial never produces flowers or seeds the first year. There are relatively few biennial weeds. Some examples include wild carrot, common burdock, bull and musk thistle, and poison hemlock.

Perennials

Perennial weeds live for more than two years and can be divided into two groups: simple and creeping. Simple perennials form a deep taproot and spread primarily by seed dispersal. Some examples of simple perennials include dandelion, broadleaf plantain, curly/broadleaf dock, autumn olive, and common pokeweed. Creeping perennials can be either herbaceous or woody and can spread by both vegetative structures and by seed. Some common creeping herbaceous perennials include Canada thistle, common milkweed, hemp dogbane, creeping buttercup, slender speedwell, ground ivy, quackgrass, and yellow nutsedge. Some examples of creeping woody perennials include poison ivy, multiflora rose, Japanese knotweed/bamboo, brambles, wild grape, and Virginia creeper. Creeping perennials become established by seed or by vegetative parts. Since perennial weeds live indefinitely, their persistence and spread are not as dependent on seed as the other two weed groups.

Weed Management Techniques

Over the past decade or so, there have been a number of rapid changes in weed management techniques and ideologies. New directions in weed management include shifting crop management practices, continuously changing weed control technologies, increasing concern for the environment, and using computer software and electronic information technology for decision-making, record-keeping, and data managing. Environmental concerns have resulted in more no-till, cover crop, and organic crop production systems. Advancements in technology have allowed the development of lower use rate herbicides with less soil persistence, biotechnology that produces genetically modified crops, and computers that allow us to develop predictive models for weed and crop development, while weed mapping and GPS units enhance more precise herbicide application on specific weed patches and at various herbicide rates. However, despite all these advances, mechanical and chemical tactics still provide the majority of weed control in many settings. Regardless of the weed control tactic or setting, knowledgeable and experienced field consultants and technicians are necessary to diagnose problems, interpret information and results, and provide practical advice about weed management.

Since weeds are so prevalent in many areas of the landscape, management techniques are necessary to maintain order. Weed management is most successful when it involves an integrated approach using a variety of methods. The common methods used to manage weeds include prevention and cultural, mechanical, biological, and chemical means. Relying on any single tactic can lead to severe problems, such as high costs and crop failure. In planning a weed management strategy, keep in mind the available equipment and time, land characteristics, weed spectrum, and yield objective. Management inputs such as herbicides can sometimes be reduced, but alternative approaches must be substituted if the production level is to be maintained.

Integrated Weed Management

In addition to the following information, please consult **A Practical Guide for Integrated Weed Management in Mid-Atlantic Grain Crops**, available at https://growiwm.org/wp-content/uploads/2019/11/IWMguide.pdf?x93413.

Corn and soybean fields that are weed-free for the first four to six weeks after planting will often yield the same as fields that are weed-free for the entire growing season. This approach relies on a residual soil-applied herbicide program. Weeds that germinate with the crop but are controlled in a timely fashion (three to four weeks after planting) will not impact final yields. This approach relies on effective and timely postemergence weed control. In addition, if weeds are kept out of the field for four to six weeks after crop emergence, any weeds that invade later will not reduce yield significantly, although they may produce seeds, cause harvesting problems, or reduce crop quality.

Also, it is not necessary to control all weeds in a field to achieve maximum yield. Weed populations of 10 to 20 weeds per 10 square yards are sufficient to cause severe yield loss. However, weed populations at one plant per 10 square yards will have no impact on final yield. The impact of weed populations between one and 10 per yard is difficult to predict. The decision to treat the field depends on the weed species present, crop vigor, weather conditions, and herbicide cost.

Prevention

Preventive methods are used to stop the spread of weeds. It is usually easier to prevent the introduction of weeds than it is to control them after establishment. Preventive practices include cleaning tillage and harvesting or mowing equipment of weed seeds and vegetative structures; planting certified, weed-free crop seed or sod; and controlling weeds in barnyards, around structures, and along fencerows, roadways, and ditch banks. Scouting areas to assess weed populations and controlling them before they spread farther is another means of preventing additional weed problems.

Early Season Weed Scouting

The first key to weed management is proper weed identification. The best method for timely identification is through field scouting. The first reports on weed conditions in a field are needed within two weeks after crop emergence to evaluate herbicide performance and determine if there is a need for rotary hoeing, cultivation, or postemergence herbicides. Earlier scouting will be needed in no-till fields where a knockdown or early pre-plant herbicide can be applied. Identify and record all weed species found. Determine the severity of the infestation by counting the number of weeds found per 10 feet of row for large infestations or per 100 feet of row for smaller infestations in all areas sampled. Sample areas should represent no more than 5 acres, so sample enough areas to get an accurate count of the different weeds present in the field or on the farm. The approximate height and growth stage of both weeds and crop should be recorded.

Along with weed reports, early soil moisture observations are important. They serve as indicators of herbicide effectiveness. Adequate moisture is necessary for effective weed control with all soil-applied herbicides. Too little rainfall can mean there is not enough moisture to allow adequate mobilization of the herbicide; too much rain can cause more soluble herbicides to move downward below the zone where they are most effective. Postemergence herbicides usually are most effective when weeds are young and actively growing. The degree of control with these herbicides will vary due to differences in weed species, growth stages, weather conditions, and herbicide application method. To select the best possible herbicide and apply it at the optimum time to maximize control, the manager needs to be able to identify weed seedlings when they are small.

Cultural Techniques

Cultural crop management techniques provide a healthy crop to best compete with weeds. Competition from crop, turf, or desirable vegetative cover can be an inexpensive and effective aid to weed management if used to its fullest advantage. Examples of cultural techniques include following soil test recommendations for fertilizer and lime; selecting the best varieties for the environmental conditions; planting dense populations at the proper timing; using proper mowing practices; scouting fields or areas regularly for weeds, insects, and diseases, and controlling them when necessary; and including crop rotations and cover crops in the system. Composting, ensiling, or feeding weeds or weed-infested crops to livestock can destroy the viability of weed seeds. The heat and/or digestive acids break down the majority of weed seeds. However, some seeds pass through livestock or the composting process unharmed and can germinate if spread back onto the land.

Cover Crops

Cover crops provide important benefits to the Mid-Atlantic region, including soil and water conservation and nutrient retention. Some growers are also finding that cover crops can help reduce weed problems, especially winter annuals like horseweed. The following management factors should be considered to enhance weed suppression with your cover crops.

Species Selection

Choose cover crops based on your objectives. If weed suppression is an objective, select an aggressive species that will cover the ground quickly. If you desire a cover crop that will protect the soil through the fall and winter and suppress winter annual weeds, plant a winter cereal in late summer or early fall.

Establishment Date

Establishing a winter-hardy cover such as cereal rye as early in the fall as possible will result in greater cover crop biomass over the winter and rapid growth during the spring. Other establishment dates may be preferable for different cover crops depending on the species and your objectives.

Planting Considerations

The seeding rate and arrangement of the cover crop can influence weed suppression. Planting at higher-than-normal seeding rates and in narrow rows can influence the amount of soil cover, particularly in the first several weeks after seeding. Thick, dense cover crop stands can help reduce the establishment of weeds. Planting with a drill increases seed-to-soil contact and is more reliable for getting a good cover crop stand than broadcast seeding.

Soil Fertility

It is important to provide adequate soil fertility to cover crops to ensure they are competitive and successful. This is particularly true for small grains like cereal rye and wheat and forage radish, which require adequate nitrogen. Lime may be necessary to maintain or raise the soil pH for legumes like hairy vetch and red clover. Regular soil tests will help you determine how best to manage your cover crops so as to maximize their beneficial effects on weed suppression and soil quality.

Termination Timing

Allowing a cover crop to grow as long as possible before termination reduces weed populations through competition for light, nutrients, and moisture. In no-till, letting the cover crop achieve maximum dry matter production (often at flowering or beyond) will increase weed suppression. This may mean delaying termination and cash crop planting until the cover crop has achieved sufficient growth to suppress weeds (weed suppression can require dry matter production of at least 4,000 pounds per acre but is optimized at 7,000 pounds per acre). Keep in mind, however, that high-biomass cover crops can be more challenging to manage, might need shorter season cash crops to allow for adequate cover crop growth, and may require specialized planting equipment or may increase the potential for some insect pest problems.

Cover crops can be terminated mechanically or with herbicides. Each method has advantages and disadvantages. Mowing can be effective for some annual cover crops, but the mulch can degrade quite rapidly because it has been chopped. Plowing can be an effective physical control for cover crops, but the benefit of the weed-suppressive mulch in the subsequent cash crop is lost. The roller-crimper offers effective physical control of some annual cover crops, but without any accompanying herbicides, control is delayed until the winter annual cover crops are flowering and can be inconsistent. Rolling creates a longer lived mulch layer than mowing. Herbicides can effectively control most cover crops, but product selection and application timing are important.

Mechanical Techniques

Mechanical or physical techniques either destroy weeds or make the environment less favorable for seed germination and weed survival. These techniques include pulling weeds by hand, hoeing, mowing, plowing, disking, cultivating, and digging. If adequate weed control is obtained from other methods, such as herbicides, tillage or cultivation may not be necessary, which in turn could avoid soil crusting and soil erosion that can occur when soils are routinely tilled. Mowing removes the seed heads of most weeds and reduces the amount of seed spread in an area. Mowing is used primarily for weed control in lawns, meadows, pastures, waste areas, and along roadsides. Digging or pulling is an effective method of controlling a limited number of weeds. Smaller weeds can be easily pulled by hand or hoed in small garden areas or flower beds; however, the use of heavy machinery could be necessary to remove large woody weeds such as multiflora rose, tree of heaven, and autumn olive. Mulching (using straw, wood chips, compost, gravel, plastic, landscape fabric, etc.) can also be considered a mechanical control means because it uses a physical barrier to block light and impede weed growth. In landscaping and vegetable production, it usually helps to reduce the need for other weed management tactics.

Biological Techniques

Biological weed control involves the use of other living organisms, such as insects, diseases, or livestock, for the management of certain weeds. In theory, biological control is well suited for an integrated weed management program. However, the limitations of biological control are (1) it is a long-term undertaking, (2) its effects are neither immediate nor always adequate, (3) only certain weeds are potential candidates, and (4) the rate of failure for past biological control efforts has been fairly high. There have been a few success stories of weed species (e.g., St. Johnswort, prickly pear, multiflora rose, purple loosestrife, thistles) being managed or affected by insect or disease biocontrol agents. Herbivores such as sheep and goats can provide successful control of some common pasture weeds. Finally, conservation biological control can improve our ability to manage weeds and use less herbicide. This involves enhancing populations of natural enemies by manipulating field habitats to create more favorable environments for predator insects and rodents. Ground beetles, crickets, ants, and mice are some of the more common weed-seed predators. In general, providing cover in the form of living or dead crops, causing less soil disturbance, and avoiding the use of toxic pesticides can encourage these biocontrol agents. Research continues in this area of weed management.

Chemical Techniques

Chemicals used for the control of weeds are called herbicides. Herbicides can be defined as crop- (or desirable plant-) protecting chemicals used to kill weedy plants or interrupt normal plant growth. Herbicides provide a convenient, economical, and effective way to help manage weeds. They allow fields to be planted with less tillage, allow earlier planting dates, and provide additional time to perform the other tasks that farm or personal life require. Due to reduced tillage, soil erosion has been reduced from about 3.5 billion tons in 1938 to 1 billion tons in 1997, thus reducing soil from entering waterways and decreasing the quality of the nation's surface water. Without herbicide use, no-till agriculture becomes impossible. However, herbicide use also carries risks that include environmental, ecological, and human health effects. It is important to understand both the benefits and disadvantages associated with chemical weed control before selecting the appropriate control.

Herbicides may not be a necessity on some farms or landscape settings, but without the use of chemical weed control, mechanical and cultural control methods become that much more important. There are many kinds of herbicides from which to choose. Many factors determine when, where, and how a particular herbicide can be used most effectively. Understanding some of these factors enables you to use herbicides to their maximum advantage.

No-Till Weed Management

Successful production of no-till crops requires control of existing vegetation at planting (cover crops and weeds) and broadleaf and grass weeds that emerge after planting. A diversity of herbicides and cover crop and residue situations makes it impossible to utilize a single program to efficiently control weeds and grasses in all situations. Herbicide selection based on weed identification histories of each field is necessary to achieve maximum yield potential. Fields with heavy crop residues may require the maximum labeled rate of residual herbicides for acceptable performance. Encapsulated formulations, when available, can be less readily absorbed by heavy crop residues and could perform more consistently.

Cultivation and mechanical weed control are very difficult or impossible, and they are generally not considered an option in most no-till production systems. However, some companies manufacture high-residue cultivators that are designed for use in no-till/reduced-till systems. The authors have had a number of trials examining their effectiveness, and generally two passes will provide about a 50% reduction in weed dry matter. Combining these tools with herbicides can provide a more integrated approach to weed management.

Existing vegetation is traditionally controlled by the non-selective herbicides, which are often tank-mixed with residual herbicides. Burndown herbicide options include paraquat or glyphosate and perhaps a growth regulator herbicide (Group 4) such as 2,4-D. No-till crop production tends to favor perennial weed populations because their root systems are not disrupted by tillage. No-till also favors small-seeded grasses and broadleaf weeds (such as lambsquarters and pigweed) rather than large-seeded weeds, such as velvetleaf.

Escalating herbicide costs and an interest in keeping herbicide use to a minimum encourage many people to consider the use of postemergence herbicide programs. Experience leads the authors to strongly recommend that existing vegetation should always be controlled prior to planting. In the Mid-Atlantic region, soil moisture is often the factor that most limits yield. The decision to apply burndown herbicides early pre-plant, at planting, or as a delayed preemergence (spike) treatment to control existing emerged vegetation should always be made with consideration to the impact of the existing vegetation on the availability of soil moisture. Preemergence or postemergence herbicides that can provide residual weed control can then be selected that will control weeds that emerge after planting. Reducing or eliminating some or all of the residual preemergence herbicides can reduce costs in fields that historically have required postemergence herbicide applications.

Herbicides

Herbicides are the primary weed management tool in no-till production systems. Careful selection and application are critical to maximizing their effectiveness.

Some Considerations When Using Herbicides

The perfect herbicide does not exist. No single herbicide is capable of controlling all weeds that can develop in a crop or planting. Since every herbicide has advantages and disadvantages, selecting the correct herbicide(s) is crucial. Consider the following points before you choose or apply any herbicide.

- Is it registered for use on the crop or area you want to treat? If it is, the directions for use and rate of application will appear on the label. Recommended rates for soil-applied herbicides can vary according to the soil texture and the amount of organic matter in the soil. Labels usually give a range of rates because soil types differ in the amount of herbicide that binds to soil particles. The application for postemergence treatments varies with weed size and climatic conditions. Weeds that are growing under dry conditions or during prolonged cool weather will not actively translocate a systemic herbicide. A herbicide rate that is higher than the rate used on actively growing weeds may be needed.
- Will it control the weeds that are causing the biggest problem, and does it take into account methods for managing herbicide resistance? Many weed control measures fail because the chosen herbicide will not control the weeds that are present.
- Can it be used effectively at the current stage of crop or weed growth? Very few herbicides can be applied at any stage during the growth cycle of a plant. Pendimethalin and metolachlor are good examples of how growth stage affects herbicide performance. They are excellent herbicides for annual grasses when applied before the grass weeds emerge; however, they are useless if applied after the weeds have emerged.
- Can the herbicide be used effectively and safely under the current conditions? Soil-applied herbicides must move into the soil to be taken up by roots and shoots of weed seedlings and perennial plant parts. Rainfall is usually adequate to provide soil incorporation of soil-applied herbicides, but in the absence of rainfall, weed control may be poor. The effectiveness of soil-applied herbicides can be reduced if the chemical is intercepted by debris from a previous crop, a prior application of livestock manure, thatch, or other barrier. Depending on the amount of crop residue, reduced-tillage cropping systems may require higher application rates of soil-applied herbicides than are required by conventional systems. Vegetation remaining on the soil surface binds some of the herbicide and prevents even distribution of the herbicide. Herbicides can also be lost to runoff, leaching, or volatilization.
- Will the herbicide(s) interact negatively with other pesticides, fertilizers, or other inputs being used on the crop or area? Because of such interactions, injury or death to desirable plants may occur.

- Is the herbicide being applied to a "normal" crop or a genetically modified crop? Since genetically modified crops look similar to normal crops when growing, misapplication can occur and the crop can be unintentionally killed or severely injured. Make sure to record the type of crop that was planted in each field.
- Will carryover of the herbicide result in a residue that might affect the crop or cover crop you want to plant next in rotation? Herbicide carryover is a problem with chemicals that persist in sufficient quantity to injure succeeding plantings. Some examples of herbicides prone to carryover include the triazines (atrazine and simazine), dinitroanilines (Treflan, Curbit, Barricade, Prowl), ALS inhibitors (Classic, Cimarron, Steadfast, Outrider, Spirit, Pursuit, Python), and pigment inhibitors (Command, Balance, Callisto, Impact). These herbicides can provide season-long control of certain weeds. However, if an excessive rate is applied, if the soil pH is above 7.0, or if the weather during the growing season is cool and dry, the natural breakdown of the chemicals might not occur and carryover may result. Read labels carefully for warnings about carryover and rotation.
- What is the appropriate method of application (e.g., broadcast, band, directed, spot)? Is it convenient to use ready-to-use products, or does it require special equipment or need to be mixed with water before application? Are there other characteristics, such as compatibility with other herbicides when tank mixing or staining, that make it difficult to use?
- Does the herbicide label recommend that a surfactant, crop oil, or other additive be used to improve leaf coverage or herbicide performance? Many postemergence herbicides require the use of an adjuvant in the mixture (see the Herbicide Spray Additives section later in this chapter).
- Can this product be used safely on the intended planting? What is required to handle, mix, and apply it safely during and after use? Is it a restricted-use pesticide?
- Can the herbicide injure nontarget plants in adjacent areas? Exercise caution to avoid drift, runoff, leaching to groundwater, and cross-contamination of other materials. Be especially alert to the potential for residues left in sprayers when spraying a different crop.

Classification of Chemical Weed Control

Herbicides can be classified several ways, including weed control spectrum, labeled crop usage, chemical families, mode of action, application timing/method, and others. For this publication, herbicides will be grouped according to mode and site of action, which are also important in understanding herbicide resistance in weeds.

Timing of Application: Preemergence or Postemergence

Preemergence or soil-applied herbicides control weeds at the seed germination stage or as they are emerging from the soil. Postemergence or foliar herbicides control emerged weeds. Combinations of preemergence and postemergence herbicides may be necessary to control the various types of weeds in an area.

Contact or Translocated

Contact herbicides kill or injure only the part of the plant that the spray droplets come into contact with, so adequate spray coverage is very important. Annual weeds may be killed, but regrowth of perennial weeds from belowground parts usually occurs following application of a contact herbicide. (On a side note, sometimes the term "contact" is used to describe an herbicide that is applied postemergence or sprayed directly on the weed and thus "contacts" the foliage of the plant. When used in this context, it may have a different meaning and the herbicide could have systemic activity throughout the plant, depending on the product.) Translocated (or systemic) herbicides are absorbed by the leaves or roots of the plants and move within the plant. They are needed to kill underground parts of perennial weeds.

Selective or Nonselective

Nonselective herbicides kill or injure almost all plants, while selective herbicides kill some plants but do little or no damage to others. Herbicides would be of little value if it were not for the fact that most herbicides can be applied just before crop planting or emergence, and even over the top after crop emergence, without excessive injury. Most of the herbicides labeled for use today will selectively remove most of the weeds without injuring the crop or planting.

Selectivity is accomplished primarily by two methods: selectivity by placement and true selectivity. Selectivity by placement is accomplished by avoiding or minimizing contact between the herbicide and the desired crop. An example is wiping or directing an herbicide, such as glyphosate, on a weed without exposing the desired plant. Selectivity by this means is as good as any, as long as the excess herbicide is not washed off the weeds and leached into the root zone where it might be absorbed by the root. Selectivity by placement is also accomplished when an herbicide that does not readily leach is applied to the soil surface for control of shallow-rooted weeds but does not leach into the root zone of a more deeply rooted crop such as fruit trees or established alfalfa.

Selectivity that is true tolerance as a result of some morphological, physiological, or biochemical means is referred to as true selectivity. The herbicide can be applied to the foliage of the crop or to the soil in which the crop is growing without danger of injury. Although true tolerance may be the best type of selectivity, it is not perfect. Such things as crop growth stage, cuticle thickness, hairiness of the leaf surface, location of the growing point, air temperature and humidity, spray droplet size, and the surface tension of spray droplets all can influence herbicide activity. When conditions are ideal for herbicide activity, even true selectivity may not adequately prevent some crop injury.

Fumigants

Fumigants may kill all living things in the soil, including weeds, weed seeds, insects, and disease organisms.

Herbicide Mode and Site of Action

To be effective, herbicides must (1) adequately contact plants, (2) be absorbed by plants, (3) move within the plants to the site of action without being deactivated, and (4) reach toxic levels at the site of action. The term "mode of action" refers to the sequence of events from absorption into plants to plant death, or in other words, how a herbicide works to injure or kill the plant. The specific site the herbicide affects is referred to as the site or mechanism of action. Understanding herbicide mode and site of action is helpful in knowing what groups of weeds are killed, specifying application techniques, diagnosing herbicide injury problems, and preventing herbicide-resistant weeds.

A common method of grouping herbicides is by their mode of action. Although a large number of herbicides are available in the marketplace, several have similar chemical properties and herbicidal activity. Herbicides with a common chemistry are grouped into families. Also, two or more families may have the same mode of action and can thus be grouped into classes. **Table 1** lists several groups of herbicides and information related to their mode of action.

The following section provides a brief overview of herbicide functions in the plant and associated injury symptoms for each of the herbicide classes found in **table 1**.

Growth Regulators – Groups 4 and 19

Also called auxins, synthetic auxins, and hormones, growth regulators are effective on annual and perennial broadleaf plants and usually have no activity on grasses or sedges except at high application rates. They produce responses similar to those of natural growth-regulating substances called auxins. Application of artificial auxins, such as 2,4-D, upsets normal growth as follows:

- Cells of leaf veins rapidly divide and elongate, while cells between veins cease to divide. This results in long, narrow, straplike young leaves.
- Water content increases, making treated plants brittle and easily broken.
- Cell division and respiration rates increase, and photosynthesis decreases. Food supply of treated plants is nearly exhausted at their death.
- Roots of treated plants lose their ability to take up soil nutrients, and stem tissues fail to move food and water effectively through the plant.

The killing action of growth-regulating chemicals is not caused by any single factor but results from the effects of multiple disturbances in the treated plant.

Injury symptoms: Broadleaf plant leaves become crinkled, puckered, strap-shaped, stunted, and malformed; leaf veins appear parallel rather than netted; and stems become crooked, twisted, and brittle, with shortened internodes. If injury occurs in grasses (e.g., corn), new leaves do not unfurl but remain tightly rolled in an onion-like fashion, and stems become brittle, curved, or crooked, with short internodes. A lesser effect in corn is the fusion of brace roots, noticed later in the season.

Table 1. Important herbicide groups for corn, soybean, small grain, commercial vegetable, and forage.

Herbicide Class/MOA					
WSSA group[1]	Site of action	No. resistant in U.S.	Family	Common name	Trade name
Lipid synthesis inhibitors					
1	ACCase inhibitors (acetyl CoA carboxylase)	15	Aryloxyphenoxy-propionate (fops)	fenoxaprop	Puma, Tacoma
				fluazifop	Fusilade
				quizalofop	Assure II, Targa
			Cyclohexanedione (dims)	clethodim	Select Max
				sethoxydim	Poast
			Phenylpyrazolin	pinoxaden	Axial XL

Table 1. Important herbicide groups for corn, soybean, small grain, commercial vegetable, and forage. (cont.)

Amino acid synthesis inhibitors					
2	ALS inhibitors (acetolactate synthase)	52	Imidazolinone	imaxamox	Beyond, Raptor
				imazapic	Plateau
				imazapyr	Arsenal
				imazethapyr	Pursuit
				pyrithiobac	Staple
			Pyrimidinylthio-benzoic acid	flucarbazone	Everest
			Sulfonylaminocarbonyltriazolinone	propoxy-carb-azone	Olympus
				thiencarba-zone	component of Capreno, Corvus
			Sulfonylurea	chlorimuron	Classic
				chlorsulfuron	Glean
				foramsulfuron	Option
				halosulfuron	Permit, Sandea
				imazosulfuron	League
				iodosulfuron	Autumn
				mesosulfuron	Osprey
				metsulfuron	Cimarron, others
				nicosulfuron	Accent Q
				prosulfuron	Peak
			Sulfonylurea	rimsulfuron	Matrix, Resolve
				sulfosulfuron	Outrider
				thifensulfuron	Harmony
				tribenuron	Express
				triflusulfuron	UpBeet
			Triazolopyrimidine	cloransulam	FirstRate
				flumetsulam	Python
				pyroxsulam	PowerFlex

Table 1. Important herbicide groups for corn, soybean, small grain, commercial vegetable, and forage. (cont.)

9	EPSP synthase inhibitor (5-enolpyruvyl-shi-kimate-3-phos-phate)	17	Organophosphorus	glyphosate	Roundup, Touch-down, others
Growth regulators					
4	T1R1 auxin re-ceptors (synthetic aux-ins)	10	Arylpicolinate	halauxi-fen-methyl	Elevore
			Benzoic acid	dicamba	Clarity
			Carboxylic acid	aminopyralid	Milestone
				clopyralid	Stinger
				fluroxypyr	Starane, Vista
				picloram	Tordon
				quinclorac	Facet
				triclopyr	Garlon, Remedy
			Phenoxy	2,4-D	Various
				2,4-DB	Butyrac, various
				MCPA	Various
19	Auxin transport inhibitor	0	Semicarbazone	diflufenzopyr	Component of Status
Photosynthesis inhibitors					
5	Photosystem II inhibitors (mobile) differ-ent binding than 6 and 7	26	Phenylcarbamate	phenmedip-ham	Spin-Aid
			Triazine	atrazine	Atrazine
				prometon	Pramitol
				simazine	Princep
			Triazinone	hexazinone	Velpar
				metribuzin	Glory, Metribuzin, TriCor
			Uracil	terbacil	Sinbar
6	Photosystem II inhibitors (nonmobile) different binding than 5 and 7	1	Benzothiadiazole	bentazon	Basagran
			Nitrile	bromoxynil	Maestro
7	Photosystem II inhibitors (mobile) differ-ent binding than 5 and 6	11	Urea	diuron	Direx, Karmex
				linuron	Linex, Lorox
				tebuthiuron	Spike

Table 1. Important herbicide groups for corn, soybean, small grain, commercial vegetable, and forage. (cont.)

Nitrogen metabolism inhibitor					
10	Glutamine synthetase inhibitor	1	Amino acid derivative	glufosinate	Finale, Liberty, Rely
Pigment inhibitors					
12	Phytoene desaturase biosynthesis inhibitor	1	Pyridazinone	norflurazon	Solicam
13	DOXP synthase inhibitor (1-deoxy-D-xyulose 5-phosphate)	1	Isoxazolidinone	clomazone	Command
27	HPPD inhibitors (4-hydroxy-phenyl-pyruvate-dioxygenase)	2	Isoxazole	isoxaflutole	Balance Flexx
			Pyrazole	pyrasulfotole	Component of Huskie
			Pyrazolone	tolpyralate	Shieldex
				topramezone	Armezon, Impact
			Triketone	mesotrione	Callisto
				tembotrione	Laudis
Cell membrane disrupters					
14	PPO inhibitors (protoporphyrinogen oxidase)	2	Aryl triazolinone	carfentrazone	Aim
				fluthiacet	Cadet
				sulfentrazone	Authority, Spartan
			Diphenyl ether	acifluorfen	Ultra Blazer
				fomesafen	Reflex
				lactofen	Cobra, Phoenix
				oxyfluorfen	Goal
			N-phenylphthalimide	flumiclorac	Resource
				flumioxazin	Château, Valor
			Oxadiazole	oxadiazon	Ronstar
			Pyrimidinedione	saflufenacil	Kixor, Sharpen
22	Photosystem I electron diverter	6	Bipyridylium	diquat	Reglone
				paraquat	Gramoxone

Table 1. Important herbicide groups for corn, soybean, small grain, commercial vegetable, and forage. (cont.)

Seedling root growth inhibitors					
3	Microtubule inhibitors	6	Benzamide	pronamide	Kerb
			Dinitroaniline	ethalfluralin	Curbit, Sonalan
				oryzalin	Surflan
				pendimethalin	Pendulum, Prowl, others
				prodiamine	Barricade
				trifluralin	Treflan, others
			Phthalic acid	DCPA	Dacthal
			Pyridazine	dithiopyr	Dimension
Seedling shoot growth inhibitors					
8	Lipid synthesis inhibitors (not ACCase)	5	Phosphorodithioate	bensulide	Prefar
			Thiocarbamate	cycloate	Ro-Neet
				EPTC	Eptam, Eradicane
15	Long-chain fatty acid inhibitors	1	Acetamide	napropamide	Devrinol
			Chloroacetamide	acetochlor	Breakfree, Degree, Harness Topnotch, Warrant, others
				dimethenamid	Outlook
				metolachlor	Dual, Cinch, others
			Oxyacetamide	flufenacet	Define
			Pyrazole	pyroxasulfone	Zidua
16	Specific site unknown	0	Benzofurane	ethofumesate	Nortron
Cell wall synthesis inhibitors					
20	Cellulose inhibitor (Site A)	0	Nitrile	dichlobenil	Casoron, others
21	Cellulose inhibitor (Site B)	0	Benzamide	isoxaben	Gallery
29	Cellulose inhibitor (unspecified site)	0	Alkylazaine	indaziflam	Alion

[1] WSSA group is a system of classifying herbicides, based on site of action, developed by the Weed Science Society of America.

Amino Acid Biosynthesis Inhibitors – Groups 2 and 9

These herbicides are effective mostly on annual broadleaves, while a few in this large group have activity on grasses, nutsedge, and/or perennial plants. (Glyphosate [Roundup], for example, is a broad-spectrum herbicide and has activity on all types of plants.) These herbicides work by interfering with one or more key enzymes that catalyze the production of specific amino acids in the plant. When a key amino acid is not produced, the plant's metabolic processes begin to shut down. Different herbicides affect different enzymes that catalyze the production of various amino acids, but the result is generally the same – the shutdown of metabolic activity with eventual death of the plant.

Injury symptoms: Plants that are sensitive to these herbicides stop growth almost immediately after foliar treatment: seedlings die in two to four days, established perennials in two to four weeks. Plants become straw-colored several days or weeks after treatment, gradually turn brown, and die.

Fatty Acid (Lipid) Biosynthesis Inhibitors – Group 1

These herbicides are rapidly absorbed by grasses and translocated to the growing points, where they inhibit meristematic activity, stopping growth almost immediately. They have no activity on broadleaf plants and are most effective on warm-season grasses such as Johnsongrass, shattercane, corn, fall panicum, giant foxtail, and crabgrass. Cool-season grasses like quackgrass, annual and perennial ryegrass, orchardgrass, timothy, and small grains are not as sensitive as warm-season grasses. Some of these herbicides are weaker on perennial species than other products. They are frequently referred to as "postgrass" and "graminicide" herbicides.

Injury symptoms: Growing points are killed first, resulting in the death of the leaves' inner whorl. Older, outer leaves of seedlings appear healthy for a few days, and those of perennials for a couple of weeks, but eventually they also wither and die. After several weeks, the growing points begin to rot, allowing the inner leaves to be easily pulled out of the whorl. Sensitive grasses commonly turn a purplish color before dying.

Seedling Growth Inhibitors (Root and Shoot) – Groups 3 and 8

Herbicides in this group prevent cell division primarily in developing root tips and are effective only on germinating small-seeded annual grasses and some broadleaves.

Injury symptoms: Seeds of treated broadleaved plants germinate, but they either fail to emerge or emerge as severely stunted seedlings that have thickened, shortened lower stems, small leaves, and short, club-shaped roots. Seedlings of taprooted plants, such as soybeans and alfalfa, usually are not affected, nor are established plants with roots more than a couple inches deep.

Grass seeds germinate but generally fail to emerge. Injured seedlings have short, club-shaped roots and thickened, brittle stem tissue. Seedlings die from lack of moisture and nutrients because of the restricted root system.

Seedling Growth Inhibitors (Shoot) – Group 15

Herbicides in this class are most effective on annual grasses and yellow nutsedge. Depending on the product, some will control small-seeded annual broadleaves. These herbicides cause abnormal cell development or prevent cell division in germinating seedlings. They stop the plant from growing by inhibiting cell division in the shoot and root tips while permitting other cell duplication processes to continue. This is followed by a slow decline in plant vigor.

Injury symptoms: Germinating grasses normally do not emerge. If they do, young leaves fail to unfold, resulting in leaf looping and an onion-like appearance. The tip of the terminal leaf becomes rigid and not free-flapping (flaglike). The leaves of broadleaved plants turn dark green, become wrinkled, and fail to unfold from the bud. The roots become shortened, thickened, brittle, and clublike.

Photosynthesis Inhibitors (Mobile) – Groups 5 and 7

These herbicides are effective primarily on annual broadleaves, while some provide control of grasses as well. Photosynthesis-inhibiting herbicides block the photosynthetic process so captured light cannot be used to produce sugars. In the presence of light, green plants produce sugar from carbon dioxide and water. Energy is needed for carbon, hydrogen, and oxygen atoms to rearrange and form sugar. To supply this necessary energy, electrons are borrowed from chlorophyll (the green material in leaves) and replaced by electrons split from water. If chlorophyll electrons are not replaced, the chlorophyll is destroyed and the plant's food-manufacturing system breaks down. The plant slowly starves to death due to lack of energy.

As soil-applied treatments, these herbicides permit normal seed germination and seedling emergence but cause seedlings to lose their green color soon afterward. With the seeds' food supply gone, the seedlings die. These herbicides are more effective on seedling weeds than on established perennial weeds. Herbicides such as prometon (Primitol) and tebuthiuron (Spike) are considered soil sterilants. Soil sterilants are nonselective chemicals that can kill existing vegetation and keep the soil free from vegetation for one or more years.

Injury symptoms: In broadleaved plants, early seedling growth appears normal, but shortly after emergence (when energy reserves in cotyledons are depleted), leaves become mottled, turn yellow to brown, and die. In most cases, the oldest leaves turn yellow on the leaf margins first, the veins remain green, and eventually the plant turns brown and dies. Herbaceous and woody perennials starve very slowly because they have large energy reserves in roots or rhizomes to live on while photosynthesis is inhibited. The herbicide may have to effectively inhibit photosynthesis for a full growing season to kill trees or brush. This kind of death may be slow, but it is certain.

Photosynthesis Inhibitors (Nonmobile, "Rapid-Acting") – Group 6

Herbicides in this group have activity primarily on annual and some perennial broadleaves and are applied to the plant foliage. The mode of action is the same as the mobile photosynthesis inhibitors.

Injury symptoms: Their activity within the plant is similar to that of the mobile photosynthesis inhibitors except the injury occurs at the site of contact, causing "leaf burning" and eventual death of the plant.

Cell Membrane Disrupters – Groups 14 and 22

These herbicides control mostly broadleaves. Certain products have some activity on grasses, and paraquat (Gramoxone) provides broad-spectrum control of many different species.

These herbicides are referred to as contact herbicides, and they kill weeds by destroying cell membranes. They appear to burn plant tissues within hours or days of application. Good coverage of the plant tissue and bright sunlight are necessary for maximum activity. The activity of these herbicides is delayed in the absence of light.

Injury symptoms: All contact herbicides cause cellular breakdown by destroying cell membranes, allowing cell sap to leak out. Affected plants initially have a water-soaked appearance, followed by rapid wilting and "burning" or leaf speckling and browning. Plant death occurs within a few days.

Pigment Inhibitors – Groups 12, 13, and 27

These herbicides provide control of many annual broadleaves and some grasses. These products are referred to as "bleachers" because they inhibit carotenoid biosynthesis or the HPPD enzyme by interfering with normal chlorophyll formation, turning plant parts white.

Injury symptoms: Symptoms are very evident and easy to identify. Affected plants either do not emerge or emerge white or bleached and eventually die. Older leaf tissue is affected first.

Phosphorylated Amino Acid (Nitrogen Metabolism) Disrupters – Group 10

This herbicide (glufosinate) provides broad-spectrum control of most annual grasses and broadleaves and some perennials. It affects growth by disrupting nitrogen metabolism, thus interfering with other plant processes. It is a contact herbicide with slight translocation throughout the plant. Good spray coverage and sunlight are important for maximum efficacy.

Injury symptoms: Injury is similar to that of the cell membrane disrupter herbicides. Sensitive plants show leaf burning, yellowing and browning, and eventual death after a week or so. Perennials generally take longer for symptoms and death to occur.

Unknown Herbicides

This category contains miscellaneous products for which the mode of action and family are unknown. Dazomet (Basamid) and metam (Vapam) are considered soil fumigants. These products are applied to the soil and covered with a gas-tight tarp, where they are converted to gases and penetrate the soil to kill weeds, diseases, and nematodes. Endothall (Aquathol) is used for aquatic weed control. Fosamine (Krenite) is used in noncrop areas to control perennial weeds and brush.

Other compounds – such as pelargonic acid (Scythe), fatty acid herbicides, and clove oil and vinegar – are contact, nonselective, broad-spectrum, foliar-applied products that are sometimes used for weed control in organic crop production settings. However, because they basically "burn" only the plant tissue they contact, there is potential for plant regrowth.

Trade Name, Formulation Notations, and Premixes

Certain publications list many herbicides by trade name (or product name) and formulation, for example: Roundup 4S or Permit 75WDG. Roundup is the trade name and 4S stands for 4 pounds of active ingredient (glyphosate) per gallon of product in a soluble (S) formulation. Permit is formulated as a water-dispersible granule with each granule (or certain unit) containing 75% active ingredient (halosulfuron) in a water-dispersible granule (WDG) formulation. The remaining parts of the formulation contain inert ingredients, which have no effect on weed control. Additional information about formulation and ingredients can be found in another part of this publication and on the product's label and safety data sheet.

Premixes contain two or more herbicide active ingredients mixed into one product by the manufacturer. The actual premix formulation can vary but commonly contains two or more herbicides that are already used together. The primary reason for using premixes is convenience. Many herbicide products are now marketed as premixes.

Herbicide Safeners

Herbicide safeners, also called antidotes or protectants, are chemicals that help prevent injury to crops without reducing weed control. Early discovery of compounds capable of safening herbicides started in the late 1940s with the phenoxy herbicides, but commercialization really started with seed treatments and soil-active safeners in the 1970s and early 1980s. In general, herbicide safeners allow crops with fair tolerance to an herbicide to metabolize or detoxify the herbicide more quickly, thus providing increased crop safety. To date, safeners have only been developed for grass crops such as corn and wheat with few advances in dicot or broadleaf crops. Some of the more notable of these safeners include dichlormid (Eradicane and some acetochlor formulations), benoxacor (Dual II), and the seed treatment fluxofenim (Concept), which allows chloroacetamide herbicide use in sorghum. More recently, a number of Group 2 (ALS) and other herbicides use isoxadifen (Accent Q, Resolve Q, Status, Steadfast Q, etc.), which provides increased safety from foliar applications. The most recently launched safener is cyprosulfamide, which provides preemergence and foliar safening with several herbicides. Cyprosulfamide is used in a number of Bayer CropScience products, including Balance Flexx, Corvus, Capreno, and DiFlexx.

Generic or Post-Patent Products

The pace of novel herbicide active ingredient commercialization has greatly slowed over the last 20 years and many herbicides are going off patent. Also, several new manufacturers have entered the herbicide market and are reintroducing older active ingredients. Most original brands still dominate, but the post-patent product market is growing. Be cautious and consider all factors when looking at generic herbicide alternatives, especially guarantees for resprays on product failures. Contact your local dealer for details.

Herbicide Spray Additives (Adjuvants)

Additives, or adjuvants, are substances in herbicide formulations or that are added to the spray mixture to improve herbicidal activity or application characteristics. Over 70% of all herbicides recommend the use of one or more adjuvants in the spray mixture. In general, there are two types of adjuvants: formulation and spray. Formulation adjuvants are "already in the container" from the manufacturing process. These help with mixing, handling, effectiveness, and providing consistent performance.

Spray adjuvants can be divided into special-purpose adjuvants and activator adjuvants. Special-purpose adjuvants include compatibility agents, buffering agents, antifoam agents, drift retardants, and others that widen the range of conditions for herbicide use. Activator adjuvants are commonly used to enhance postemergence herbicide performance by increasing herbicide activity, absorption, and rainfastness and decreasing photodegradation. These include surfactants (i.e., "surface active agents"), crop oil concentrates, vegetable oil concentrates, wetting agents, spreader stickers, nitrogen fertilizers, penetrants, and others. Commonly used surfactants are nonionic surfactants and organosilicones, which are typically used at a rate of 1 quart per 100 gallons (0.25% volume/volume) of spray mixture. Crop oil concentrates are 80% to 85% petroleum-based plus 15% to 20% surfactant, while vegetable oil concentrates contain vegetable or seed oil in place of petroleum oil. Oil concentrates are typically included at a rate of 1 gallon per 100 gallons (1% volume/volume) of spray mixture. In general, oil concentrates are "hotter" than surfactants, so they provide better herbicide penetration into weeds under hot/dry conditions, but they are more likely to cause greater crop injury under normal growing conditions. Nitrogen fertilizers such as UAN (a mixture of ammonium nitrate, urea, and water) or AMS (ammonium sulfate) are used in combination with surfactants or oil concentrates to increase herbicide activity and reduce problems with hard water. Many blended adjuvants are available that include various combinations of special purpose adjuvants or activator adjuvants.

Be sure to include the proper adjuvant(s) for the herbicide being used. Most herbicide labels specify the type and amount of additive to use. Failure to follow the recommendations can result in poor weed control or excessive crop injury.

Managing Herbicides

Proper management of herbicides is critical to mitigate human health, environmental, and other potential hazards as well as maximize herbicidal efficacy.

Environmental Hazard Warnings

Some herbicide labels carry Environmental Hazard Warnings on the label. The environmental hazard may specify a "water-quality advisory," which requires special precautions for coarse-textured (sandy) soils, soils with a shallow water table, and soils with other potential water-contamination risks. Herbicides with water-quality advisories have been detected in small amounts in water supplies after normal agricultural use. Additional environmental dangers include toxicity to fish and wildlife and hazards to endangered species. Check the label or specific hazard warning information before using a product.

Herbicide Use Rate

The recommended use rates of soil-applied herbicides often vary with soil texture, organic matter content, and tillage systems. The use of soil-applied herbicide rates that are incorrect for the soil texture, pH, and organic matter can result in poor weed control or crop injury. Consult the herbicide label for the proper herbicide rate for your soils.

Most of the herbicides recommended in this publication are selective. At the recommended rate of application, they will selectively control or injure weeds but not seriously damage the crop in which these weeds are growing. When using selective herbicides, you should carefully follow the recommended application rate and follow instructions related to the use of surfactants and other additives. Using higher herbicide rates or additives that are not recommended can result in severe crop injury. You must accept responsibility if you use an herbicide in a manner other than that directed on the herbicide label.

Herbicide Persistence and Crop Rotation Intervals

Herbicides are applied to the soil to manage weeds. It is desirable for the chemicals to control weeds during the season of application, but they should not persist and affect subsequent crop growth. The length of time that an herbicide remains active in the soil is called "soil persistence" or "soil residual life." With some herbicides, there may be a fine line between controlling the weeds for the entire growing season and then planting a sensitive rotation crop. Anything that affects the disappearance or breakdown of herbicides will affect persistence. Herbicides vary in their potential to persist in the soil. Some herbicide families that have persistent members include the triazines (Group 5), uracils (Group 7), ureas (Group 7), sulfonylureas (Group 2), dinitroanilines (Group 3), isoxazolidinones (Group 13), imidazolinones (Group 2), and pyridines (Group 23). Factors that determine the length of time herbicides will persist fall into three categories: soil factors, climatic conditions, and herbicidal properties. The factors within each of these categories can strongly interact with one another.

Soil Factors

The soil factors affecting herbicide persistence include soil composition, soil chemistry, and microbial activity. Soil composition is a physical factor that is determined by relative amounts of sand, silt, and clay (the soil texture) and the organic-matter content. An important chemical property of the soil that can influence herbicide persistence is pH. The microbial aspects of the soil environment include the type and abundance of soil microorganisms present. Soils containing more clay and organic matter (heavier) tend to bind herbicides more strongly and they will persist longer. Also, higher soil pH (>7) can be more problematic for some herbicides.

Climatic Factors

The climatic variables involved in herbicide breakdown are moisture, temperature, and sunlight. Herbicide degradation rates generally increase as temperature and soil moisture increase because both chemical and microbial decomposition rates increase with higher temperatures and moisture levels. Cool, dry conditions slow down herbicide degradation. Carryover problems are always greater the year following a drought. If winter and spring conditions are wet and mild following a previously dry summer, the likelihood of herbicide carryover is lower.

Herbicide Properties

An herbicide's chemical properties affect its persistence. Properties include water solubility, vapor pressure, and susceptibility of the molecule to chemical or microbial alteration or degradation.
Much of this boils down to the herbicide half-life – the time it takes for 50% of the active ingredient to dissipate. Soil and climatic factors influence the rate of dissipation. The basic manufacturers, along with universities and some other research organizations, have evaluated the persistence of herbicides in soil for local conditions, and it can vary widely.

Avoiding Herbicide Persistence in Subsequent Crops

There are several ways to avoid herbicide carryover problems. First, check the re-crop statement on the herbicide label and do not plant a sensitive crop prior to the specified time. Second, always apply the correct rate of any pesticide for your specific soil type and weed problem. This means applying the lowest rate of the chemical consistent with obtaining the desired effect. Higher rates of more persistent products certainly carry more risk of injury to following crops. Accurate acreage determination, chemical measurement, proper sprayer calibration, and uniform application are essential for avoiding misapplication problems. **Always read the label before applying any herbicide.**

In summary, the first step in avoiding herbicide persistence problems is choosing less persistent products. Check the herbicide label for re-crop statements before selecting any material. With all pesticides, use the appropriate rates and application timings. The use of selective tillage, herbicide combinations, and tolerant crops and varieties will also help reduce the risk of carryover crop injury. Wise herbicide use will ensure the continued availability of these important weed management tools for the future. **Table 2 (page 195)** provides the cash crop rotation restrictions for common herbicides that are used in multiple crops. These restrictions are the label guidelines and may be due to concerns about herbicide residues accumulating in forage or feed or carryover injury.

Herbicide Persistence and Rotation to Cover Crops

The question about whether corn or soybean herbicide programs will pose a problem for establishing fall cover crops has become a common one, particularly in areas of severe drought, where corn is harvested earlier than normal and the desire to plant a cover/forage crop is strong. If you look at the rotation crop restrictions for corn and soybean herbicides in this guide **table 2**, you will see that many products limit rotation to alfalfa and/or the clovers, as well as some of the small grains. This is a good place to start when thinking about rotation to fall cover crops. However, these tables are inadequate because these cash crop rotation restrictions may be due to the concern for herbicide residues accumulating in forage or feed rather than carryover injury. If the crop is not going to be harvested and consumed by livestock or humans, the primary concern is carryover injury and achieving an acceptable stand that provides the benefits of a fall or winter cover. Cover crops that are not harvested can be planted after any herbicide program, but the grower assumes the risk of crop failure.

Two factors become important when trying to predict the potential for carryover injury to rotation crops: (1) how long the herbicide lasts or persists in the soil, assuming it has soil activity, and (2) how sensitive the rotation crop is to potential herbicide residues. Most guidelines are for “normal” conditions (e.g., not severe drought). In general, products with a four-month or less rotation restriction for the species of interest, close relative, or sensitive species (e.g., clovers) should pose little problem. These products typically have half-lives of less than 30 days. Species sensitivity can play a role if only a small amount of residue is necessary to cause injury, and the herbicide persists. Quite often, small-seeded legumes and grasses like the clovers and ryegrass, and mustard species like canola are very sensitive to some herbicides.

Table 2. Herbicide rotation restrictions for cash crops.

The information listed in this rotation restriction table is the authors' interpretation of label statements. Consult the label if two or more of these materials are applied during the same season. Herbicide labels are constantly changing; therefore, this list is not a substitute for the most recent herbicide label.

AH = After harvest

B = Bioassay of soil recommended before planting

NI = No information

NR = No restrictions

NS = Next season

NY = Next year

SY = Second year following application

	Rotation restriction (months after application)																									
Trade name	Alfalfa	Cabbage	Clover	Cotton	Cucumber	Field corn	Grain sorghum	Lima bean	Muskmelon	Onion	Peanut	Peas	Pepper	Pumpkin	Snap bean	Soybean	Spring oat	Squash	Sweet corn	Tobacco	Tomato	Watermelon	White potato	Winter barley	Winter rye	Winter wheat
2,4-D[1]	3	3	3	1	3	0.25 -1	1	3	3	3	1	3	3	3	3	0.25 -1[1]	1	3	1	3	3	3	1	1	1	1
Accent/ Accent Q	10[1]	10[2]	10	10	10[2]	NR	10-18[1]	10-18[1]	10[2]	10[2]	10[2]	10	10[2]	10[2]	10	0.5	8	10[2]	10	10[2]	10[2]	10[2]	10[1]	4	4	4
Acuron	18	18	18	10	18	NR	10	18	18	18	10	18	18	18	18	10	4	18	NR	18	18	18	10	4	4	4
Acuron Flexi[23]	10	18	18	10	18	NR	10	18	18	18	10	18	18	18	18	10	4	18	NR	18	18	18	10	4	4	4
Afforia (2.5 oz)	4[24]	4[24]	4[24]	1	4[24]	0.5[24]	1	4[24]	4[24]	4[24]	1.5	3	4[24]	4[25]	3	NR[24]	4[24]	4[24]	3	1.5	4[24]	4[24]	4[24]	3	3	1[24]

Table 2. Herbicide rotation restrictions for cash crops. (cont.)

Trade name	Alfalfa	Cabbage	Clover	Cotton	Cucumber	Field corn	Grain sorghum	Lima bean	Muskmelon	Onion	Peanut	Peas	Pepper	Pumpkin	Snap bean	Soybean	Spring oat	Squash	Sweet corn	Tobacco	Tomato	Watermelon	White potato	Winter barley	Winter rye	Winter wheat
Aim	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Anthem Flexx (5.46 oz)				25							25												0			
Anthem Maxx (4.87 oz)	10	18	18	4	18	NR	10[25]	11	18	18	4	11	18	18	11	NR	11[25]	18	NR	18	9	18	1	11[25]	11[25]	4[25]
Armezon/ Impact (0.75 oz)	9	18	18	9	18	NR	9	9	18	18	9	9	18	18	9	9	3	18	NR	18	18	18	9	3	3	3
Armezon PRO (16-20 fl oz/A)	9	18	18	9	18	NR	9	9[3]	18	18	9	9[3]	18	18	9[3]	9	4	18	NR	18	18	18	9	4	4	4
Assure II	4	4	4	NR	4	4	4	4	4	4	4	NR	4	4	NR	NR	4	4	4	4	4	4	4	4	4	4
Atrazine	SY	SY	SY	NY	SY	NR	NR	SY	SY	SY	NY	SY	SY	SY	SY	NY	SY	SY	NR	SY	SY	SY	SY	NY	NY	NY
Authority Edge	12	18[9]	18	12[1]	18	4	10–18[1]	9	18	18	4	9	18	18	9	NR[1]	12–18[1]	18	12	18	18	18	4	11–18[1]	11–18[1]	4–10[1]
Authority Elite/Broad Axe XC	12	2[9]	12B	18[4]	12B	10	10	12B	12B	12	4	12B	12B	12B	12B	NR	12	12B	18	10	4	12B	4	4.5	4.5	4.5
Authority First/Sonic	12	30B	30B	12–18[1]	30B	10–18[1]	12	12	30B	30B	12	9	30B	30B	12	NR	12	30B	10–18[1]	30[1]	30B	30B	18	12	12	4
Authority MTZ	12	18	18	18[4]	18	10	12	18	18	18	12	18	18	18	18	NR	18	18	18	12	NR[9]	18	12	4	4	4

Table 2. Herbicide rotation restrictions for cash crops. (cont.)

Trade name	Alfalfa	Cabbage	Clover	Cotton	Cucumber	Field corn	Grain sorghum	Lima bean	Muskmelon	Onion	Peanut	Peas	Pepper	Pumpkin	Snap bean	Soybean	Spring oat	Squash	Sweet corn	Tobacco	Tomato	Watermelon	White potato	Winter barley	Winter rye	Winter wheat
Authority Supreme	12	18[9]	18	12–18[1]	18	4	10[1]	9	18	18	4	9	18	18	9	NR[1]	12[1]	18	10	18	18	18	4	11[1]	11[1]	4[1]
Authority XL	12–18[1]	18	18	18	18	10–18[1]	10–18[1]	36	36	36	18	36	36	18	36	NR	12–18[1]	36	18	10–18[1]	12–18[1,9]	18	36	4	4	4
Autumn Super[1]	18B	18B	18B	10	18	1	18B	18B	18B	18B	18B	18B	18B	18B	18B	2	18B	18B	9	18B	18B	18B	18B	9	18B	3
Axial Bold, Axial Star, Axial XL	3	1	3	3	3	3	3	3	3	1	3	3	3	3	3	3	3	3	3	3	3	3	1	NR	3	NR
Axiom	12	12B	12	8	12B	NR	12	12B	12B	18	12B	12B	12B	12B	12B	NR	12	12B	12B	12B	12B	12B	1	12	12	0.23–4
Balance Flexx[1]	10[1]	18	18	10[1]	18	NR	6	18	18	18	11	18	18	18	18	6	18	18	6	12	18	18	6	6	4	4
Basagran	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Basis	10[6]	18	10[6]	1[6]	10	NR	10[6]	18	18	18	18	10	18	18	10	10[6]	9	18	10	18	1	18	NR	3	3	3
Basis Blend[6].	10[6]	18	10[6]	1[6]	10	NR	10[6]	18	18	18	1.5	10	18	18	10	10[6]	9	18	10	1.5	1	18	1	3	3	3
Beyond	3	9	18	9	9	8.5[8]	9	NR	9	9	9	NR	9	9	NR	NR	9	9	8.5	9	9	9	9	9	4	3[8]
Bicep products	SY	SY	SY	NY	SY	NR	NR[10]	SY	SY	SY	NY	SY	SY	SY	SY	NY	SY	SY	NY	SY	SY	SY	SY	NY	NY	NY
Boundary	4.5	12	12	12	12	4	12	12	12	18	12	8	12	12	12	NR	12	12	4	12	12	12	NR	4.5	12	4.5
Buctril/ Maestro	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Cadet	AH	AH	AH	AH	AH	NR	AH	AH	AH	AH	AH	AH	AH	AH	AH	NR	AH	AH	NR	AH	AH	AH	AH	AH	AH	AH

Table 2. Herbicide rotation restrictions for cash crops. (cont.)

Trade name	Alfalfa	Cabbage	Clover	Cotton	Cucumber	Field corn	Grain sorghum	Lima bean	Muskmelon	Onion	Peanut	Peas	Pepper	Pumpkin	Snap bean	Soybean	Spring oat	Squash	Sweet corn	Tobacco	Tomato	Watermelon	White potato	Winter barley	Winter rye	Winter wheat
Callisto	10	18	18	10	18	NR	NR	18	18	18	10	10[1]	18	18	10[1]	10	NR	18	NR	10	18	18	10	4	4	4
Callisto Xtra	NY	18	18	NY	18	NR	NR	18	18	18	NY	18	18	18	18	NY	18	18	NR	NY	18	18	NY	NY	18	NY
Canopy[1]	10	18	12	10	18	10	12	30	30	30	18	12	30	18	12	NR	30	30	18	10[9]	10[9]	18	30	4	4	4
Canopy Blend	10	18	18	18	18	10[26]	18	30	30	30	18	12	30	18	18	NR	4	30	18	18[9]	10[9]	18	30	4	30	4
Canopy EX	10	18	12	10	18	10[1]	10[1]	30	30	18[1]	8	12	30	18	12	0.25[1]	4	30	18	10[9]	10[9]	18	18[1]	4	4	4
Caparol	12	5	12	5	12	5	12	12	12	8	12	5	12	12	12	12	12	12	5	12	12	12	12	12	12	12
Capreno[1]	10–18	18	18	10	18	NR	10	18	18	18	11	18	18	18	18	10	10	18	10	12	18	18	18	10	18	4
Chaparral	SYB	SYB	SYB	SYB	SYB	NY	NY	SYB	SYB	SYB	SYB	SYB	SYB	SYB	SYB	SYB	NY	SYB	SYB	SYB	SYB	SYB	SYB	NY	NY	NY
Chateau (up to 3 oz)[11]	5[11]	12B	5[11]	2[11]	12B	0.5–1	1[1]	12B	12B	12B	NR	4	12B	12B	4	NR	5[11]	12B	4	2	12B	12B	5[11]	4	4	2
Cimarron Max/met-sulfuron[1]	12[1]	NYB	12[1]	NYB	NYB	NYB	NYB	NYB	NYB	NYB	NYB	NYB	NYB	NYB	NYB	NYB	10	NYB	NYB	NYB	NYB	NYB	NYB	10	NYB	1
Cimarron Plus	4	B	4–12[1]	B	B	12[1]	B	B	B	B	B	B	B	B	B	12[1]	10	B	B	B	B	B	B	10	NYB	1
Clarity	4	4	4	0.75–1.5[5]	4	NR	NR	4	4	4	4	4	4	4	4	0.5–1[5]	0.5–1.5[5]	4	4	4	4	4	4	0.5–1.5[5]	0.5–1.5[5]	0.5–1.5[5]
Classic[1]	12	18	12	9	18	9	9	30	30	30	15	9	30	18	9	NR	3	30	18	10[9]	10[9]	18	30	3	3	3
Cobra	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR

Table 2. Herbicide rotation restrictions for cash crops. (cont.)

Trade name	Alfalfa	Cabbage	Clover	Cotton	Cucumber	Field corn	Grain sorghum	Lima bean	Muskmelon	Onion	Peanut	Peas	Pepper	Pumpkin	Snap bean	Soybean	Spring oat	Squash	Sweet corn	Tobacco	Tomato	Watermelon	White potato	Winter barley	Winter rye	Winter wheat
Command/ Upstage	12	9	12	NR[12]	9	9	9	12	9	12	9	NR[1]	NR	NR[1]	9	NR	12	NR[1]	9	NR	9[9]	9	9	12	12	12
Corvus	17	17B	17B	10	17B	NR	17B[1]	17B	17B	17B	11[1]	17B	17B	17B	17	9	17	17B	9	12[1]	17B	17B	17	9	4	4
Crossbow[30]	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI
Curbit	AH	AH	AH	AH	NR	AH	AH	AH	NR	AH	NR	AH	AH	NR	AH	NR	AH	NR	AH	AH	AH	NR	AH	AH	AH	AH
Curtail	10.5–18[1]	10.5–18[1]	10.5B	10.5B	10.5B	1	10.5–18[1]	10.5B	10.5B	10.5–18[1]	10.5B	18	10.5B	10.5B	10.5B	10.5–18[1]	1	10.5B	10.5–18[1]	10.5B	10.5B	10.5B	18	1	10.5B	1
Dacthal	8	AH	8	8	8	8	8	8	AH	AH	8	8	AH	8	8	8	8	8	8	8	AH	NR	AH	8	8	8
Degree Xtra	SY	SY	SY	NY	SY	NR	NR[10]	SY	SY	SY	SY	SY	SY	SY	SY	NY	SY	SY	NR	NY	SY	SY	SY	SY	SY	AH
Devrinol	12	NR	12	12	12	12	12	12	12	12	12	12	NR	12	12	12	6	12	12	NR	NR	12	12	6	6	6
DiFlexx	4	4	4	2	4	NR	2	4	4	4	4	4	4	4	4	2[1]	2	4	4	4	4	4	4	2	4	2
DiFlexx Duo	10	18B	18B	10	18	NR	10	18B	18	8/ 18[27]	11	10	18B	18	10	8	4	18	4	12	10	18	10	4	4	4
Distinct[1]	1	4	4	1	4	0.25	1	4	4	4	4	4	4	4	4	1	1	4	4	4	4	4	4	1	1	1
Dual products	4	2[1]	9	NR	12	NR	NR[10]	NR	12	2[1]	NR	NR	2	2[1]	NR	NR	4.5	12	NR	NY	2[1]	12	NR	4.5	4.5	4.5
DuraCor	24B	24B	24B	24B	24B	12	24B	24B	24B	24B	24B	24B	24B	24B	24B	24B	12	24B	12	24B	24B	24B	24B	12	12	12
Elevore	9	15B	9	1	15B	0.5	0.5	15B	15B	15B	9	9	15B	15B	15B	0.5	0.5	15B	15B	15B	15B	15B	24B	0.5	0.5	0.5
Enlist Duo	NI	NS	NS	1[32]	NS	0.23–0.5[32]	NS	NS	NS	NS	NS	NS	NS	NS	NS	1[32]	NS	NS	0.2–0.5	NS	NS	NS	NS	NS	NS	NI

Table 2. Herbicide rotation restrictions for cash crops. (cont.)

Trade name	Alfalfa	Cabbage	Clover	Cotton	Cucumber	Field corn	Grain sorghum	Lima bean	Muskmelon	Onion	Peanut	Peas	Pepper	Pumpkin	Snap bean	Soybean	Spring oat	Squash	Sweet corn	Tobacco	Tomato	Watermelon	White potato	Winter barley	Winter rye	Winter wheat
Envive	10	18	12	10	18	10	12	30	30	30	8	12	30	18	12	NR	10	30	18	10[9]	12[9]	18	30	4	4	4
Eptam	NR	AH	AH	AH	AH	AH	AH	AH	AH	AH	AH	AH	AH	AH	NR	AH	AH	AH	AH	AH	AH	AH	NR	AH	AH	AH
Evik	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	3	11	11	11	11	11	10	3	3	3
Expert	SY	SY	SY	NY	SY	NR	NR[10]	SY	SY	SY	NY	SY	SY	SY	SY	NY	SY	SY	NY	SY	SY	SY	SY	NY	NY	NY
Extreme	4	18	4	18	18	8.5[8]	18	NR	18	40B	NR	NR	18[9]/ 40B	40B	2	NR	18	40B	18	9.5	18[9]/ 40B	18	26	4	4	3
Facet L	24B	10	24B	10	10	10	NR	10	10	10	10	24B	24B	10	10	10	10	10	10	24B	24B	10	24B	10	10	NR
Fierce/ Fierce EZ	10	18	18	1–2[1]	18	0.25–1[1]	18	11	18	18	4	11	18	18	11	NR	11–12[1]	18	18	12	18	18	4	11–12[1]	11–12[1]	1–2[1]
Fierce XLT[1]	18	18–30	18	18–30	18–30	10–18	18	18–30	18–30	18–30	18–30	18–30	18–30	18–30	18–30	NR	18–30	18–30	18–30	18[9]	18[9]	18–30	18–30	18	18	4
Finesse Cereal and Fallow (0.4 oz)	B	B	B	18	B	18	4–18[1]	B	B	B	B	B	B	B	B	18[14]	10	B	B	B	B	B	10	10–16[1]	0–4[1]	0–4[1]
FirstRate	9	18	18	9	18	9	9	9	18	18	9	9	18	18	9	NR	9	18	18	18[15]	18	18	18	12	18	4
Flexstar/ Flexstar GT	18	18	18	NR	12	10	18	4	12	18	10	4	10[9]/12	10	NR	NR	18	12	10	18	10[9]/12	10	NR	4	4	4
FulTime/ Keystone	15	SY	SY	NY	SY	NR	NY	SY	SY	SY	SY	15	SY	SY	SY	NY	15	SY	NR	15	SY	SY	15	15	15	15
Fusilade/ Fusion	2	2	2	NR	2	2	2	2	2	NR	NR	1	1	1	1	NR	2	2	2	2	2	2	2	2	2	2

Table 2. Herbicide rotation restrictions for cash crops. (cont.)

Trade name	Alfalfa	Cabbage	Clover	Cotton	Cucumber	Field corn	Grain sorghum	Lima bean	Muskmelon	Onion	Peanut	Peas	Pepper	Pumpkin	Snap bean	Soybean	Spring oat	Squash	Sweet corn	Tobacco	Tomato	Watermelon	White potato	Winter barley	Winter rye	Winter wheat
Glyphosate products	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	1	NR	NR	NR	NR	NR	NR
Goal/Goal Tender	2	1	2	0.25	2	10	10	1-2	2-3[1]	4[1]	2	2	1[9]	2	2	0.25	10	3	10	2	1[9]	1-2[1]	2	10	10	10
Gramoxone/paraquat	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
GrazonNext HL	24B	24B	24B	24B	24B	12	24B	24B	24B	24B	24B	24B	24B	24B	24B	24B	12	24B	12	24B	24B	24B	24B	12	12	12
Grazon P+D	B	B	B	B	B	B	8	B	B	B	B	B	B	B	B	B	8	B	B	B	B	B	B	2	2	2
Halex GT	10	18	18	10	18	NR	NR[10]	18	18	18	10	10[1]	18	18	10[1]	10	4.5	18	NR	10	18	18	10	4.5	4.5	4.5
Harmony Extra SG	1.5	1.5	1.5	0.5	1.5	0.5	0.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	0.25	1.5	1.5	1.5	1.5	1.5	1.5	1.5	NR	1.5	NR
Harmony SG	1.5	1.5	1.5	0.25	1.5	NR	NR	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	NR	NR	1.5	1.5	1.5	1.5	1.5	1.5	NR	1.5	NR
Harness	9	SY	9	NS	SY	NR	NR[10]	SY	SY	SY	NY	NS	SY	SY	NS	NS	NS	SY	NR	NS	SY	SY	NS	NS	NS	4
Harness Max	10	18	18	10	18	NR	NR[10]	18	18	18	18	18	18	18	18	10	NY	18	18	18	18	18	18	NY	NY	4
Harness Xtra	SY	SY	SY	NS	SY	NR	NS	SY	SY	SY	SY	SY	SY	SY	SY	NS	SY	SY	NR	SY	SY	SY	SY	SY	SY	SY
Hornet WDG	10.5[1]	26B	26B	18	26B	NR	12	10.5[1]	26B	26B	18	18[16]	26B	26B	18[16]	10.5	4	26B	18[16]	18	26B	26B	18	4	4	4
Huskie	4[1]	1	1	1	1	4	0.25	1	1	9[1]	1	9	1	1	9	4	1	1	1	1	1	1	9	0.25	1	0.25

Table 2. Herbicide rotation restrictions for cash crops. (cont.)

Trade name	Alfalfa	Cabbage	Clover	Cotton	Cucumber	Field corn	Grain sorghum	Lima bean	Muskmelon	Onion	Peanut	Peas	Pepper	Pumpkin	Snap bean	Soybean	Spring oat	Squash	Sweet corn	Tobacco	Tomato	Watermelon	White potato	Winter barley	Winter rye	Winter wheat
Impact Core	9	18	18	10	18	NR	9	18	18	18	10	18	18	18	18	10	9	18	NR	18	18	18	10	9	9	4
Instigate	18	18	18	10	18	NR	10	18	18	18	10	10[1]	18	18	10[1]	10	9	18	10	10	18	18	10	4	4	4
Karmex	24	24	24	NR	24	NY	NY	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24
Kerb[1]	NR	3-6	NR	3-5	3-6	12	12	3	3-6	3-6	12	3-4	3-6	3-6	3-4	3-4	12	3-6	12	12	3-6	3-6	3	12	12	12
Keystone NXT	SY	18	SY	NY	18	NR	NY	SY	18	18	SY	SY	18	18	18	NY	SY	18	NR	SY	18	18	SY	15	15	15
Laudis	10	18	18	10	18	NR	10	18	18	8[1]	11	10	18	18	10	8	4	18	NR	12	10	18	10	4	4	4
LeadOff (1.5 oz)	10	18	10[1]	1	10	NR	10	18	18	18	1.5	10	18	18	10	1[1]	9	18	10	1.5	1	18	1	3	3	3
Lexar/Lexar EZ	18	18	18	NY	18	NR	NR[10]	18	18	18	NY	18	18	18	18	NY	NY	18	NR	18	18	18	18	NY	NY	NY
Liberty	6	2.3	6	NR	6	NR	6	6	6	2.3	6	6	6	6	6	NR	2.3	6	NR	6	6	18	2.3	2.3	2.3	2.3
Lightning	9.5	40B	40B	9.5[1]	40B	8.5[8]	18	9.5	40B	40B	9.5	9.5	40B	40B	9.5	9	18	40B	18	9.5	40B	40B	26	9.5	4	4
Lorox/Linex	4	4	4	4	4	NR[1]	NR[1]	4	4	4	4	4	4	4	4	NR[1]	4	4	4	4	4	4	NR[1]	12	4	4
Lumax/Lumax EZ	18	18	18	NY	18	NR	NR[10]	18	18	18	NY	18	18	18	18	NY	NY	18	NR	18	18	18	18	4.5	4.5	4.5
Marvel	18	18	18	NR	18	10	18	18	18	18	10	10	4[9]	18	NR	NR	4	18	18	18	4[9]	18	NR	4	4	4
Matrix	4	12	18	10	10	NR	18	10	18	10	18	8	12	12	10	4	9	18	10	18	NR	12	NR	12	12	4
Metribuzin products	4	18	18	18	18	4	18	18	18	18	18	8	18	18	18	4	18	18	4	18	4	18	12	4[1]	18	4[1]

Table 2. Herbicide rotation restrictions for cash crops. (cont.)

Trade name	Alfalfa	Cabbage	Clover	Cotton	Cucumber	Field corn	Grain sorghum	Lima bean	Muskmelon	Onion	Peanut	Peas	Pepper	Pumpkin	Snap bean	Soybean	Spring oat	Squash	Sweet corn	Tobacco	Tomato	Watermelon	White potato	Winter barley	Winter rye	Winter wheat
Milestone	24B	24B	24B	24B	24B	12	24B	24B	24B	24B	24B	24B	24B	24B	24B	24B	12	24B	24B	24B	24B	24B	24B	12	12	12
Optill[1]	4	40B	4	18	18	8.5[8]	18	4	40B	40B	4	4	18	40B	4	0-1	18	40B	18	9.5	18	40B	26	9.5	4-18	4[8]
Osprey	10	10	10	3	10	3	3	10	10	10	3	3	10	10	10	3	10	10	10	10	10	10	10	1	10	0.25
Outlook[1]	4-6	6-9	6-9	4	6-9	NR	NR[10]	6-9	6-9	6-9	NR	4	6-9	6-9	6-9	NR	4	6-9	NR	6-9	6-9	6-9	6-9	4	4	4
Outrider	3B	3B	3B	3B	3B	3B	3B	3B	3B	3B	3B	3B	3B	3B	3B	3B	3B	3B	3B	3B	3B	3B	3B	3B	3B	NR
Overdrive	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Pasture-Gard HL	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	4	NI	NI	NI	NI	NI	NI	4	NI	4
Peak (0.25 oz)[1]	22	22	22	10	22	1[8]	1	22	22	22	10	10	22	22	10	10	NR	22	10	10	22	22	22	NR	NR	NR
Permit	9	15	9	4	2	1[8]	2	NI	9	18	6	9	10	9	2	9[1]	2	9	3	36	2	9	9	2	2	2
Permit Plus	9	15	9	4	2	1	2	NI	9	18	6	9	10	9	2	9[1,14]	2	9	3	36	2[9]	9	9	2	2	2
Perpetuo	10	18	18	2-4	18	NR	6-8[1]	11	18	18	2-4[1]	9-11[1]	18	18	11	NR	18	18	8	18	18	18	4	18	18	1-4
Poast	NR	NR	NR	NR	NR	30	30	NR	NR	NR	NR	NR	NR	NR	NR	NR	30	NR	30[7]	NR	NR	NR	NR	30	30	30
PowerFlex HL	9	12	12	3[1]	12	9	9	12	12	12	9	9	12	12	12	3[1]	9	12	9	12	12	12	9	9	12	1
Prefar[1]	4	NR	4	4	NR	4	4	4	NR	NR	4	4	NR	NR	4	4	4	NR	4	4	NR	NR	4	4	4	4
Prefix	18	18	18	1	12	10	18	4	12	18	4	4	10[9]	10	NR	NR	4.5	12	10	18	10[9]	10	1	4.5	4.5	4.5
Princep 4L	SY	SY	SY	NY	SY	NR	NY	SY	SY	SY	NY	SY	SY	SY	SY	NY[17]	SY	SY	NY	SY	SY	SY	SY	NY	NY	NY

Table 2. Herbicide rotation restrictions for cash crops. (cont.)

Trade name	Alfalfa	Cabbage	Clover	Cotton	Cucumber	Field corn	Grain sorghum	Lima bean	Muskmelon	Onion	Peanut	Peas	Pepper	Pumpkin	Snap bean	Soybean	Spring oat	Squash	Sweet corn	Tobacco	Tomato	Watermelon	White potato	Winter barley	Winter rye	Winter wheat
Prowl H2O	6[1]	NY	NY	NR	NY	NR[18]	NY	NR	NR	NY	NR	NR	NR[1]	NY	NR	NR	NY	NR	NR[18]	NR[1]	NR[1]	NR	NR[1]	4[1]	NY	4[1]
Pursuit[1]	4	18	4	18[19]	18	8.5[8]	18	NR	18	18	NR	NR	18[9]	40B	2	NR	18	40B	18	9.5	18[9]	18	18[1]	4[1]	4	4
Python	4	26B	26B	18	26B	NR	12	4	26B	26B	4	4	26B	26B	4[1]	NR	4	26B	18[1]	9	26B	26B	12	4	4	4
Raptor	3	9	18	9	9	8.5[8]	9	NR	9	9	9	NR	9	9	NR	NR	9	9	8.5	9	9	9	9[1]	9[1]	4	3
Realm Q	10	18	18[1]	10	18	NR	10	18	18	18	10	10[1]	18	18	10[1]	10	9	18	10	10	18	18	10	4	4	4
Reflex	18	18	18	NR	12	10	18	4	12	18	4	4	10[9]	10	NR	NR	4	12	10	18	10[9]	10	NR	4	4	4
Remedy Ultra[30]	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI
Resicore	10.5[28]	18	18	12	18	NR[28]	10.5[28]	18	18	18	18	18	18	18	18	10.5[28]	10.5[28]	18	10.5	18	18	18	18	10.5[28]	10.5[28]	4
Resolve SG (1 oz)	10	18	10[1]	10	10	NR	10	18	18	18	18	10	18	18	10	10[14]	9	18	10	18	1	18	NR	18	18	3
Resolve Q (1.25 oz)	10	18	10[1]	1	10	NR	10	18	18	18	1.5	10	18	18	10	2[1]	9	18	10	1.5	1	18	NR	3	3	3
Resource	1	1	1	1	1	NR	1	1	1	1	1	1	1	1	1	NR	1	1	1	1	1	1	1	1	1	1
Revulin Q	10[1]	18	18	10	18	NR	10[1]	18	18	18	18	18	18	18	18	10	8	18	10[20]	18	18	18	10[1]	4	4	4
Ro-Neet	AH	AH	AH	AH	AH	AH	AH	AH	AH	AH	AH	AH	AH	AH	AH	AH	AH	AH	AH	AH	AH	AH	AH	AH	AH	AH
Sandea	9	15	9	4	2	1[8]	2	36	9	18	6	9	10	9	2	9[1]	2	9	3	36	2	9	9	2	2	2
Scepter[1]	18	18	18	18	18	9.5[13]	11	11	18	18	11	18	18	18	11	NR	11	18	18	9.5	18	18	18	11	18	3
Select/Select Max	NR	NR	NR	NR	NR	0.2	1	NR	NR	NR	NR	NR	NR	NR	NR	NR	1	NR	1	1	NR	NR	NR	1	1	1

Table 2. Herbicide rotation restrictions for cash crops. (cont.)

Trade name	Alfalfa	Cabbage	Clover	Cotton	Cucumber	Field corn	Grain sorghum	Lima bean	Muskmelon	Onion	Peanut	Peas	Pepper	Pumpkin	Snap bean	Soybean	Spring oat	Squash	Sweet corn	Tobacco	Tomato	Watermelon	White potato	Winter barley	Winter rye	Winter wheat
Sentrallas	4	4	4	4	4	NR	NR	4	4	4	4	4	4	4	4	4[1]	NR	4	4	4	4	4	4	NR	4	NR
Sequence	4	NY	9	NR	NI	NR	NR	NR	NI	NI	NI	NR	NY	NI	NR	NR	4.5	NI	NI	NY	61	NI	NY	4.5	4.5	4.5
Sharpen (1 oz)[1]	4	4	4	1.5	4	NR	NR	4	4	4	4	NR	4	4	4	0-1	NR	4	0.5	4	4	4	4	NR	NR	NR
Shieldex	9	9	12	9	9	NR	9	12	9	12	9	9	12	9	9	9	3	9	NR	12	9	9	9	3	3	3
Sierra[1]	24	24	24	24	24	11	24	24	24	24	24	11	24	24	24	9[14]	24	24	24	24	24	24	9	9	24	NR
Sinate	9	18	18	9	18	NR	9	18	18	18	9	9-18[1]	18	18	9-18[1]	9	3	18	NR	18	18	18	9	3	3	3
Sinbar	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24
Solicam	16	24B	24B	1-16[1]	24B	24B	24B	24B	24B	24B	1-16[1]	24B	24B	24B	24B	1.5-16[1]	24B	24B	24B	24B	24B	24B	24B	24B	24B	24B
Sonalan	AH	AH	AH	AH	AH	AH	AH	AH	AH	AH	NR	AH	AH	AH	AH	NR	AH	AH	AH	AH	AH	AH	AH	AH	AH	AH
Spartan	12	NR	12B	18	12B	10	10[1]	NR	12B	12B	12B	12B	12B	12B	12B	NR	12	12B	18	NR	NR[9]	12B	12B	4	4	4
Spartan Charge	12	NR[9]	12B	12-18[1]	12B	4	10[1]	12B[1]	12B	12B	NR	12B	12B	12B	12B	NR	12	12B	12	NR	NR[9]	12B	4	4	4	4
Spin-Aid	AH	AH	AH	AH	AH	AH	AH	AH	AH	AH	AH	AH	AH	AH	AH	AH	4	AH	AH	AH	AH	AH	AH	4	4	4
Spirit	18	10	18	10	18	1[8]	10	18	18	18	18	10	18	18	10	10	3	18	8	10	10	18	10	3	3	3
Spur	10.5	NR	10.5B	10.5-18B	10.5-18B	NR	10.5	10.5B	10.5-18B	10.5	10.5B	18B	10.5B	10.5-18B	10.5B	10.5-18	NR	10.5B	NR	10.5B	10.5B	10.5-18B	18B	NR	10.5B	NR
Starane Ultra	4	4	4	4	4	NR	NR	4	4	4	4	4	4	4	4	4[31]	NR	4	NR	4	4	4	4	NR	NR	NR
Status	1[5]	4	4	1[5]	4	0.25	1[5]	4	4	4	4	4	4	4	4	1[5]	1[5]	4	4	4	4	4	4	1[5]	1[5]	1[5]

Table 2. Herbicide rotation restrictions for cash crops. (cont.)

Trade name	Alfalfa	Cabbage	Clover	Cotton	Cucumber	Field corn	Grain sorghum	Lima bean	Muskmelon	Onion	Peanut	Peas	Pepper	Pumpkin	Snap bean	Soybean	Spring oat	Squash	Sweet corn	Tobacco	Tomato	Watermelon	White potato	Winter barley	Winter rye	Winter wheat
Steadfast Q	10[1]	18	10[1]	10	10-18	NR	10-18	10-18	10-18	10-18	10-18	10	10-18	10-18	10	0.5	8	10-18	10[20]	10-18	10-18	10-18	10[1]	4	4	4
Stinger	10.5	NR	18	18B	18B	NR	10.5	18B	18B	10.5	18B	18B	18B	18B	18B	10.5[1]	NR	18B	NR	18B	18B	18B	18B	NR	NR	NR
Storm	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	NR	3.3	3.3	3.3	3.3	NR	1.5	3.3	3.3	3.3	3.3	3.3	3.3	1.5	1.5	1.5
Stout	10[1]	18	10[1]	10	18	NR	10	18	18	18	18	10	18	18	10	0.5	8	18	10[20]	18	18	18	10[1]	4	4	4
SureStart/ Triple FLEX	NY[1]	26B	NY[1]	26B	26B	NR	12	26B	26B	26B	26B	NY	26B	26B	26B	NY[1]	NY	26B	18[1]	18	26B	26B	18	NY	NY	4
Surpass NXT	9	NI	9	NY	NI	NR	NR[10]	NY	NI	NI	NI	NY	NI	NI	NY	NY	NY	NI	NR	NY	NY	NI	NY	NY	NY	4
Surveil	10	30B	30B	9	30B	9	9	9	30B	30B	9	9	30B	30B	9	NR	9	30B	18	10[21]	30B	30B	18	30B	30B	3
Synchrony XP[1]	12	18	12	9	18	9	9	30	30	30	15	9	30	18	9	NR	3	30	18	9[9]	9[9]	18	30	3	3	3
Targa	4	4	4	NR	4	4	4	4	4	4	4	NR	4	4	NR	NR	4	4	4	4	4	4	4	NR	4	NR
Tavium	6	6	9	1.4[1]	12	4	6	6	12	6	6	6	6	6	6	1[1]	4.5	12	4	NY	6	12	6	4.5	4.5	4.5
Treflan	NR	NR	5	NR	5	12-14[33]	12- 14	NR	5	5	NR	NR	NR[9]	5	NR	NR	12-14[33]	5	12-14[33]	5	NR	5	NR	NR	NR	NR
Trivence	10	18	18	18	18	10[1]	18	30	30	30	18	12	30	18	30	NR	18	30	18	18[9]	12[9]	18	30	4	30	4
Ultra Blaz-er	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	NR	3.3	3.3	3.3	3.3	NR	1.3	3.3	3.3	3.3	3.3	3.3	3.3	1.3	1.3	1.3
Valor SX/ Valor EZ (up to 3 oz)	5[11]	6-12B	5[11]	2[11]	6-12B	0.5-1[1]	1	6-12B	6-12B	6-12B	NR	4	6-12B	6-12B	4	NR	5[11]	12	4	2[11]	6-12B	6-12B	5[11]	4	4	2[11]
Valor XLT[22]	12	18	12	10	18	10	10	18	18	18	18	12	18	18	12	NR	18	18	18	10[9]	12-18[9]	18[1]	18	4	4	4

Table 2. Herbicide rotation restrictions for cash crops. (cont.)

Trade name	Alfalfa	Cabbage	Clover	Cotton	Cucumber	Field corn	Grain sorghum	Lima bean	Muskmelon	Onion	Peanut	Peas	Pepper	Pumpkin	Snap bean	Soybean	Spring oat	Squash	Sweet corn	Tobacco	Tomato	Watermelon	White potato	Winter barley	Winter rye	Winter wheat
Varisto	3	9	18	9	9	8.5[29]	9	NR	9	9	9	NR	9	9	NR	NR	9	9	8.5	9	9	9	9[29]	9[29]	4	3[29]
Verdict	7	7	7	6	7	NR	NR	7	7	7	7	4	7	7	7	NR	4	7	NR	7	7	7	7	4	4	4
Vida	1	1 day	1	NR	1 day	NR	1 day	1 day	1 day	1 day	1	1 day	1 day	1 day	1 day	NR	1 day	1 day	1	1	1 day	1 day	NR	1 day	1 day	NR
Warrant	9	NI	9	NR	NI	NR	NR[10]	NY	NI	NI	NR	SY	NI	NI	NY	NR	NY	NI	NY	NY	NI	NI	NY	NY	NY	4
Warrant Ultra	18	NI	18	1	NI	10	18	NY	NI	NI	10	10	NI	NI	NY	NR	4	NI	10	NI	NI	NI	NI	4	4	4
XtendiMax[1]	4	4	4	1[1]	4	NR	0.5[1]	4	4	4	4	4	4	4	4	1	1	4	4	4	4	4	4	1	1	1
Yukon	9	15	9	4	9	1[8]	2	NI	9	18	6	9	10	9	2	9[1]	2	9	3	NI	2[9]	9	9	2	2	2
Zeus XC	12	NR[9]	12B	18	12B	10	10[1]	12B	12B	12B	4	12B	12B	12B	12B	NR	12	12B	18	NR	NR[9]	12B	12B	4	4	4
Zidua/ Zidua SC (3 oz or 5 fl oz)[1]	10	18	18	4	18	NR	10	11	18	18	4	11	18	18	11	NR	11	18	NR	18	18	18	4	11	11	4
Zone Defense	12	4[34]	4[34]	18	12	10	10	4[34]	4[34]	12	NR	4[34]	12	12	12	NR	12	12	18	1	4[9,34]	4[34]	4[34]	4	4	4

[1] Read the label for additional restrictions due to application rate, timing, geographical region, rainfall, soil pH, tillage, variety, or supplemental labeling.

[2] Eighteen months with a soil pH > 6.5. At rates greater than 2.1 oz/A, a rotation interval of 30 months and a successful field bioassay are required.

[3] Rotation interval for lima bean is 18 months if Armezon PRO is applied at greater than 20 fl oz/A. Rotation interval for pea and snap bean is extended to 18 months if Armezon PRO is applied at greater than 25 fl oz/A.

[4] Cotton can be planted after 12 months where Authority Elite/BroadAxe was applied at rates less than 36 oz/A, Authority MTZ DF at rates less than 17 oz/A, or Authority First/Sonic at rates less than 5 oz/A and the following conditions are met: medium and fine soils, pH < 7.2, and rainfall or irrigation must exceed 15 inches after herbicide application and prior to planting cotton.

[5] Following application of Clarity and a minimum of 1 inch of rainfall or overhead irrigation, a waiting interval of 21 days is required per 8 fl oz/A applied prior to planting cotton, 30 days per pint restriction for soybean, and 20 days per pint restriction for small grains. If less than 1 inch of rainfall or irrigation is received after

application and Status is applied at greater than 5 oz/A, the rotation interval is 4 months.

[6] If Basis rate is 0.33-0.5 oz/A or Basis Blend rate is 1.25 oz/A, alfalfa, sorghum, pea = 18 months; soybean, snap bean = 10 months; STS soybean = 1 month; spring oat = 9 months. If Basis rate is greater than 0.5 oz/A or Basis Blend rate is 2.5oz/A, cotton = 10 months and 18 months if less than 15 inches of rainfall or irrigation occur after application and before the rotational crop is planted. STS soybean = 4 months. If Basis rate is 0.33 oz/A or Basis Blend rate is 0.825, soybean = 0.5 month.

[7] NR for Poast Protected corn hybrids.

[8] NR for IMI (IR/IT) or Clearfield (CL) varieties.

[9] Transplanted.

[10] Use safener with seed.

[11] Cotton may be planted no-till or strip-till after 14 or 21 days when applied at 1 oz/A or 1.5-2 oz/A, respectively. For winter wheat, at rates up to 2 oz/A, the rotation interval is 7 days for no-till or minimum-till wheat and 30 days for conventional-till wheat. At least 1 inch of rainfall/irrigation must occur between application and cotton, field corn, grain sorghum, tobacco, or wheat planting, or crop injury may occur. For alfalfa, clover, potato, and spring oats, the rotation interval is 5 months if the soil is tilled prior to planting or 10 months if no tillage is preformed prior to planting. At lower rates of Valor/Rowel/Chateau, rotation interval for many crops is reduced. Chateau may be applied to potato following hilling at a rate of 1.5 oz/A. Consult labels for more specific information.

[12] Command may be applied preemergence to cotton only if Di-Syston or Thimet insecticides are applied in furrow with the seed at planting.

[13] Corn hybrids that are classified as IMI-corn or as tolerant (IT) or resistant (IR) may be planted in the spring of the year following regardless of rainfall or time interval from chemical treatment to corn planting. Rotation interval varies by tillage type and use rate. Consult the label for specific rotation intervals.

[14] Rotation interval is shorter for STS soybean.

[15] Transplanted tobacco = 10 months if ≤0.3 oz/A.

[16] If Hornet WDG rate is <4 oz/A, snap beans, peas, and some varieties of sweet corn = 10.5 months.

[17] If no more than 2 lb ai applied the previous year.

[18] Regardless of tillage, be sure to plant corn at least 1.5 inches deep and completely cover with soil.

[19] Cotton may be planted 9.5 months following Pursuit if all of the following criteria are met: Pursuit is applied to peanuts only, soil texture is sandy loam or loamy sand only, and greater than 16 inches of rainfall/irrigation is received following application of Pursuit through October of the application year.

[20] The rotation interval for the sweet corn varieties 'Merit', 'Carnival', and 'Sweet Success' is 15 months.

[21] Transplanted tobacco may be planted 10 months after application of 2.1 oz/A of Surveil. Tobacco in seeded nurseries may be planted 18 months after application of 2.1 oz/A of Surveil and following a successful field bioassay. At rates greater than 2.1 oz/A, a rotation interval of 30 months and a successful field bioassay are required.

[22] Rotation intervals based on soil pH < 7.0. In Pennsylvania, rotation interval for clover, lima bean, muskmelon, onion, pepper, spring oat, squash, and white potato is 18, 30, 30, 30, 30, 30, 30, and 30 months, respectively. Consult seed corn agronomist regarding inbred sensitivity to Valor XLT/Rowel FX prior to planting inbred seed corn lines.

[23] If applied after June 1, rotating to crops other than corn (all types) may result in crop injury.

[24] For BOLT or non-BOLT soybean and minimum- or no-till field corn, if Afforia is used on coarse-textured soils such as sands and loamy sands, or on high-pH soils (>7.9), extend time to planting by 7 additional days. For minimum- or no-till wheat in the states of Delaware, Maryland, New Jersey, or Virginia, Afforia may be applied at a minimum of 7 days before planting. Do not use on Durum wheat and do not irrigate between emergence and spike. Wheat must be planted at least 1 inch deep. Do no graze until wheat has reached 5 inches in height. For conventional-till field corn, grain sorghum, cotton, and wheat, at least 1 inch of rainfall/irrigation must occur between application and planting, or crop injury may occur. For alfalfa, cabbage, clover, cucumber, lima bean, muskmelon, onion, pepper, pumpkin, spring oat, squash, sweet corn, tobacco, tomato, watermelon, and white potato, the rotation interval is 4 months if the soil is tilled prior to planting. If no tillage is performed prior to planting these crops, the rotation interval is extended to 8 months.

[25] Rotation interval for spring oat or winter barley at 5.7 oz/A or greater rates is extended to 18 months. For winter wheat, at 5.7 oz/A or greater rates the rotation interval is extended to 6 months.

[26] Seed corn inbred lines vary in sensitivity to herbicides; therefore, users should seek advice from a seed corn agronomist regarding inbred sensitivity to Canopy Blend prior to planting inbred seed corn.

[27] For onion, the rotation interval for irrigated and nonirrigated is 8 and 18 months, respectively.

[28] For corn, if the original corn crop is lost, do not make a second application. Injury may occur to soybean planted the year following application on soils having a calcareous subsurface layer if products containing atrazine were used at rates greater than 0.75 lb/ai atrazine/A in tank mixtures and/or sequentially with Resicore. If Resicore is applied after June 1, rotating to crops other than corn or grain sorghum the next spring may result in crop injury.

[29] NR for Clearfield corn (field and seed). For wheat, planting non-Clearfield cultivars in areas receiving less than 10 inches of precipitation from time of application up until wheat planting may result in wheat injury. Injury potential increases if less than normal precipitation occurs in the 2 months just after Varisto application. For barley, the rotation interval at pH > 6.2 and >18 inches of rainfall/irrigation is 9 months, at pH < 6.2 and <18 inches of rainfall/irrigation and with moldboard plowing the rotation interval is 9 months, and at pH < 6.2 and < 18 inches rainfall/irrigation and without moldboard plowing the rotation interval is 18 months. For potato, the rotation interval at pH > 6.2 and >18 inches of rainfall/irrigation is 9 months and 18 months at pH < 6.2 and <18 inches of rainfall/irrigation.

[30] Rotation information is unknown for this product. Contact manufacturer for recommendations.

[31] In Delaware and Virginia, a Special Local Needs Label 24(c) has approved a 3-month plant-back restriction for soybean after an application to winter wheat.

[32] NR for Enlist varieties.

[33] In areas receiving 20 inches of rainfall or irrigation, 12 months after a spring application or 14 months after a fall application of Treflan 4L or 4EC. Labeled for these crops or after crop plants have emerged.

[34] Rotation is 8 months in no-till.

Herbicide-Resistant Crops

Herbicide-resistant crops are available for use in crop production systems. Corn, soybean, sorghum, alfalfa, and canola varieties are currently the key agronomic crops with herbicide resistance that can be grown in the Northeast. Herbicide resistance in crops results from two different procedures: tolerance selection and genetic engineering techniques. Tolerance selection involves selecting naturally occurring herbicide-tolerant cells from a particular crop cultivar or cell culture and incorporating them into crop varieties and hybrids using traditional breeding techniques. Genetically engineering herbicide-resistant plants (also called a GMO) involves transferring a gene with a certain trait from one organism to another (e.g., from bacteria to plant) using complex technology. The transferred genetic trait or traits are then incorporated into crop varieties using breeding techniques. (The same genetic engineering technology is used to create crop protection to insect pests [e.g., Bt corn].) Several crop protection chemical companies and seed companies are involved in developing and marketing these crops. Following is a brief summary of the herbicide-resistant crop varieties currently available or soon to be released..

Clearfield (CL) corn is non-GMO that was developed by tolerance selection to be resistant to imidazolinone herbicides (e.g., Pursuit, Scepter). Although these hybrids were initially introduced to help manage herbicide carryover, Pursuit and Pursuit-containing products such as Lightning can be applied directly to the CL corn hybrids as part of the weed management program.

Enlist corn, cotton, and soybean are genetically engineered to resist 2,4-D. In addition to 2,4-D resistance, Enlist corn is resistant to the aryoxyphenoxy-propionate herbicides (FOPs), such as Assure II (quizalofop). Enlist corn and soybean are also stacked with Roundup Ready and LibertyLink traits. A new low-volatility 2,4-D formulation (2,4-D choline or Colex-D) has been developed for use with this technology and is available as Enlist One (2,4-D) and Enlist Duo (2,4-D + glyphosate).

Inzen Z herbicide-tolerant sorghum is a non-GMO trait that provides tolerance to certain Group 2 or ALS-inhibitor herbicides. Zest WDG (nicosulfuron) from Corteva is the product that is co-marketed with Inzen Z sorghum.

LibertyLink (LL) corn and soybean are genetically engineered (GMOs) to allow over-the-top applications of Liberty (glufosinate) herbicide. This program provides broad-spectrum control of annual broadleaves and grasses of low-to-moderate pressure. Sequential applications or tank mixtures may be required for new weed flushes and perennials.

Roundup Ready alfalfa, corn, cotton, canola, and soybean were developed using genetic engineering techniques. They have an altered target site not sensitive to glyphosate and allow postemergence applications of glyphosate directly to alfalfa, corn, canola, and soybean. Glyphosate-resistant weeds are a major and growing issue in Roundup Ready crops.

LibertyLink GT27 soybeans are genetically engineered to resist glyphosate, Liberty (glufosinate), and isoxaflutoe (Alite 27). However, Alite 27 is not registered in the mid-Atlantic region.

The STS and BOLT soybean/herbicide systems enhance crop safety from certain sulfonylurea herbicides such as Harmony (thifensulfuron) and Classic (chlorimuron). STS is a non-GMO, but BOLT also includes the GMO glyphosate-resistant trait. Although these varieties were developed to be used in combination with STS-labeled herbicides, they also provide greater safety from many of the ALS (Group 2) herbicides. The BOLT herbicide-resistance trait provides enhanced resistance to additional herbicides such as Basis Blend (rimsulfuron).

Xtend soybean were introduced for the first time in 2017. These soybean are genetically engineered to allow preemergence and over-the-top application of dicamba. Xtend soybean are also Roundup Ready. Three different dicamba products (Engenia, XtendiMax, and Tavium specially formulated for reduced drift are labeled for Xtend soybean. All other dicamba products are not allowed. In addition, a number of stewardship guidelines are required, including using low-drift nozzles, at least 15 GPA carrier, and making applications only when certain environmental conditions exist to reduce the potential for off-site movement. In the Mid-Atlantic region, this technology is best suited for burndown application in no-till for control of winter annual weeds, including horseweed/marestail. Over-the-top application and use in double-crop soybean is not encouraged due to greater concern for off-target movement.

Xtendflex cotton and soybean allow three herbicides to be used over-the-top: dicamba, Liberty (glufosinate), and glyphosate. Three different dicamba products (Engenia, XtendiMax, and Tavium specially formulated for reduced drift are labeled for Xtendflex crops. All other dicamba products are not allowed. Application, stewardship, and other recommendations made in Xtend soybean apply to Xtendflex crops.

Herbicide-Resistant Weeds

A number of weed species that once were susceptible to and easily managed by certain herbicides have developed resistance. These weeds are no longer controlled by applications of previously effective herbicides. As a result of repeated use of a certain type of herbicide on the same land, many different species of weeds have developed resistance to these chemicals. Globally, resistance has developed in all herbicide modes of action in about 262 weed species, and the number of species continues to increase each year. (**More information about herbicide-resistant weeds and herbicide modes of action can be found at weedscience.org.**) It is believed that within any population of weeds, a few plants have sufficient tolerance to survive any herbicide that is used. Since only the survivors can produce seed, it is only a matter of time until the population of resistant weeds (or biotypes) outnumbers the susceptible type.

Depending on the herbicide family and weed species, resistance can occur within five to 20 years. Reasons or mechanisms for resistance vary depending on the herbicide family. Resistant biotypes may have slight structural or biochemical differences at the cellular level from their susceptible counterparts that make them less sensitive to certain herbicides, and therefore they are not killed. Regardless of the mechanism for resistance, becoming familiar with the herbicide mode of action can help when designing programs that prevent the introduction and spread of herbicide-resistant weeds.

Growers, consultants, and those working with herbicides to manage weeds should know which herbicides are best suited to combat specific resistant weeds. The Weed Science Society of America developed a grouping system to help with this process. Herbicides that are classified as the same WSSA group number kill weeds using the same site of action. Therefore, choose a combination of different herbicide sites of action that each contribute to the control of the target weeds. In other words, make sure to have at least two unique sites of action that are effective against the same weed during the season whether in tank mixtures or sequential applications. Tank mixing multiple, effective sites of action is better than sequential applications/rotation of sites of action. Try to avoid using the same products and herbicide sites of action every year. This practice is especially important on weeds that are typically prone to resistance, such as pigweed species, common lambsquarters and common ragweed, horseweed, and foxtail species (**table 3, page 212**).

WSSA group numbers can be found on many herbicide product labels and used as a tool to choose herbicides in different mode of action groups so mixtures or rotations of active ingredients can be planned to manage weeds and resistant species better. Keep in mind that many products contain similar active ingredients even though the products may have different trade or brand names. Using a different product or brand does not guarantee that you are selecting a different herbicide site of action. Refer to **table 1 (page 175)** for herbicide – or WSSA – site of action group numbers and corresponding herbicides. Other resources, such as university pest guides or recommendations, can provide effectiveness ratings of numerous herbicides on many different weed species to help with this process of developing appropriate weed management programs.

Table 3. Weed species prone to resistance and of concern in the Mid-Atlantic region.

	WSSA site of action number (see table 1, page 175)															
	1	2	3	4	5	6	7	8	9	10	11	13	14	15	22	27
Broadleaf species																
Amaranth, palmer		MA	W	W	W				MA				W	W		W
Chickweed, common		MA		W	W											
Horseweed/marestail		MA			W		W		MA						MA	
Lambsquarters, common		W			MA				W							
Pigweed, redroot/ smooth		MA			MA	W	W		W				W			
Ragweed, common		MA			W		W		MA				MA			
Ragweed, giant		W							W							
Waterhemp		W		W	W				W				W			W
Grass species																
Barnyardgrass	W	W	W	W	MA		W	W	W			W		W		
Foxtail, giant	W	MA			MA											
Goosegrass	W	W	W		W				W				MA		W	
Johnsongrass	MA	MA	W						W							
Ryegrass, Italian	MA	MA					W		W	W	W			W	W	
Shattercane		MA														

MA (orange)	Species confirmed to be resistant to a particular site of action in the Mid-Atlantic U.S.
W (maroon)	Species confirmed to be resistant to a particular site of action worldwide.

Dependence on a single strategy or herbicide site of action for managing weeds will increase the likelihood of additional herbicide resistance problems in the future. Management programs to combat herbicide resistance should emphasize an integrated approach. Some management guidelines for an integrated approach include using herbicide tank mixtures containing more than one effective site of action that are active on similar weeds, shorter residual herbicides, crop rotations that allow for application of different herbicide classes, judicious and noncontinuous use of herbicide-resistant crops in a rotation, nonchemical control measures, and combinations of weed management techniques, such as avoiding spreading resistant weed seed with machinery or in manure, and ensiling to help destroy weed-seed-infested forage.

Reducing the risk for developing herbicide-resistant weed populations requires incorporating a number of guidelines in managing fields, including:

- Spray only when necessary.
- Use alternative methods of control whenever possible, such as mechanical cultivation or delayed planting (row crops), mowing (forage crops), and using weed-free crop seeds.
- Rotate crops and their accompanying herbicides' site of action.
- Limit number of applications of herbicide(s) with same site of action in a given growing season.
- Use mixtures or sequential herbicide treatments having different sites of action that will control the weeds of concern.
- Scout fields after herbicide application to detect weed escapes or shifts.
- Clean equipment before leaving fields infested with or suspected to have resistant weeds.

Virginia Cooperative Extension
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Part XIV.

Nutritional Composition of Feeds

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For ration formulation, an accurate and precise description of the nutritional composition of feeds is needed. Feed composition varies greatly by plant species, stage of growth, and environmental conditions. Therefore, a good sampling technique and an actual feed analysis is recommended beyond the use of a feed library. This is particularly important for forages.

This chapter describes the main nutritional constituents of the feeds most commonly used in Virginia **(table 1, page 217)**. Terms used in the table heading are defined on below.

Definitions of Terms

ADF (% DM) – Acid detergent fiber concentration as a percentage of dry matter.

ADICP (% CP) – (Acid detergent.) Insoluble crude protein concentration as a percentage of crude protein.

ADL (% DM) – Acid detergent lignin concentration as a percentage of dry matter.

Ash (% DM) – Ash concentration as a percentage of dry matter.

CP (% DM) – Crude protein concentration as a percentage of dry matter.

DM (% AF) – Dry matter concentration as a percentage of as-fed.

Fat (% DM) – Fat concentration as a percentage of dry matter.

ME (Mcal/lb) – Metabolizable energy in megacalories per pound of dry matter.

NDF (% DM) – Neutral detergent fiber concentration as a percentage of dry matter.

NE_m (Mcal/lb) – Net energy for maintenance in megacalories per pound of dry matter.

NEg (Mcal/lb) – Net energy for gain in megacalories per pound of dry matter.

NEl (Mcal/lb) – Net energy for lactation in megacalories per pound of dry matter.

RDP (% CP) – Rumen degradable protein concentration as a percentage of crude protein.

RUP (% CP) – Rumen undegradable protein concentration as a percentage of crude protein.

Soluble CP (% CP) – Soluble crude protein concentration as a percentage of crude protein.

Starch (% DM) – Starch concentration as a percentage of dry matter.

Sugar (% DM) – Sugar concentration as a percentage of dry matter.

TDN (% DM) – Total digestible nutrients as a percentage of dry matter.

Table 1. Nutritional composition of feeds.

Feed	DM (% AF)	Ash (% DM)	TDN (% DM)	ME (Mcal/lb)	NE_m (Mcal/lb)	NE_g (Mcal/lb)	NE_l (Mcal/lb)	CP (% DM)	RDP (% CP)	RUP (% CP)	Soluble CP (% CP)	ADICP (% CP)	Fat (% DM)	NDF (% DM)	ADF (% DM)	ADL (% DM)	Starch (% DM)	Sugar (% DM)
Alfalfa, fresh	30.7	6.2	63.0	1.04	0.64	0.38	0.64	23.1	–	–	–	8.7	1.5	37.9	31.4	–	–	–
Alfalfa, haylage	41.0	12.1	63.0	1.04	0.64	0.37	0.64	20.1	–	–	25.2	13.7	2.0	42.5	36.1	6.4	1.9	1.9
Alfalfa, hay	87.0	11.9	55.2	0.90	0.52	0.27	0.52	19.8	–	–	25.2	12.2	1.6	41.7	33.3	6.8	3.0	8.7
Alfalfa, cubes	91.0	12.0	56.0	0.92	0.54	0.28	0.54	18.1	68.8	31.0	39.3	8.2	2.1	45.5	35.4	7.6	1.4	–
Almond, hulls	89.2	8.3	59.1	0.97	0.58	0.32	0.58	5.5	53.1	46.9	40.9	11.5	2.8	39.0	32.7	11.1	2.5	15.1
Bakery co-products	88.9	4.1	91.9	1.51	1.04	0.72	1.04	13.1	66.4	33.4	23.2	5.7	10.0	13.9	7.4	2.0	37.6	6.3
Barley, dry grain	89.7	2.8	84.1	1.38	0.94	0.64	0.94	12.8	49.1	50.8	27.6	2.2	2.2	18.3	7.1	1.8	56.7	10.7
Barley, steam-flaked grain	81.1	2.9	84.0	1.38	0.94	0.64	0.94	12.5	–	–	–	–	2.1	26.3	8.4	–	59.3	–
Barley, silage	33.6	8.7	60.6	1.00	0.60	0.34	0.60	12.1	79.1	20.8	65.3	4.9	3.5	54.8	34.7	4.8	9.2	–
Barley, hay	88.0	8.4	60.2	0.99	0.60	0.34	0.60	11.0	67.1	32.8	44.7	4.1	2.4	56.9	33.9	4.3	5.7	–
Barley, straw	85.1	12.1	48.3	0.80	0.41	0.16	0.41	6.1	–	–	–	0.6	1.0	71.6	50.1	5.2	–	–
Beet pulp, dry	91.5	6.8	66.6	1.10	0.69	0.42	0.69	9.1	46.7	53.2	21.9	7.0	1.1	41.3	26.4	3.9	0.9	8.6
Bermudagrass, fresh	34.9	8.6	57.3	0.94	0.55	0.30	0.55	15.2	67.5	32.4	42.4	6.3	2.8	66.6	36.1	5.0	1.8	–
Bermudagrass, silage	39.0	8.7	55.4	0.91	0.52	0.27	0.52	13.5	70.3	29.7	53.6	8.0	3.2	66.6	40.3	6.4	2.6	–

Table 1. Nutritional composition of feeds. (cont.)

Feed	DM (% AF)	Ash (% DM)	TDN (% DM)	ME (Mcal/lb)	NE_m (Mcal/lb)	NE_g (Mcal/lb)	NE_l (Mcal/lb)	CP (% DM)	RDP (% CP)	RUP (% CP)	Soluble CP (% CP)	ADICP (% CP)	Fat (% DM)	NDF (% DM)	ADF (% DM)	ADL (% DM)	Starch (% DM)	Sugar (% DM)
Bermudagrass, hay	93.0	7.9	56.3	0.93	0.54	0.28	0.54	11.1	58.3	41.6	32.7	5.4	1.9	66.9	35.7	5.4	4.8	5.8
Blood meal	89.6	2.8	74.6	1.23	0.81	0.52	0.81	95.1	25.2	74.6	14.2	21.4	1.2	–	–	–	–	–
Brewers' grains, dry	93.2	4.6	72.0	1.18	0.77	0.49	0.77	25.0	40.3	59.1	17.9	19.3	8.5	52.1	25.4	6.7	5.8	–
Brewers' grains, wet	25.9	4.4	73.9	1.21	0.80	0.23	0.80	28.5	36.2	63.8	11.4	21.8	9.5	50.0	24.3	6.7	4.8	0.5
Bromegrass, silage	42.1	–	55.0	0.90	0.52	0.26	0.52	9.0	–	–	–	11.9	–	71.1	43.1	–	–	–
Bromegrass, hay	88.3	8.8	52.0	0.85	0.47	0.22	0.47	8.3	–	–	24.6	7.4	1.6	65.9	40.3	–	2.6	9.9
Canola, grain	94.7	4.3	109.2	1.80	1.26	0.90	1.26	23.9	62.9	37.0	41.5	11.1	39.8	28.3	22.0	6.4	1.4	–
Canola meal	90.4	7.4	71.1	1.17	0.76	0.48	0.76	40.9	57.5	42.3	32.2	17.4	7.3	30.2	21.4	8.8	1.3	8.8
Citrus pulp, dry	87.7	7.4	70.0	1.15	0.74	0.47	0.74	6.9	59.5	40.3	41.1	5.6	2.4	24.0	20.4	2.5	1.0	–
Corn, dry grain	87.2	1.4	87.6	1.44	0.99	0.68	0.99	8.8	34.6	65.3	21.1	3.1	3.8	9.7	3.6	1.2	72.1	1.8
Corn, high-moisture grain	70.5	1.5	90.4	1.49	1.02	0.71	1.02	8.8	44.6	55.3	30.0	2.5	3.9	9.9	3.7	1.2	71.3	2.2
Corn, steam-flaked grain	80.7	1.3	95.0	1.56	1.08	0.76	1.08	8.5	29.5	70.4	8.2	4.1	3.2	9.0	3.6	1.3	76.2	–
Corn, whole-plant silage	33.1	4.2	67.7	1.11	0.71	0.44	0.71	8.2	74.5	25.4	55.7	3.7	3.3	43.0	25.5	3.2	32.6	4.3
Corn, dry gluten feed	88.9	8.2	80.0	1.31	0.88	0.59	0.88	22.6	63.7	37.1	51.7	8.9	3.3	35.1	11.2	1.9	16.9	2.7

Table 1. Nutritional composition of feeds. (cont.)

Feed	DM (% AF)	Ash (% DM)	TDN (% DM)	ME (Mcal/lb)	NE_m (Mcal/lb)	NE_g (Mcal/lb)	NE_l (Mcal/lb)	CP (% DM)	RDP (% CP)	RUP (% CP)	Soluble CP (% CP)	ADICP (% CP)	Fat (% DM)	NDF (% DM)	ADF (% DM)	ADL (% DM)	Starch (% DM)	Sugar (% DM)
Corn, dry gluten meal	90.4	2.9	87.8	1.44	0.99	0.68	0.99	68.2	30.0	69.7	14.7	15.1	2.4	8.1	4.8	2.3	15.4	0.2
Corn, dry distillers' grains w/solubles	90.0	5.3	89.0	1.46	1.00	0.69	1.00	30.8	32.0	67.9	16.5	27.9	10.7	33.7	16.2	4.9	5.9	1.2
Corn, wet distillers' grains w/solubles	31.4	5.1	98.0	1.61	1.12	0.79	1.12	30.6	29.9	69.9	15.6	26.4	10.8	31.5	15.3	4.7	6.1	0.9
Cottonseed, whole	92.6	4.1	93.0	1.53	1.06	0.74	1.06	22.9	–	–	32.8	22.9	19.5	47.8	42.9	–	2.2	–
Cottonseed, meal	88.6	7.5	69.6	1.15	0.74	0.46	0.74	45.0	57.2	42.7	16.9	14.3	3.9	33.6	23.7	8.5	1.7	–
Cottonseed, hulls	91.3	3.6	42.0	0.69	0.31	0.07	0.31	6.7	29.9	70.1	21.5	17.0	2.7	81.1	65.1	19.3	1.1	–
Feather meal	92.0	2.8	79.1	1.30	0.87	0.58	0.87	91.1	29.2	70.8	10.3	113.6	9.7	–	–	–	–	–
Fescue, hay	88.9	8.4	58.3	0.96	0.57	0.31	0.57	9.2	–	–	–	8.7	2.1	65.0	40.3	30.1	–	–
Fish meal	92.3	20.0	81.9	1.35	0.91	0.61	0.91	66.2	54.9	45.0	25.2	13.2	11.9	–	–	–	–	–
Forage sorghum, fresh	30.6	7.8	60.1	0.99	0.60	0.34	0.60	8.9	65.6	34.3	40.6	5.1	2.2	56.0	34.9	4.0	12.0	–
Forage sorghum, silage	88.7	7.6	58.8	0.97	0.58	0.32	0.58	9.1	62.0	32.0	36.9	5.0	2.1	58.5	36.9	5.0	9.5	–
Forage sorghum, hay	88.7	7.6	58.8	0.97	0.58	0.32	0.58	9.1	62.0	38.0	36.9	5.0	2.1	58.5	36.9	5.0	9.5	–
Forage sorghum x Sudan, fresh	30.6	7.8	60.1	0.99	0.60	0.34	0.60	8.9	65.6	34.4	40.6	5.1	2.2	56.0	34.9	4.0	12.0	–

Table 1. Nutritional composition of feeds. (cont.)

Feed	DM (% AF)	Ash (% DM)	TDN (% DM)	ME (Mcal/lb)	NE_m (Mcal/lb)	NE_g (Mcal/lb)	NE_l (Mcal/lb)	CP (% DM)	RDP (% CP)	RUP (% CP)	Soluble CP (% CP)	ADICP (% CP)	Fat (% DM)	NDF (% DM)	ADF (% DM)	ADL (% DM)	Starch (% DM)	Sugar (% DM)
Forage sorghum x Sudan, silage	31.3	10.2	56.1	0.92	0.54	0.28	0.54	12.3	69.5	30.4	50.5	6.5	3.3	61.1	39.4	5.6	2.9	5.8
Forage sorghum x Sudan, hay	88.8	8.8	56.8	0.93	0.55	0.29	0.55	11.0	64.8	35.2	39.3	4.5	2.0	62.7	38.4	4.8	2.9	12.6
Pearl millet, fresh	36.2	–	52.5	0.86	0.48	0.23	0.48	12.2	–	–	43.7	8.0	–	65.3	34.5	–	–	–
Pearl millet, silage	34.9	11.8	53.0	0.87	0.49	0.24	0.49	12.3	68.0	31.9	47.7	6.3	2.3	61.9	40.3	6.0	3.6	–
Pearl millet, hay	86.3	11.4	52.5	0.86	0.48	0.24	0.48	9.5	60.2	39.6	36.8	5.7	1.7	62.5	37.7	6.5	2.9	–
Molasses (beet)	–	27.2	75.0	1.23	0.81	0.53	0.81	10.9	–	–	–	–	–	–	–	–	–	70.6
Molasses (cane)	66.0	12.2	72.0	1.18	0.77	0.49	0.77	8.6	–	–	–	–	1.9	–	–	–	12.0	60.0
Oats, dry grain	89.9	3.1	83.0	1.36	0.92	0.62	0.92	12.6	43.5	56.5	27.4	4.3	6.2	26.7	13.3	3.0	44.1	–
Oats, fresh	29.6	9.7	61.1	1.00	0.61	0.35	0.61	16.5	73.4	26.4	50.9	5.6	3.7	52.7	34.0	4.2	2.7	–
Oats, silage	33.8	9.8	58.0	0.95	0.56	0.30	0.56	12.7	77.5	22.4	63.4	5.5	3.7	58.9	38.5	5.3	3.1	–
Oats, hay	89.6	7.1	59.9	0.99	0.60	0.33	0.60	8.7	65.9	33.9	44.8	3.7	2.2	59.1	37.1	4.7	4.0	–
Oats, straw	84.2	6.9	44.3	0.73	0.35	0.10	0.35	4.8	–	–	53.0	1.9	1.3	73.8	49.3	7.1	1.4	–
Orchardgrass, hay	91.5	10.5	56.2	0.92	0.54	0.28	0.54	13.8	–	–	–	8.1	2.3	57.4	36.7	6.0	–	–
Peanut, hulls	93.4	3.8	42.8	0.70	0.32	0.08	0.32	9.5	47.0	52.5	24.5	19.5	1.2	68.5	58.9	23.0	1.2	–

Table 1. Nutritional composition of feeds. (cont.)

Feed	DM (% AF)	Ash (% DM)	TDN (% DM)	ME (Mcal/lb)	NE_m (Mcal/lb)	NE_g (Mcal/lb)	NE_l (Mcal/lb)	CP (% DM)	RDP (% CP)	RUP (% CP)	Soluble CP (% CP)	ADICP (% CP)	Fat (% DM)	NDF (% DM)	ADF (% DM)	ADL (% DM)	Starch (% DM)	Sugar (% DM)
Peanut, meal	94.1	5.6	80.8	1.33	0.89	0.60	0.89	44.9	71.8	28.2	29.8	12.5	7.7	19.9	13.2	3.3	6.9	–
Rye, dry grain	89.9	1.8	80.8	1.33	0.90	0.60	0.90	11.3	77.1	22.5	46.5	1.4	1.4	15.4	7.5	1.6	58.3	–
Rye, fresh	33.0	10.2	65.1	1.07	0.67	0.40	0.67	18.7	74.3	25.6	49.1	5.8	4.0	51.7	32.0	3.7	1.9	–
Rye, silage	36.8	10.1	59.6	0.98	0.59	0.33	0.59	14.6	76.1	23.8	60.5	5.8	3.9	57.7	37.5	4.8	1.6	1.5
Rye, hay	90.4	9.6	63.7	1.05	0.65	0.39	0.65	18.7	66.5	33.3	35.6	6.1	3.4	51.5	30.9	4.3	2.3	–
Sorghum, dry grain	88.7	2.1	86.0	1.41	0.96	0.66	0.96	11.6	28.6	71.1	19.5	8.9	3.5	7.2	4.6	1.2	71.2	0.1
Sorghum, high-moisture grain	69.9	2.7	86.0	1.41	0.96	0.66	0.96	10.4	–	–	3.5	9.3	3.5	9.3	5.5	–	72.9	–
Sorghum, steam-flaked grain	81.0	1.4	93.0	1.53	1.06	0.74	1.06	10.1	–	–	–	82.2	2.6	9.7	6.3	–	75.2	–
Sorghum, silage	36.5	10.1	59.0	0.97	0.58	0.32	0.58	9.2	–	–	3.8	9.0	2.4	49.2	31.1	5.6	4.6	2.5
Sorghum, hay	84.8	11.0	54.5	0.90	0.51	0.25	0.51	9.0	–	–	38.5	8.4	1.6	56.4	36.5	2.9	7.3	–
Soybean, whole	92.9	5.5	91.0	1.50	1.03	0.71	1.03	40.0	71.0	29.0	53.0	10.6	20.6	18.0	10.8	1.9	1.0	–
Soybean, roasted	93.3	5.6	97.4	1.62	1.11	0.79	1.11	40.5	56.3	43.6	16.7	9.8	21.0	21.8	11.5	2.2	1.3	–
Soybean, extruded	92.5	6.2	91.9	1.51	1.04	0.73	1.04	44.4	57.8	42.2	24.7	6.2	13.1	16.6	10.9	1.8	1.3	–
Soybean, hulls	90.0	5.1	62.6	1.03	0.64	0.37	0.64	12.4	46.8	53.1	30.5	6.4	2.3	64.8	46.4	2.47	1.1	2.2

Table 1. Nutritional composition of feeds. (cont.)

Feed	DM (% AF)	Ash (% DM)	TDN (% DM)	ME (Mcal/lb)	NE_m (Mcal/lb)	NE_g (Mcal/lb)	NE_l (Mcal/lb)	CP (% DM)	RDP (% CP)	RUP (% CP)	Soluble CP (% CP)	ADICP (% CP)	Fat (% DM)	NDF (% DM)	ADF (% DM)	ADL (% DM)	Starch (% DM)	Sugar (% DM)
Soybean, high-protein meal	89.2	7.4	79.5	1.31	0.88	0.58	0.88	52.9	70.4	29.5	44.1	10.2	1.9	11.3	7.5	1.2	2.0	13.3
Soybean, low-protein meal	91.7	6.4	81.1	1.33	0.90	0.60	0.90	46.5	55.9	44.1	19.5	9.0	8.3	18.8	10.9	1.5	5.1	11.6
Soybean, heated meal	89.8	6.6	79.3	1.30	0.87	0.58	0.87	48.9	50.5	49.4	13.1	10.8	8.3	22.7	10.9	1.8	1.3	–
Sudangrass, fresh	30.9	10.9	54.8	0.90	0.51	0.26	0.51	12.9	67.0	32.8	42.7	5.7	3.0	61.0	37.3	4.7	2.1	–
Sudangrass, silage	31.3	12.0	53.5	0.88	0.45	0.24	0.45	12.1	70.2	29.7	51.9	6.6	3.1	62.3	40.8	5.8	1.8	0.8
Sudangrass, hay	89.0	9.3	54.5	0.90	0.51	0.26	0.51	8.3	57.9	42.0	34.6	4.1	1.6	65.8	41.1	5.1	1.6	–
Switchgrass, hay	94.2	3.4	46.1	0.76	0.38	0.13	0.38	3.4	–	–	–	8.8	1.2	81.1	46.7	6.6	–	–
Teff, hay	88.0	10.5	45.0	0.74	0.36	0.11	0.36	10.7	–	–	–	16.9	1.1	66.4	38.0	–	–	–
Timothy, hay	87.8	8.5	57.0	0.94	0.55	0.29	0.55	9.4	–	–	–	–	1.9	63.8	38.0	–	–	14.2
Triticale, dry grain	88.8	2.0	82.7	1.36	0.92	0.60	0.92	12.1	67.3	32.6	30.2	2.5	1.7	14.1	4.5	1.8	61.0	–
Triticale, fresh	26.0	8.9	61.4	1.01	0.62	0.35	0.62	15.3	77.0	22.7	50.1	4.3	2.9	56.6	34.2	3.5	1.7	0.8
Triticale, silage	33.0	10.7	57.8	0.95	0.56	0.30	0.56	13.9	81.8	18.1	69.7	5.0	3.7	58.6	38.2	4.7	1.9	1.7
Triticale, hay	90.3	8.4	58.5	0.96	0.57	0.31	0.57	11.6	68.9	31.1	45.9	3.5	2.1	57.7	36.7	4.7	5.1	–
Wheat, dry grain	88.9	2.3	86.8	1.43	0.98	0.67	0.98	13.8	64.2	35.6	29.3	2.4	1.9	12.4	4.2	1.5	62.4	8.6

Table 1. Nutritional composition of feeds. (cont.)

Feed	DM (% AF)	Ash (% DM)	TDN (% DM)	ME (Mcal/lb)	NE_m (Mcal/lb)	NE_g (Mcal/lb)	NE_l (Mcal/lb)	CP (% DM)	RDP (% CP)	RUP (% CP)	Soluble CP (% CP)	ADICP (% CP)	Fat (% DM)	NDF (% DM)	ADF (% DM)	ADL (% DM)	Starch (% DM)	Sugar (% DM)
Wheat, steam-flaked grain	83.0	2.0	86.8	1.43	0.97	0.67	0.97	14.4	–	–	–	3.1	1.9	13.6	5.5	–	64.9	–
Wheat, fresh	34.1	8.9	61.7	1.01	0.62	0.36	0.62	15.3	75.5	24.4	52.8	4.5	3.0	54.1	33.0	3.9	4.1	26.3
Wheat, silage	34.1	10.3	59.1	0.97	0.58	0.32	0.58	12.7	82.1	17.8	67.4	5.0	3.4	56.5	36.6	4.8	6.6	1.8
Wheat, hay	89.9	8.2	58.8	0.97	0.58	0.32	0.58	11.1	66.0	33.9	40.3	3.9	2.0	57.9	35.9	4.8	4.7	9.4
Wheat, straw	91.8	7.5	50.0	0.82	0.44	0.19	0.44	5.1	65.4	34.5	40.8	5.0	1.4	73.7	50.2	7.4	1.6	2.5
Wheat, bran	90.1	5.5	71.9	1.18	0.77	0.49	0.77	17.5	64.4	35.7	39.8	3.2	4.3	40.1	13.7	4.2	21.2	–
Wheat, middlings	88.9	5.4	72.9	1.20	0.79	0.51	0.79	18.6	68.2	31.6	40.5	3.4	4.1	38.3	13.2	3.7	25.6	–
Whey, wet	16.6	12.7	80.9	1.33	0.90	0.60	0.90	6.3	96.5	7.0	81.4	2.8	4.0	–	–	–	–	50.6
Whey, dry	93.8	12.7	82.2	1.36	0.91	0.62	0.91	13.9	80.1	23.2	85.6	–	2.0	–	–	–	–	56.1

Source: National Academies of Sciences, Engineering, and Medicine. 2016. Nutrient Requirements of Beef Cattle. 8th revised ed. Washington, DC: The National Academies Press.

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Part XV.

Diagnostic Laboratory Services

NOTE: Access to the following laboratory services can be obtained through your local Virginia Cooperative Extension Office.

Pre-sidedress Nitrate Soil Test for Corn

Funded through the Virginia Department of Conservation and Recreation, field test kits are available for measuring soil nitrate concentrations. These tests should be conducted on cornfields with a history of manure or biosolids applications within the previous three years, on fields that received applications of commercial fertilizer nitrogen of 30 pounds or less in a starter band, or on fields of less than 40 pounds broadcast at planting. Test results are used to determine the most appropriate level of nitrogen to be applied as a sidedress on corn. Contact an Extension agent or a nutrient management specialist from the Department of Conservation and Recreation to assist with the test.

Soil Testing

Soil samples are analyzed for specific soil nutrients to determine proper application rates of fertilizer and lime for optimum plant growth. Routine analysis includes soil pH, P, K, Ca, Mg, Zn, Mn, Cu, Fe, B, and estimated CEC. Soluble salts and organic matter tests are also available.

Sampling and mailing instructions are found on the sample boxes and forms, which should be sent directly to the lab with the soil sample along with any payment. Completed soil test results, along with a recommendation on fertilization and liming, are emailed to the client. For more information, go to www.soiltest.vt.edu or contact your local Virginia Cooperative Extension office.

Insect Identification – Department of Entomology

Insect samples and insect-damaged plant material are handled and processed through the Insect Identification Laboratory. Insects from any structural, plant, or animal hosts are accepted and are identified to the lowest taxonomic level needed for control decisions. Control recommendations accompany insect identification results, which are sent electronically to each Extension office. Extension offices are supplied with alcohol vials and mailing tubes for specimen shipment. Samples should not be submitted before reviewing instructions on the back of the insect identification submission form 444-113.

Plant Diagnosis

The Plant Disease Clinic is a service lab to Extension offices that provides diagnoses of plant diseases caused by fungi, bacteria, viruses, and other plant pathogens, as well as diagnoses of abiotic problems and identification of nonweedy plants. Physical and/or digital samples can be submitted through local VCE offices. Your Extension agent or a staff member can provide the Plant Disease Diagnostic Form (VCE publication 450-097), which must be completed and included with each sample, and advise on proper sample submission. There is a fee for sample diagnosis. For further information on the Plant Disease Clinic and guidelines on sample submission, please visit the **Plant Disease Clinic website** at https://spes.vt.edu/affiliated/plant-disease-clinic.html.

Weed Identification

Farmers and homeowners can submit plant samples for weed identification to the Virginia Weed Identification Clinic through their county Extension agent.

Find your Extension agent: https://ext.vt.edu/offices.html

For agents:

- Virginia Weed Identification Website: https://weedid.cals.vt.edu
- Weed Indentification Clinic: https://agweedsci.spes.vt.edu/extension/weedid/_jcr_content.html

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Part XVI.

Commonly Used Weights and Measures

Row Length per Acre		
Row spacing (inches)	Total length (yards)	Total length (feet)
12	14,520	43,560
20	8,712	26,136
24	7,260	21,780
30	5,808	17,424
36	4,840	14,520
40	4,356	13,069
42	4,149	12,446

Mass and Weight		
Unit	Grams	Approximate US equivalent
Metric ton	1,000,000	1.1 tons
Quintal	100,000	0.62 mile
Kilogram	1,000	106.36 yards
Hectogram	100	32.81 feet
Gram	10	39.37 inches
Decigram	0.10	3.94 inches
Centigram	0.01	0.39 inch
Milligram	0.001	0.04 inch

Metric System - Length		
Unit	Number of meters	Approximate US equivalent
Kilometer	1,000	0.62 mile
Hectometer	100	109.36 yards
Decameter	10	32.81 feet
Meter	1	39.37 inches
Decimeter	0.1	3.94 inches
Centimeter	0.01	0.39 inch
Millimeter	0.001	0.01 inch

Metric System - Area		
Unit	Number of square meters	Approximate US equivalent
Square kilometer	1,000,000	0.3861 square mile
Hectare	10,000	2.47 acres
Are	100	119.6 square yards
Centare	1	10.76 square feet
Square centimeter	0.000001	0.155 square inch

Metric System - Volume		
Unit	Number of cubic meters	Approximate US equivalent
Decastere	10	13,100 cubic yards
Stere	1	1,310 cubic yards
Decistere	0.10	3.53 cubic feet
Cubic centimeter	0.000001	0.061 cubic inch

Metric System - Capacity				
		Approximate US measurement equivalent		
Unit	Number of liters	Cubic	Dry	Liquid
Kiloliter	1,000	1.31 cubic yards		
Hectoliter	100	3.53 cubic feet	2.84 bushels	
Decaliter	10	0.35 cubic feet	1.14 pecks	2.64 gallons
Liter	1	61.02 cubic inches	0.908 quart	1.057 quarts
Deciliter	0.10	6.1 cubic inches	0.18 pint	0.210 pint
Centiliter	0.01	0.60 cubic inches		0.338 fluid ounce
Milliliter	0.001	0.06 cubic inch		0.28 fluid dram

Energy Values	
One horsepower (746 watts)	The force required to raise 33,000 lbs by 1 foot per minute.
British thermal unit (Btu)	252 calories.
Calorie	The amount of heat needed to raise the temperature of 1 gram of water by one degree centigrade.
Watt	The power developed in a circuit by a current of 1 ampere flowing through a potential difference of 1 volt (1/746 horsepower).

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Part XVII.

Calibration of Sprayers

Authored by:

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Be sure to calibrate your sprayer properly. Using too much pesticide can injure your crop; using too little can result in little or no pest control. Apply all pesticides at the recommended rate. Never exceed the labeled rate. Pressure, nozzle size, spacing of nozzles, and speed of the application all affect the application rate.

Large-Area Method of Calibration

1. Adjust tractor speed, pressure, and orifice size according to manufacturer's directions.
2. Measure and stake off 1 acre (43,560 square feet) in the field to be treated.
3. Fill tank on sprayer with water.
4. Maintain constant pressure and speed in spraying the acre. Mark pressure, throttle, and gear settings.
5. Remember: The amount of water necessary to refill the tank is equal to gallons per acre.
6. Make up the spray solution with the correct amount of chemical in the amount of water applied per acre.
7. Make the application at pressure, throttle, and gear settings used in calibrating.

Short-Course Method of Calibration

1. Measure off a course of 163 1/3 feet in the field to be treated.
2. Adjust tractor speed, pressure, and orifice size according to manufacturer's directions.
3. Spray over the measured course, catching the discharge from one nozzle.
4. Measure discharge with a standard measuring cup.
5. $$\frac{\text{Number of cups x 200}}{\text{Nozzle spacing in inches}} = \text{gallons/A}$$
6. Make up spray solution with the correct amount of chemical in the amount of water that will be applied to each acre.
7. This procedure may also be used when calibrating for band treatments. For band applications, substitute bandwidth for nozzle spraying.

Table 1. Calibration Tables and Information - Travel Speed Chart- Time Required in Seconds to Travel

Miles per Hour	100 ft	200 ft	300 ft
1	68	136	205
2	34	68	102
3	23	46	68
4	17	34	51
5	14	27	41
6	11	23	34
7	10	20	29
8	9	17	26
9	8	15	23
10	7	14	21

1 mph = 88 feet per minute
1 mph = 1.466 feet per second
Speed in mph = No. 35 inch steps per minute/30

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