EXTENSION
AGRICULTURE AND NATURAL RESOURCES

WVU Extension Crop Fertilization Recommendations

For over 40 years, the West Virginia University Soil Testing Laboratory has used the Mehlich-1 soil extraction system to measure soil test values for the plant nutrients phosphorus (P), potassium (K), calcium (Ca) and magnesium (Mg). This methodology does not provide simultaneous extraction for the micronutrient minerals, iron (Fe) and aluminum (Al) needed for determining P-sorption in soils. The Mehlich-3 extraction provides improved performance by extracting major and minor nutrients as well as iron and aluminum at one time. In 2018, the Soil Testing Laboratory changed to the Mehlich-3 extraction methodology. To accompany this change, WVU Extension has updated the crop fertilization recommendations to better meet the needs of livestock, agronomic crops, commercial horticultural producers and home gardeners. This publication is provided for those interested in understanding how these updated fertilization recommendations were developed and implemented.

Fertilizer recommendations for agronomic crops are based on the expected yield of the given crop when grown on the dominant soil in the field. Two recommended fertilization rates are provided. The lower rate is the crop sufficiency rate, or the minimal amount of fertilizer nutrients – nitrogen (N), phosphorus pentoxide (P_2O_5), and potassium oxide (K_2O) – needed to achieve the expected yield that year. The higher rate is the build to optimum rate, which is the amount needed to achieve the expected yield and increase the soil test phosphorus and potassium values into the optimum range over time. When soil test values for a nutrient are below optimum, that nutrient needs to be applied for the crop to achieve its expected yield. When soil test values are in the optimum range, the crop should achieve its expected yield without the addition of that nutrient that year. At the low end of the optimum range, replacement values for the nutrients removed in the crop are recommended. When soil test values are in or above the high end of the optimum range, a zero recommendation for that nutrient is made since the addition of more nutrient is a waste of money.

The fertilization recommendations for commercial horticultural crops grown in the open field or in high tunnels are based on the Mid-Atlantic vegetable recommendations. Fertilizer recommendations for home horticultural crops are taken from previous WVU recommendations. For these crops, no adjustment is made for soil yield potential. These high-value crops are most frequently grown on the best natural soils in the field or in manufactured soils in high tunnel environments.

Photosynthesis

Plants capture energy from sunlight to make sugar, starches, proteins and other compounds for growth and reproduction. Plants use the solar energy to bind carbon from carbon dioxide (CO_2) in the air and hydrogen from water to make carbohydrates, releasing oxygen for our respiration. To do all this work, plants need nutrients from the soil to make chlorophyll, proteins, cell walls and other plant parts. When animals eat plants, they take on and use that solar energy in their bodies. All terrestrial organisms are powered and held together by solar energy.

Nutrients Plants Need

Mineral nutrients needed by plants in relatively large amounts, otherwise known as macro minerals, include nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and sulfur (S). Mineral nutrients needed by plants in relatively small amount (micro minerals), include boron (B), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo) and zinc (Zn). The standard WVU soil test reports Mehlich-3 extractable minerals in parts per million (ppm) of elemental nutrient per unit of soil. Testing for micro-nutrients, electrical conductivity (EC) and soil organic matter (OM) are available at an additional cost.

Crop Yield Potential and Adaptation

The amount of nutrients needed by a plant is a function of the crop's growth rate and yield (Tables 1 and 2). The crop's yield is a function of its genetic potential and the soil's ability to provide adequate nutrients in a timely manner to achieve the genetic potential. A crop's yield potential is related to the plants photosynthetic and growth physiology, its rooting depth, and its ability to reach down into the soil to find water and plant nutrients during dry spells. Alfalfa roots can grow 20 to 50 feet deep when the soil allows it to. White clover and orchardgrass roots will use the top 6 to 12 inches of soil. Corn has a high photosynthetic potential and deep rooting habit where soils allow. Corn has also been bred to have improved light interception and photosynthesis, which has increased its yield potential. Soybeans have a lower photosynthetic potential and shallower rooting system, resulting in a lower yield potential. Between 1940 and 2018, plant breeders and agronomic management have increased yields more than fivefold for corn, threefold for wheat, and twofold for soybeans, compared to their 1940 yields (Dr. Bryan G. Hopkins, Soil Science Society of America –North American Proficiency Testing). This causes greater nutrient uptake by these crops to achieve their current yield potential. Under similar soil and weather conditions, small grain crop and cool-season forage yields (Table 3) are highly correlated to corn yield. Different forage species are highly correlated with the yield of orchardgrass on good soils (Table 4), but differences are to be expected when soil drainage comes into play. On poorly drained soils, reed canary grass will outperform other species and alfalfa will do very poorly, compared to other legumes.

Crop Nutrient Removal Per Yield Unit

Nutrient removal by a crop is the product of crop yield and nutrient content in the yield. When analyzing crop nutrient content for livestock feeds, nutrients are measured as crude protein (CP) and elemental content of phosphorus and potassium (Table 5). Total nitrogen is multiplied by 6.25 to measure crude protein content. The P_2O_5 content in a crop is measured by multiplying elemental phosphorus content by 2.3. The K_2O content is measured by multiplying the elemental potassium content by 1.2 (Table 6). For grain crops, these values do not vary a great deal. Forage crop nutrient uptake varies greatly based on forage quality measured as crude protein (Table 7). As forage crude protein increases, the content of fertilizer equivalent N, P_2O_5 and K_2O increases per ton of dry matter. The low crude protein values are for low quality hay, while the high crude protein values apply to high quality hay and pasture.

Soil Series and Expected Crop Yield

Potential crop yield is the average yield of an adapted variety of the crop when grown on a good soil using the crop's best management practices (Tables 1 and 2). Achieved crop yield may be lower due to lower quality soil, management and limiting weather factors.

Soil Water Holding Capacity Within the Rooting Zone

The main soil characteristic responsible for high crop yield is its ability to hold plant available soil water (ASW) within the rooting zone (Figures 1 and 2). This is the product of water held per foot of soil and crop rooting depth in the soil. Rooting depth is a crop characteristic and may be limited by soil characteristics, such as the soil being shallow to bed rock or the presence of a seasonal high water table. Deep soils allow deep rooted crops to reach down and find water during dry periods. Shallow soils limit rooting depth and provide less available water between rainfall events.

Soil texture impacts the ability of soil to hold plant available water (Table 8). Field capacity is the amount of water a soil holds after 24 hours of free drainage. The wilting point is the water held in a dry soil when the plant begins to wilt. The soil moisture between these two values is plant available soil water that allows the plant to live and grow. Sandy soils do not hold as much plant available water as loamy soils. Clay soils hold more water than loamy soils but hold it so tight that less of it is available. Soil health plays an important role. Soils high in organic matter hold more plant available soil water per unit depth (Figure 3). They also have more large soil pores that allow rainfall to infiltrate into the soil rather than run off the surface. Water infiltrating into the soil during a rain is partly a function of soil texture, but it is dependent on macro pores occurring in the soil and the stability of soil aggregates, both of which are tied to soil organic matter and health.

Soil Drainage

Soil drainage impacts plant growth and timely crop management, which affects yield. Internal drainage that results in a seasonal high water table limits root growth in the soil, therefore rooting depth and plant available soil water between rainfall events. Surface drainage occurs in two forms. A soil on a steep slope may have high surface drainage and poor water infiltration during a rain. Field experience in West Virginia has found that when the slope of a soil increases by 10 % (e.g., from a 6% to a 16% slope), crop yield decreases 7% to 10%. Another case is a soil at the bottom of a slope that receives surface drainage from above. These soils may do well in dry weather, but in wet weather, they have excess moisture that interferes with crop growth or field management. Another situation is a soil on a flood plain that is subject to flooding during high water periods.

Soil Organic Matter

Soil organic matter is an indirect measure of soil fertility and health. Soil organic matter is composed of dead plant and animal parts and animal feces that are food to the macro- and microorganisms in the soil. There are two basic forms of soil organic matter

– active and residual. Active soil organic matter is readily available as food for soil organisms. Different forms of organic matter are consumed by different organisms. Once the organisms have eaten what they can, the residual soil organic matter, or humus, is quite stable. This organic matter helps increase soil cation exchange capacity, which hold positively charged plant nutrients, such as K, Ca and Mg. While consuming soil organic matter, the soil organisms develop soil macro- and micro-pores, and provide chemicals that stabilize soil structure. The macro-pores help increase water infiltration during rains and movement of oxygen into the soil. Micro-pores help retain plant available water, so an increase in soil organic matter could also increase plant available soil water holding capacity above what is expected based on soil texture alone. In pastures, perennial hay crops and no-till soils, soil organic matter is greatest near the surface and decreases with depth (Figure 4).

Soil Health and Bulk Density

Soil bulk density is a measure of soil weight per unit volume. Pore space within the soil reduces soil bulk density. Pore space within the soil holds oxygen and plant available water for plant roots and soil microbes. Ideally, it is good to have 50% pore space in soil. Earthworms, soil microorganisms and roots decrease bulk density by making pores. Compaction of soil by machinery, livestock and human foot traffic reduces bulk density, reducing oxygen and water infiltration into the soil.

Soil Fertility and Yield

Crop yield will be limited if there are not enough plant nutrients available in the soil. Sufficiency of plant nutrients in the soil is measured by soil testing. About 20% to 25% of crop production cost is the value of plant nutrients needed to grow the crop. When using added fertilizers, applying more than the crop needs is a waste of money and can harm the environment. Applying too little fertilizer results in depressed crop yield, which increases the unit production cost since other costs have not changed. Soil testing and using fertilization recommendations based on sound science and field experience is the best way to optimize crop yield.

Plant Response to Soil Test Phosphorus and Potassium

In the WVU Soil Testing Lab, soils are tested for their content of plant available P, K, Ca, and Mg. When crops are grown in soil that is below optimum in soil test P (M-3 P 30 parts per million) or K (M-3 K 90 parts per million), yields will be lower than their potential if P or K fertilizer is not applied (Figures 5 and 6). This is more consistent for P than for K since reserve K is held by clay in the soil and its availability is dependent on soil texture (amount of clay), the form of clay and soil moisture.

Plant Response to Soil pH

Soil pH is a measure of soil acidity and affects the soil's chemical and biological environment. A pH of 7.0 is neutral, while a pH below 7 is acid and a pH above 7.0 is alkaline. As a general rule, pH reflects the available Ca, Mg, Al, Mn and Fe in the soil. A higher pH reflects more Ca and Mg available in the soil. A low pH (especially when pH is below 5.5) reflects more Al, Mn and Fe available in the soil. Each plant species has its preferred pH range (Tables 9, 10 and 11). Different soil organisms also have preferred pH ranges. The yield of legumes, such as alfalfa, clover and birdsfoot trefoil, respond to soil pH largely due to their nodule bacteria responding to soil pH and fixing more N when the pH is favorable (Figure 7). With a few exceptions, like alfalfa, sweet clover, hyacinth or pecan, agronomic and horticultural plants prefer a soil pH below 6.5.

Plant Response to Added Phosphorus and Potassium Fertilizer

When soils test below optimum in P or K, crops respond to added P or K fertilizer (Figure 8). The quantitative response to P and K fertilizer differs. At a low P soil test level, P applications at three- to four-times the crop removal rate is required to get maximum crop yield. At a low K soil test level, crops only require K application at crop removal rate to produce maximum yield.

When P is added to soil, it may be fixed and held on the surface of soil particles by chemical sorption with Fe and Al. At low P soil test levels, P fixation is greater than at high P soil test values (Figure 9). More P_2O_5 is needed to change the P soil test value when a soil tests low in P than when it tests in the optimum range. When soil pH is below 5.5, there is more available Fe and Al in the soil. These compounds interact with P and make it less available.

In soils, K fixation occurs with clays that hold the K ion on the edge of the clay particles or within layers in the clay. This is a function clay and soil organic matter content impacting the cation exchange capacity (CEC) of the soil and the amount of clay capable of fixing K within the clay particles.

Plant Response to Added Nitrogen Fertilizer

Since N is not a stable nutrient, soil testing laboratories do not test samples for available N. Recommendations for N fertilization are based on crop N response in field studies. For cool-season grass hay crops, forage yields increase with annual N applications up to 350 pounds of nitrogen per acre (Figure 10). Optimal N rates are below 200 pounds per acre since there is little yield increase above this rate. As N rates go over 200 pounds per acre, plants do not take up all the N and it moves into ground water, where it can be a health hazard to livestock and humans consuming the water from springs and wells.

At the zero N rate, relative yields range from 25% to 70% (0.25 to 0.70 times) of maximum yield, averaging 42% (0.42 times) of maximum yield (Figure 10-A). This range in yield at the zero N rate is related to legumes in the stand and available soil organic matter due to previous management that provides N to the grass. When grass stands are established on sites that have an active soil organic matter pool (where sod was killed, then a new grass stand was established) or where legumes enter the stand from seed in the soil, N is provided by decomposition of soil organic matter or N fixation by legumes. In these situations, the grasses have background N and there is less yield response to added N. When grass stands are established after three to four years of growing corn and small grains, with no return of manure or crop residue to the soil, soil organic matter will have been decomposed and there is little N in the soil for grass growth. If no legumes establish from the soil seed bank, no N will be provided from that source. In these sites, grass yield response to the first input of N is as high as 40 pounds of dry matter per pound of nitrogen applied.

With application of the first 50 pounds of nitrogen per acre, yields even out. High yields at the top end of the zero N treatment are reduced and yields at the bottom end are increased. At 100 pounds of nitrogen per acre, yields are comparable to the top half of the zero N check. In grass stands with a yield potential of 5 tons per acre, the first 50 pounds of N returns 30 pounds of forage dry matter per pound of N, the second 50 pounds of N returns 26 pounds dry matter per pound of N, and the third 50 pounds of N returns 20 pounds dry matter per pound of N (Table 12).

Forage Crop Response to Legume Nitrogen

Legumes grown with grasses fix nitrogen from the air to provide N for growth. In a Kentucky study, a tall fescue ladino stand was fertilized at 0 pounds of N per acre, compared to 120 pounds of N per acre. Where no N was applied, the grass clover stand relative yield was 87% to 94% (0.87 to 0.94 times) that of the 120 pounds of N per acre stand (top yield of 4 tons per acre) (Temple and Taylor, 1966. Agron. J. 58:319). Without N, there was a 24% stand of clover in April and a 53% stand in September. Where the stand was fertilized with 120 pounds of N, there was a 2% to 15% clover stand in April and a 13% to 28% clover stand in September.

The percentage of legumes needed for maximum yield is a function of sod age and soil organic matter status. In old sods with a pool of active soil organic matter, a 25% to 30% stand of clover is adequate for maximum production. On cropped soils, where the pool of active soil organic matter was decomposed there is little available N for grass growth and legumes will dominate the stand at near maximum yield (Figure 11). On soils low in soil organic matter, the addition of 50 pounds of N per acre after seedling emergence is beneficial to grass growth. On soils high in soil organic matter, legume content over 25% will achieve maximum yield and be comparable to 120 to 160 pounds of N per acre per year on that soil (Figure 12).

Another value of using legumes to provide N is that animals consume more forage when legumes are present. A 10-year study in Virginia compared orchardgrass and tall fescue pastures fertilized with 200 pounds of N per acre per year to orchardgrass and tall fescue pastures grown with red and white clover as the N source and bluegrass grown with white clover as the N source. Animals ate more of the pasture containing clover, which reduced steer grazing days per acre but increased average daily gain, resulting in comparable gain per acre (Table 13).

Soil pH Response to Added Lime

Adding lime to an acid soil raises the soil pH. In the laboratory, the lime required to raise the soil pH to 6.6 is measured using a buffer pH solution. Through calibration, the buffer pH tells the amount of effective neutralizing value (ENV) lime needed to raise the soil pH to 6.6 (Table 14). The ENV lime is equivalent to 100% calcium carbonate that is readily available. When lime is thoroughly incorporated into the soil, this method is accurate, and the pH response is linear to applied ENV lime (Figure 13).

Change in soil pH is dependent on lime quality (ENV), method of application and time for the lime to react with the soil. When lime is well mixed into a 6-inch plow layer, it can take a year for 6 tons of lime to raise the soil pH from 5.2 to 6.6 in the soil (Figure 14). When lime is surface applied without incorporation, it may take three years for 2 tons of lime to change the soil pH from 4.8 to 6.4 (Figure 15). When an additional 2 tons of lime are applied in the second year, it takes another two years (a total of four years) to raise the soil pH to 7.0 in the top 2 inches of soil. Surface application of lime requires less lime, but more time to change the soil pH at the soil surface.

Fertilizer Recommendations

Fertilizer recommendations for vegetable crops are based on the Mid-Atlantic Vegetable Crop Production Guide. Fertilizer recommendations for home gardens are based on previous WVU recommendations. Fertilizer recommendations for wildlife plantings are based on comparable agronomic crops.

Agronomic Nitrogen Recommendations

Recommendations for nitrogen on N-fertilized hay are based on regional field research (Figure 10; Table 12). The stated N recommendation is 50 to 200 pounds of N per acre per year. This is based on 50 to 60 pounds of N per acre per hay harvest and up to three to four hay harvests per year. The maximum rate of 200 pounds is based on research showing that N rates greater than this pose a risk for N moving into the ground water and potentially causing a health risk to livestock and people using the ground water.

Crop Yield Classes

Soils are divided into five crop yield classes (Table 15), where each class approximates a quintile (20% classes) of expected crop yields from West Virginia soils. Expected crop yield under good management was extracted from all West Virginia soil surveys. Where soil surveys had different crop yields for the same soil, the highest or most recent yields were used. These crop yields were divided into quintiles (20% classes). Adjustment factors for the top quintile soils were developed for nitrogen fertilized cool-season grass hay and corn yields under best management practices (Table 16). These adjustment factors were applied to other soils for hay and corn yield in proportion to those soils' historic expected yields. The mean yield within each quintile was calculated and assigned as the expected yield for that yield class.

Predominant Soil Series

Users can find the dominant soil series in Google Maps by using these resources from the University of California Davis:

https://casoilresource.lawr.ucdavis.edu/gmap/
https://casoilresource.lawr.ucdavis.edu/
https://casoilresource.lawr.ucdavis.edu/soilweb-apps/

The USDA/NRCS Web Soil Survey can be reached directly at:
https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm

Agronomic P2O5 and K2O Recommendations

Recommendations for P_2O_5 and K_2O fertilization of agronomic crops are based on expected crop yield achieved on the dominant soil series reported in the soil sample submission (Table 17). When a dominant soil series is not reported, a yield class II soil is used as the default.

Initial fertilizer recommendations are calculated based on crop fertilizer nutrient removal rates for the crop (Table 6) at the yield obtained on a yield class II soil (Table 15). Laboratory analysis of the soil sample determines the nutrient status of the soil. These elemental nutrient values and their relative value (Table 18) are provided on the soil test report. The relative values are used to select adjustment factors (Table 19), which are applied to crop removal rate to account for plant ability to take up nutrients at that soil test level and to increase or decrease soil test values over time.

When soil test P is low, a factor of three times removal rate is used. At a low soil test P value, phosphorus applications at three to four times removal rate are necessary to achieve maximum yield (Figure 8-A). At low soil test P, plants require P fertilizer application rates at three to four times plant P uptake to achieve maximum yield. Only part of the fertilizer P is taken up by the plants. The remaining fertilizer P is attached to soil particles (due to P sorption), which raises soil test P.

When soil test K is low, factors of 1.4 and 1.6 times the crop removal rate are used for the minimum sufficiency and the build to optimum recommendation rates, respectively. At a low soil test K, K fertilization at removal rate is adequate to achieve maximum yield, extra K is recommended to increase soil test K values (Fig. 8-B). In West Virginia soils, most added K is available for crop production. Excess K will be taken up by the clay fraction of the soil and will increase soil test K. In soils testing below optimum, soils will release K from the clay fraction for crop production, but crop production will be below optimum.

As soil test value increases, the adjustment factor decreases. For the minimum sufficiency fertilization rate, this becomes 1.0 at the medium soil test level. For the build to optimum, the adjustment factor becomes 1.0 at the optimum range. Above these levels, recommended fertilization rates will result in reduced soil test values balancing at the medium and optimum soil test levels for the two recommendations, respectively.

Grain Crops

For high value or expensive crops, such as alfalfa, corn, soybeans and wheat, fertilizer adjustment factors are applied to whole plant nutrient removal at low soil test levels.

Minimum Sufficiency vs. Build to Optimum and Maintain

Two fertilizer recommendations are made. The lower minimum sufficiency recommend is for rented land that is not on a long-term lease. Recommendations on rented land are expected to maintain high yields and maintain soil test values in the medium range. If recommended fertilizer is not applied each year, yields are expected to be sub-optimal.

The higher recommendation, build to optimum, is for use on a home farm or long-term lease situation. Recommendations at the higher rate are expected to maintain high yields and maintain soil test values in the optimum range. If recommended fertilizer is not applied for a year or two, yields should not be significantly lower.

Mineral vs. Organic Fertilizers

Mineral fertilizers are most often purified minerals coming from a parent rock material or by converting N in the air to ammonia and then to urea. Organic fertilizers are available that come from composted plant material, manure and poultry litter. Organic fertilizer often carries sulfur (S) and micro minerals that may not be present in purified mineral fertilizers. Availability of N from organic sources is slow release and dependent on the source and weather.

Depth of Lime Incorporation

Lime incorporated into the soil by disking and plowing to a 6-inch depth reacts with a greater soil mass, resulting in less change in soil pH than when lime is surface applied and the soil is sampled to a 2-inch depth.

Lime Recommendations

Liming recommendations have been updated based on crop optimal pH, lime application method and increased liming cost. For surface applied lime, when the indicated crop has an optimal pH of 6.0 or greater, no lime is recommended until the pH drops below 6.0. At this point, 2 tons of effective neutralizing value (ENV) lime are recommended. When the crop has the lower optimal pH at 6.5, no lime will be recommended until the pH drops below 6.5. At this point, 2 tons of ENV lime are recommended.

For alfalfa seeding on low pH sites, 3 tons of ENV lime are recommended for no-till plantings. Under conventional tillage, 3 tons ENV lime should be disked in and a more acid tolerant crop grown for a year. The next year, the soil should be plowed 8 inches deep, and another 3 tons should be disked in to raise the pH to above 6.5.

Lime Quality

All lime recommendations are reported as ENV lime. Lime quality is based on the purity of the limestone, measured as calcium carbonate equivalent. Since magnesium weighs less than calcium, magnesium carbonate has a greater neutralizing value than calcium carbonate per ton. The second factor determining lime quality is how finely the limestone is ground. Finely ground limestone has more surface area and reacts more quickly than does coarser lime particles. Ground limestone passing a 60-mess screen is 100% effective, while ground limestone that does not pass a 20-mess screen has no practical liming effect. A limestone evaluation tool is available on the web or as an Excel spreadsheet for evaluating the cost effectiveness of different liming sources based on the analysis reported on the products label.

Recommendations of Magnesium

Soil test magnesium is set at 150 parts per million as optimum. This is generally recommended for forage crops where livestock need magnesium for health reasons. The same value is used for horticultural crops. Grain crops tolerate a lower Mg level since, at maturity, the plant prioritizes Mg partitioning into the grain. For grain crops, a soil test level of 75 parts per million may be adequate. However, since crops should be rotated for crop health and weed herbicide resistance reasons, and forage crops should be part of the rotations, the 150 parts per million is considered the long-term minimal Mg content preferred for optimum.

To correct for when soil test Mg is below optimum, the following rules are applied:

1. When soil pH is less than 6.0 and Mg is less than optimum, we recommend 2 tons ENV high Mg/dolomitic limestone be applied.
2. When soil pH is greater than 6.0 but less than 7.0 and Mg is less than optimum, we recommend bulk or pelleted dolomitic limestone, magnesium oxide, magnesium sulfate or potassium magnesium sulfate fertilizers to provide Mg.
3. When soil pH is greater than 7.0 and Mg is less than optimum, we recommend magnesium oxide, magnesium sulfate or potassium magnesium sulfate fertilizers to provide Mg.

When soils test low in Mg, dolomitic lime is the lowest cost method of increasing soil test Mg. Many high calcium limestone sources have a 3% to 24% $MgCO_3$ per ton and can have a positive impact on increasing soil Mg content (Figure 16). Dolomitic limestone can have over 40% of its weight as $MgCO_3$ and is the best option for increasing soil test Mg, when available.

Adjusting Fertilizer Recommendations for Different Crop Yields

Weather and management can limit crop yields below those expected for the soil present in a field. Poorly drained soils may have excess soil moisture in the spring and prevent timely planting or harvest management. Weather can limit yields due to low or infrequent rainfall and air temperatures outside the optimal range for the crop (cold or hot weather). Management limiting factors include improper planting and harvest management, and poor soil health (soil compaction, low soil organic matter, etc.). Spring planted crops, such as oats and corn, need to be planted relatively early or yields will be greatly reduced. For hay crops on heavy soils in wet years, getting first cut hay off in a timely manner will be difficult. No-till agriculture has less issues with wet soil in terms of getting on the field, but this results in soil compaction, which increases rainfall runoff and reduces water infiltration and crop yields.

When farm history shows that yields differ from the soil test report expected yield, WVU Extension agents and farmers should adjust P and K fertilization recommendations proportionally.

Yield Distribution of Forage Crops

Based on acres, hay is the number one harvested crop in West Virginia (Table 1). First cut hay yield and quality is determined by when the hay is harvested. Total hay yield is determined by the date of last harvest (Figure 17). First cut yield tends to increase until the plants are at full bloom. As a rule, half of cool season forage yield in West Virginia is produced by the end of June. If hay is not harvested by this time, regrowth comes in at the bottom, but seed heads and old leaves shatter and are lost from the stand and the first cut yield does not increase. If only one cut is taken and the aftermath not grazed, only about half of the annual production is harvested. When aftermath growth is grazed, most of the nutrients are returned to the field in the manure and urine produced by the grazing livestock. These factors need to be considered when developing a fertilization program for a hay field that is not intensively managed for hay.

For hay fields being harvested only one time per year, expected hay yield will be about half of the expected yield, and the P and K fertilization recommendations can be reduced by half. For two cuts of hay, the recommendations can be reduced by 25%, which is 0.75 times the reported recommendation. Rates of nitrogen fertilization for N-fertilized grass hay should remain at 50 to 60 pounds of N per acre per harvest.

Weather and Risk

Weather can be a major limiting factor in crop production. Rainfall timing and intensity determines the number of days a year that crop growth is stressed due to lack of available soil water. Drought occurs when there is too little rainfall. Excessive rainfall can waterlog the soil and cause root death and ultimately plant death if it goes on too long. Waterlogged soil also causes denitrification of nitrogen in the soil, which reduces N available for crop growth.

Across years, about two-thirds of hay yield are within 30% of the average yield (Table 2, 0.19 to 0.39 of average). When dry years reduce hay yield below expected yield, the residual P and K applied will increase soil test values, resulting in lower fertlizer recommendations over time.

Nutrient Management

Fertilizer application is only a part of nutrient management. Nutrient management is managing the balance of nutrients removed from the field or farm, compared to the nutrients being returned.

Nutrient Balance = Nutrient Imported – Nutrient Exported

Imported nutrients include fertilizer and feed brought into a field or farm. Exported nutrients include hay, feed and animals exported from a field or farm (Table 6). Pastures are a special case, since most of the nutrients are recycled within the pasture, compared to those taken off the pasture (Table 20).

These nutrients are part of the forage, feed, mineral supplements, manure or animal products.

Recycling nutrients from manure produced from feeding forage and grain crops raised on the farm is one way to keep nutrients on the farm, reducing the need to purchase new nutrients. The key is in manure management. Manure made with good bedding to absorb all the urine produced, stored under cover to prevent nutrient loss will capture most nutrients in feed consumed by livestock. When livestock are fed in a barn but spend most of their time outdoors, much of the nutrients found in the dung and urine are lost.

Tailoring Fertilizer Recommendations to Specific Sites

Fertilizer recommendations are made based on the crop being grown, crop yield and nutrient content. The fertilizer recommendation is for the crop and yield indicated on the soil test report. If the manager knows or suspects that the yield will differ from the indicated yield, they should adjust P_2O_5 and K_2O in proportion to the relative difference in yield. For example, if the expected corn silage yield based on reported soil type is 23.4 tons per acre, but the farmer knows through weighing silage wagons that the yield is 28 tons per acre, which is 1.2 times the expected yield, and fertilizer recommendations can be increased by 20% (1.2 times the reported recommendation).

Forage quality impacts needed fertilization rates. Recommendations are made based on average forage quality for the type of hay indicated. When quality is above average due to management, such as making high quality baleage, more P and K will be removed (Table 7)

The notes section of the soil test report provides specific guidelines for fertilization management based on the crop and soil fertility measure from the soil sample submitted to the lab. When questions arise, customers should contact their local WVU Extension agent responsible for helping with soil test questions. The name and contact information for agent are listed on the report.

Trace Minerals

A number of vegetable crops are sensitive to the need for boron (B) (Table 21). Soil test levels of 0.5 to 1.5 parts per million are sufficient for most vegetable crops. Vegetable crops, which have a high or medium requirement for boron, will likely respond to a pre-plant soil application of 1 to 2 pounds per acre of actual B if soil test levels are low. The 20-20-20 fertilizer, which is widely used for fertigation, contains only 0.006% of boron. When supplementing boron, the least expensive options are Borax (11% B) and Solubor (20% B). The application rates on a 100-square-foot basis for these fertilizers when the crop responds to 1 to 2 pounds of B per acre are provided in Table 22.

Electrical Conductivity (EC)

In high tunnels where rain is excluded, fertilizers can increase the salt content in the soil, resulting in poor plant health (Table 23). Excess salt is measured as electrical conductivity (EC). Different labs report EC in different units, which are largely the same:

dS/m = mmhos/cm = mS/cm

dS/m = deciSiemens per meter

mmhos/cm = milliMhos per centimeter

mS/cm = milliSiemens per centimeter

(Clarence Chavez. Electrical conductivity of salt concentration. USDA/NRCS)

https://prod.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs144p2_067096.pdf

Conclusion

Soil testing provides an index of soil fertility and determines if supplemental fertilizer is needed to meet crop yield. Fertilizing based on soil fertility, the crop nutritional need and crop yield provide the most effective fertility program. Farm records of achieve crop yields can be used to modify and fine-tune fertilizer recommendations for a farm. Management of soil nutrients through proper fertilization and recycling of nutrient feed to livestock are important ways to optimize crop production at the lowest cost.

Table 1. Potential crop yield per acre for selected crops under ideal management and soil and weather conditions, reported yield and estimated yield under good management and crop acreage in West Virginia based on 2018 Census of Agriculture.

Crop	Potential yield	Census of Agriculture Average Yield	Soil Survey yields	West Virginia acreage
Alfalfa hay	10 tons	2.9 tons	2.0-5.0 tons	17,000
Mixed grass hay	6 tons	1.8 tons	1.5-5.0 tons	570,000
Corn grain	300 bushels	152 bushels	60-140 bushels	35,000
Corn silage	NA	20 tons	NA	13,000
Oats	120 bushels	NA	35-80 bushels	NA
Soybeans	80 bushels	54 bushels	NA	26,000
Wheat	100 bushels	69 bushels	20-50 bushels	4,000
Barley	110 bushels	NA	NA	NA
Pasture	240	NA	50-200 AUD	1,595,463
MIG Pasture	310	NA	80-260 AUD	combined

Table 2. Long term yield of grass and legume forage grown on good soils under good management in the Northeast (grasses received 170 to 180 pounds of N per acre per year).

Species	**Site Years**	**Yield (tons per acre)**	**SD**	**CV**
Grasses				
Tall Fescue	55	5.0	± 1.4	0.28
Orchardgrass	68	4.8	± 1.2	0.25

Reed Canarygrass	36	4.8	± 1.5	0.31
Smooth Bromegrass	35	4.4	± 1.1	0.25
Timothy	54	4.3	± 1.2	0.28
Perennial Ryegrass	25	3.6	± 1.4	0.39
Legumes				
Alfalfa	122	6.2	± 1.2	0.19
Red clover	46	4.4	± 1.5	0.34
SD: Range that includes 66% of observations CV: SD expressed as a ratio to the average				

Table 3. Expected small grain yields relative to corn yields on West Virginia soils based on county soil surveys.

Regression	R^2	SD_{reg}	N
Wheat bushels = 7.1 + 0.305 Corn bushels	0.73	3.6	574
Oats bushels = 19.8 + 0.455 Corn bushels	0.70	5.8	502
Hay tons = 2.3 + 0.0174 Corn bushels	0.74	0.26	152

Table 4. Comparison of common cool season grasses, alfalfa and red clover to orchardgrass based on regional variety trails (WV, VA, PA, and KY). Grasses fertilized at 160 to 180 pounds of N per acre per year.

Regression	R^2	SD_{reg}	Number of Site Years
Orchardgrass = 0.76 Alfalfa SE 0.04	0.95	1.0	23
Red Clover = 0.94 Orchardgrass SE 0.07 (ns 1.00)	0.89	1.5	25
Red Clover = 0.72 Alfalfa SE 0.05	0.91	1.4	23
Tall Fescue = 1.07 Orchardgrass SE 0.02	0.98	0.7	49
Timothy = 0.87 Orchardgrass SE 0.03	0.95	1.0	48
Smooth Bromegrass = 0.87 Orchardgrass SE 0.02	0.98	0.6	31
Reed Canarygrass = 0.92 Orchardgrass SE 0.03	0.97	0.8	36
Perennial Ryegrass = 0.73 Orchardgrass	0.95	0.9	25

SE 0.03			
Intercepts were not significantly different from zero and were removed with the SDreg remaining the same or decreasing.			

Table 5. Crop yield units and nutrient content on a dry matter (DM) basis (based on average nutrient content of samples analyzed by Dairy One Forage Testing Lab).

Crop	Yield Units and Weight	Nutrient Content on DM Basis			
		DM	CP	P	K
		Percent			
Alfalfa	Ton	90	21.3	0.273	2.35
Barley, Grain	48 lbs. Bu.	87	11.9	0.395	0.55
Bermudagrass Hay	Ton	90	10.8	0.197	1.68
Cereal Silage, Barley/Oats/Rye	Ton	35	12.2	0.304	2.20
Cereal Silage, Wheat/Triticale	Ton	35	12.6	0.333	2.39
Corn, Grain	56 lbs. Bu.	85	9.1	0.311	0.41
Corn, Silage	Ton	35	8.3	0.235	1.09
Oats	32 lbs. Bu.	87	12.6	0.390	0.53
Pasture	Ton	25	18.1	0.330	2.44
Rye, Grain	56 lbs. Bu.	89	11.2	0.345	0.562
Sorghum, Grain	56 lbs. Bu.	87	12.2	0.380	0.42
Soybeans, Grain	60 lbs. Bu.	87	39.9	0.644	1.86
Tallgrass N-Fert Hay	Ton	90	10.8	0.239	1.86
Tallgrass-Legume Hay	Ton	90	12.3	0.262	1.91
Wheat, Grain	60 lbs. Bu.	87	13.6	0.380	0.45

Table 6. Fertilizer nutrient units removed by crops based on their elemental nutrient content.

Crop	Fertilizer Nutrient Content Pounds per standard DM and unit weigh				
	Standard DM	Standard unit weight pounds	N	P_2O_5	K_2O
Alfalfa	90	2000	61.3	11.3	50.8
Barley, Grain	87	48	0.82	0.39	0.29
Bermudagrass Hay	90	2000	31.1	8.16	36.3
Cereal Silage, Barley/Oats/Rye	35	2000	13.7	4.89	18.5
Cereal Silage, Wheat/Triticale	35	2000	14.1	5.36	20.1
Corn, Grain	85	56	0.73	0.36	0.24
Corn, Silage	35	2000	9.30	3.78	9.16
Oats	87	32	0.58	0.26	0.18
Pasture	100	2000	57.9	15.2	58.6
Sorghum, Grain	87	56	0.98	0.44	0.25
Soybeans, Grain	87	60	3.45	0.80	1.21
Grass N-Fert Hay	90	2000	31.1	9.89	40.2
Grass-clover Hay	90	2000	35.4	10.9	41.3
Wheat, Grain	87	60	1.18	0.47	0.29

Table 7. Fertilizer nutrient removal of nitrogen (N), phosphate (P_2O_5) and potash (K_2O) in pounds per ton of forage dry matter (DM) by forage crops based on forage quality measured as crude protein (CP) as a percent of DM (N=2020, 5% outliers removed) with the associated standard deviation (SD, average ± SD containing 66% of the observations).

CP % DM[1]	N per ton[2]	P_2O_5 per ton[3]	K_2O per ton[4]
6	19	10	33
8	26	11	37
10	32	12	41
12	38	13	46
14	45	14	50
16	51	14	54
18	58	15	58
20	64	16	62
22	70	17	66
24	77	18	71
SD	0	3	10

1. Average CP% ± SD: Dry hay 11±3, Baleage 13±4, Pasture 19±6
2. N per ton = 3.2 CP%
3. P_2O_5 per ton = 7.9 + 0.41 CP%
4. K_2O per ton = 20.6 + 2.08 CP%

Table 8. Plant-available soil water content as a percent of soil volume between field capacity and wilting point for soils differing in texture.

Soil texture	Total water at field capacity	Water at wilting point	Plant available water
Sand	11	3	8
Sandy loam	20	7	13
Loam	29	11	18
Silt loam	36	14	22
Clay loam	37	17	20
Clay	37	22	15

Adapted from Brady and Weil, “The Nature and Properties of Soils, 13th Edition”

Table 9. Preferred soil pH range for agronomic and vegetable crops.

Crop	pH range		Crop	pH range	
	Low	High		Low	High
Agronomic Crops					
Alfalfa	6.8	7.0	Millet foxtail	5.8	6.2
Barley	6.0	6.5	Oats	6.0	6.5
Birdsfoot trefoil	5.8	6.5	Orchardgrass	5.8	6.2

Buckwheat	5.5	6.0	Pearl millet	5.5	6.5
Caucasian bluestem	5.5	6.2	Red top	5.8	6.2
Clover, alsike	5.8	6.5	Reed Canarygrass	5.8	6.2
Clover, crimson	5.8	6.5	Rye, cereal	5.8	6.2
Clover, red	5.8	6.5	Ryegrass, annual	5.8	6.2
Clover, sweet	6.5	7.0	Ryegrass, perennial	5.8	6.2
Clover, white	5.8	6.5	Smooth bromegrass	5.8	6.7
Crown vetch	5.5	6.5	Sorghum	5.8	6.2
Eastern gamagrass	5.8	6.5	Soybeans	5.8	6.5
Fescue, sheep	5.0	6.2	Sudangrass	5.8	6.2
Fescue, tall	5.6	6.2	Sunflower	5.8	6.0
Hairy vetch	6.0	6.5	Switchgrass	5.5	6.5
Kentucky bluegrass	6.0	6.5	Tall oatgrass	5.8	6.2
Lespedeza, bicolor	5.5	6.2	Timothy	5.8	6.2
Lespedeza, sericea	5.0	6.2	Wheat, cereal	5.8	6.2
Matua prairie grass	6.0	7.0	Winter pea	6.0	6.5
Vegetable Crops					
Asparagus	6.0	8.0	Kale	6.0	7.5
Bean, pole	6.0	7.5	Lettuce	6.0	7.0
Beet	6.0	7.5	Pea, sweet	6.0	7.5
Broccoli	6.0	7.0	Pepper, sweet	5.5	7.0
Brussels sprout	6.0	7.5	Potato	4.8	6.5
Cabbage	6.0	7.0	Pumpkin	5.5	7.5
Carrot	5.5	7.0	Radish	6.0	7.0
Cauliflower	5.5	7.5	Spinach	6.0	7.5
Celery	5.8	7.0	Squash, crookneck	6.0	7.5
Chive	6.0	7.0	Squash, Hubbard	5.5	7.0
Cucumber	5.5	7.0	Tomato	5.5	7.5
Garlic	5.5	8.0			

Table 10. Preferred soil pH range for flowers.

Flower	pH range		Flower	pH range	
	Low	High		Low	High
Alyssum	6.0	7.5	Gladiolus	5.0	7.0
Aster, New England	6.0	8.0	Hibiscus	6.0	8.0
Baby’s breath	6.0	7.0	Hollyhock	6.0	8.0
Bachelor’s button	6.0	7.5	Hyacinth	6.5	7.5
Bee balm	6.0	7.5	Iris, blue flag	5.0	7.5
Begonia	5.5	7.0	Lily-of-the-valley	4.5	6.0
Black-eyed Susan	5.5	7.0	Lupine	5.0	6.5
Bleeding heart	6.0	7.5	Marigold	5.5	7.5
Canna	6.0	8.0	Morning glory	6.0	7.5
Carnation	6.0	7.0	Narcissus, trumpet	5.5	6.5
Chrysanthemum	6.0	7.5	Nasturtium	5.5	7.5
Clematis	5.5	7.0	Pansy	5.5	6.5
Coleus	6.0	7.0	Peony	6.0	7.5
Coneflower, purple	5.0	7.5	Petunia	6.0	7.5
Cosmos	5.0	8.0	Phlox, summer	6.0	8.0
Crocus	6.0	8.0	Poppy, oriental	6.0	7.5
Daffodil	6.0	6.5	Rose, hybrid tea	5.5	7.0
Dahlia	6.0	7.5	Rose, rugosa	6.0	7.0
Daisy, Shasta	6.0	8.0	Snapdragon	5.5	7.0
Daylily	6.0	8.0	Sunflower	6.0	7.5
Delphinium	6.0	7.5	Tulip	6.0	7.0
Foxglove	6.0	7.5	Zinnia	5.5	7.0
Geranium	6.0	8.0			

Table 11. Preferred soil pH range for trees and shrubs.

Tree or Shrub	pH range		Tree or Shrub	pH range	
	Low	High		Low	High
Apple	5.0	6.5	Juniper	5.0	6.0
Ash	6.0	7.5	Laurel, mountain	4.5	6.0
Azalea	4.5	6.0	Lemon	6.0	7.5
Basswood	6.0	7.5	Lilac	6.0	7.5
Beautybush	6.0	7.5	Maple, sugar	6.0	7.5
Birch	5.0	6.5	Oak, white	5.0	6.5
Blackberry	5.0	6.0	Orange	6.0	7.5
Blueberry	4.0	6.0	Peach	6.0	7.0
Boxwood	6.0	7.5	Pear	6.0	7.5
Cherry, sour	6.0	7.0	Pecan	6.4	8.0
Chestnut	5.0	6.5	Pine, red	5.0	6.0
Crab apple	6.0	7.5	Pine, white	4.5	6.0
Dogwood	5.0	7.0	Plum	6.0	8.0
Elder, box	6.0	8.0	Raspberry, red	5.5	7.0
Fir, balsam	5.0	6.0	Rhododendron	4.5	6.0
Fir, Douglas	6.0	7.0	Spruce	5.0	6.0
Hemlock	5.0	6.0	Walnut, black	6.0	8.0
Hydrangea, blue-flowered	4.0	5.0	Willow	6.0	8.0
Hydrangea, pink-flowered	6.0	7.0			

Table 12. Average impact of nitrogen fertilization on relative yield and achieved yield of tall fescue production when the yield potential is 5 tons per acre at 175 pounds of N per acre (midpoint rate in Table 2) and the marginal yield return to the last 50 pounds N applied.

N rate pounds per acre	Relative Yield	Achieved yield (tons per acre)	Yield added from last 50 pounds N per acre (tons per acre)	Pounds DM per pound N from last 50 pounds N
0	0.41	2.46	-	-
50	0.56	3.35	0.90	36

100	0.69	4.13	0.78	31
150	0.79	4.73	0.60	24
200	0.88	5.27	0.54	22
250	0.94	5.63	0.36	14
300	0.98	5.87	0.24	10
350	1.00	5.99	0.12	5
400	1.00	5.99	0.00	0

Table 13. Animal grazing days per acre for steers weighing an average of 700 pounds and animal average daily gain (ADG) and total animal gain per acre (pounds live weight) (Blaser's 10-year average, 700-pound steer, Middleburg, Virginia, Virginia Tech Research Bull 45).

Pasture	Steer days per acre	ADG	Gain per acre
Orchardgrass ladino clover	257	1.28	329
Orchardgrass 200 pounds N per acre	311	1.07	333
Tall fescue ladino clover	303	1.02	309
Tall fescue 200 pounds N per acre	403	0.91	367
Bluegrass white clover	258	1.21	312

Table 14. Tons of effective neutralizing lime (ENV) required per acre, tilled in to a 6-inch depth, to raise soil pH to 6.6 based on buffer pH of the soil and the regression form using in the recommendation software.

Buffer pH	Lime Requirement (Tons ENV Lime/A)	
	Table	Regression
6.6	0.0	0.1
6.4	0.9	0.9
6.2	1.9	1.9
6.0	3.0	2.9
5.8	4.2	4.2
5.6	5.6	5.6
5.4	7.1	7.1
5.2	8.7	8.7
5.0	10.5	10.5
4.8	12.4	12.4

4.6	14.4	14.5
4.4	16.5	16.7
4.2	18.8	19.0
LR = 100.1 - 26.56 * Buffer pH + 1.728 *Buffer pH^2		

Table 15. Expected crop yield by crop code and soil yield class.

Crop Code	**Crop**	Yield Units	DM %	Soil Yield Class				
				I	II	III	IV	V
				Expected Yield				
C01	Grass-clover Hay	Tons per acre	90	4.5	4.0	3.5	3.0	2.5
C02	Grass Hay N-Fertilized	Tons per acre	90	5.0	4.5	4.0	3.5	3.0
C03	Alfalfa and Alfalfa-grass Hay	Tons per acre	90	6.2	5.5	4.5	3.5	3.0
C04	Bermudagrass Hay	Tons per acre	90	6.0	5.5	4.5	3.5	3.0
C05	Grass-clover Pasture Rotationally stocked	AUM		8.0	7.0	6.2	5.3	4.4
C06	Grass Pasture Set Stocked	AUM		5.4	4.7	4.2	3.6	3.0
C07	Grass-clover seeding	Tons per acre	90	4.5	4.0	3.5	3.0	2.5
C08	Grass seeding	Tons per acre	90	5.0	4.5	4.0	3.5	3.0
C09	Alfalfa seeding	Tons per acre	90	6.2	5.5	4.5	3.5	3.0
C10	Corn, Grain	Bushels per acre	90	200	180	160	140	120
C11	Corn, Silage	Tons per acre	35	27.4	25.4	23.4	21.4	19.5
C12	Barley, Standard management	Bushels per acre	90	100	70	60	50	30
C13	Barley, Intensive management	Bushels per acre	90	115	88	75	63	38
C14	Wheat, Standard management	Bushels per acre	90	64	56	48	40	24
C15	Wheat, Intensive management	Bushels per acre	90	80	70	60	50	30
C16	Soybeans, Early season	Bushels per acre	90	50	40	35	25	20
C17	Soybeans, Late season	Bushels per acre	90	40	34	25	18	15
C18	Oats	Bushels per acre	90	80	80	70	60	60
C19	Cereal Silage, Barley/Oats/Rye	Tons per acre	35	10	9	7	4.5	3

C20	Cereal Silage, Wheat/Triticale	Tons per acre	35	12	11	9	6	4
C21	Sorghum, Grain	Bushels per acre	90	140	120	100	90	80

Soil yield class II is the default yield if a soil type is not provided.

Table 16. Historic soil survey crop yield classes were updated for hay crops and corn based on regional research and West Virginia experience.

Soil Crop Yield Class	Hay tons NRCS	Corn yield bushels NRCS	Hay adjusted factor	Hay tons adjusted CES	Hay RYE	Corn adjusted factor	Corn yield adjusted CES	Corn RYE
1	4.2	126	1.18	5.0	5.0	1.59	200	200
2	3.9	112		4.6	4.5		178	180
3	3.4	100		4.0	4.0		158	160
4	3.1	90		3.6	3.5		143	140
5	2.7	77		3.2	3.0		123	120

Crop yields across West Virginia soil types based on SSURGO used 90% inclusion by removing the top 5% and bottom 5% of reported historic yields. Yields are ranked into five classes, each representing a 20% range from the top 20% to the bottom 20%. Top quintile hay yields are adjusted to 5.0 tons per acre as observed at a 170 to180 pounds of N rate for three to four harvests per year. Top quintile corn grain yields are adjusted to 200 bushels per acre as reported by a number of producers and county agents in West Virginia. Corn silage is estimated from corn grain yield based on research conducted in Virginia where: Corn silage tons = 0.0989 Corn grain bushels + 7.6

Table 17. Example of predominant soil series and their associated, soil management group, crop class, soil yield class and environmental sensitivity ratings.

Soil Series	**Soil Mgt Group**	**Crop Class**						**Environmental Sensitivity Ratings**	
		Corn	**Grain Sorghum**	**Small Grain**	**Soybeans**	**Alfalfa**	**Grass, Clover, Hay, Pasture**	**Sensitivity**	**Limitation**
Airmont	BB	IV	IV	III	IV	NS*	III	M	Wetness
Albrights	BB	IV	IV	III	IV	NS*	III	M	Wetness
Albrights (drained)	W	IV	IV	IV	III	NS*	IV	H	Drainage
Allegheny	L	II	II	I	II	III	II	L	-
Alluvial Land, wet	NN	V	V	V	V	NS	IV	M	Leaching
Andover	BB	IV	IV	III	IV	NS	III	H	Wetness
Andover (drained)	W	IV	IV	IV	III	NS	IV	H	Drainage
Ashton	L	II	II	I	II	III	II	L	-
Atkins	NN	V	V	V	V	NS	IV	H	Wetness
Atkins (drained)	H	II	II	III	II	NS	IV	H	Drainage
Bagtown	CC	IV	IV	II	IV	NS	III	M	Leaching
Barbour	CC	IV	IV	II	IV	NS	III	M	Leaching
Basher	HH	IV	IV	III	IV	NS	IV	L	-
Basher (drained)	A	I	I	I	Ia	I	I	H	Drainage
Beech	HH	IV	IV	III	IV	NS	IV	L	-
Beech (drained)	L	II	II	I	II	III	II	H	Drainage
Belmont	M	II	II	I	II	I	II	L	-
Benevola	M	II	II	I	II	I	II	L	-
Berks	FF	IV	IV	III	IV	NS	III	M	Leaching
Bethesda	FF	IV	IV	III	IV	NS	III	M	Leaching
Bigpool	L	IIb	IIb	I	II	III	II	L	-
Blackthorn	G	IIa	IIa	I	II	II	I	M	Leaching
Blago	Z	IVa	IVa	IV	III	NS*	III	H	Wetness
Blago (drained)	P	IIb	IIb	II	II	NS*	III	H	Drainage

Table 18. Definition of relative soil fertility ratings based on Mehlich-3 extraction evaluated by ICP expressed as parts per million soil (ppm).

Rating	M-3 P ppm	M-3 K ppm	M-3 Ca ppm	M-3 Mg ppm	Rating
Low -	0	0	0	0	Low -
Low	5	15	200	25	Low
Low +	10	30	400	50	Low +
Medium -	15	45	600	75	Medium -
Medium -	20	60	800	100	Medium -
Medium +	25	75	1000	125	Medium +
Optimum -	30	90	1200	150	Optimum -
Optimum	40	120	1600	200	Optimum
Optimum +	50	150	2000	250	Optimum +
Excess	60	180	2400	300	Excess

Values in cells are the low end of the rating with the rating extending to just below (<) the value in the next higher cell.

Table 19. Crop removal multiplication factors used to increase fertilizer recommendations as a function of crop removal and relative soil test level to reflect what the plant needs for production at that soil test level and to increase or decrease soil test value over time.

Relative Soil Test Level	Crop Removal Multiplication Factor			
	P_2O_5 Removal		K_2O Removal	
	Minimum Sufficiency	Build to Optimum and Maintain	Minimum Sufficiency	Build to Optimum and Maintain
Low -	3.0	3.00	1.4	1.6
Low	2.5	2.67	1.3	1.5
Low +	2.0	2.33	1.2	1.4
Medium -	1.5	2.00	1.1	1.3
Medium	1.0	1.67	1.0	1.2
Medium +	0.5	1.33	0.5	1.1
Optimum -	0.0	1.00	0.0	1.0
Optimum	0.0	0.50	0.0	0.5

<table>
<tr><td>Optimum +</td><td>0.0</td><td>0.00</td><td>0.0</td><td>0.0</td></tr>
<tr><td>Excess</td><td>0.0</td><td>0.00</td><td>0.0</td><td>0.0</td></tr>
<tr><td colspan="5">For grain crops at low soil test level, whole plant nutrient removal needs to be used since that need is greater than just the grain removal rate. Nutrients not taken off in the grain or harvested straw or stover will increase soil fertility.</td></tr>
</table>

Table 20. Magnitude of nutrient cycling and animal product removal on nutrient movement within and out of a pasture.

Nutrient	N	P_2O_5	K_2O
Nutrient Movement	Pounds Fertilizer		
Nutrient cycled by grazing 6 AUM (2.3 tons DM)	161	40	152
Nutrients removed in a 500-pound steer	16	7	1
Nutrients removed in 100 hundredweight milk	51	23	17

Table 21. Boron requirement of vegetable crops.

High Requirement (>1 pound per acre)	**Medium Requirement (0.5-1.0 pound per acre)**	**Low Requirement (<0.5 pound per acre)**
Asparagus	Tomato	Corn
Beets	Lettuce	Pea
Chard	Sweet potato	Bean
Cabbage	Carrot	Potato
Broccoli	Onion	Cucumber
Cauliflower	Leek	
Brussels sprouts	Spinach	
Collards		
Celery		
Rutabaga		

Adapted from: Knott’s Handbook for Vegetable Growers, 5th ed. and Midwest Vegetable Production Guide for Commercial Growers (ID-56).

Table 22. Application rate of boron (B) containing fertilizers based on soil test levels of B.

Fertilizer	% B	Application rates based on soil test level (ounces per 100 square-feet)		
		Optimum	Medium	Low
Borax	11	0	0.3	0.6
Solubor	20	0	0.2	0.4

Table 23. Electrical conductivity interpretation for soils using a 1:2 soil to water extract.

EC mmhos/cm (or mS/cm)	Effect
<0.40	Salinity effects mostly negligible, excepting possible beans and carrots.
0.40 – 0.80	Very slightly saline; but yields of very salt Sensitive crops such as flax, clovers (alsike, red), carrots, onions, bell peppers, lettuce, sweet potatoes may be reduced by 25% to 50%.
0.81 – 1.20	Moderately saline. Yield of salt-sensitive crops restricted. Seedlings may be injured. Satisfactory for well drained greenhouse soils. Crop yields reduced by 25% to 50% may include broccoli and potato plus the other plants above.
1.21 – 1.60	Saline soils. Crops tolerant include cotton, alfalfa, cereals, grain sorghum, sugar beets, Bermuda grass, tall wheat grass and Harding grass. Salinity higher than desirable for greenhouse soils.
1.61 – 3.20	Strongly saline. Only salt-tolerant crops yield satisfactory. For greenhouse crops, leach soil with enough water so that 2 to 4 quarts (2 to 4 liters) pass through each square foot (0.1 square-meter) of bench area, or one pint of water (0.5 liter) per inch (15 centimeters) pot; repeat after one hour. Repeat again if readings are still in high range.
> 3.20	Very strongly saline. Only salt-tolerant grasses, herbaceous plants, certain shrubs and trees will grow.

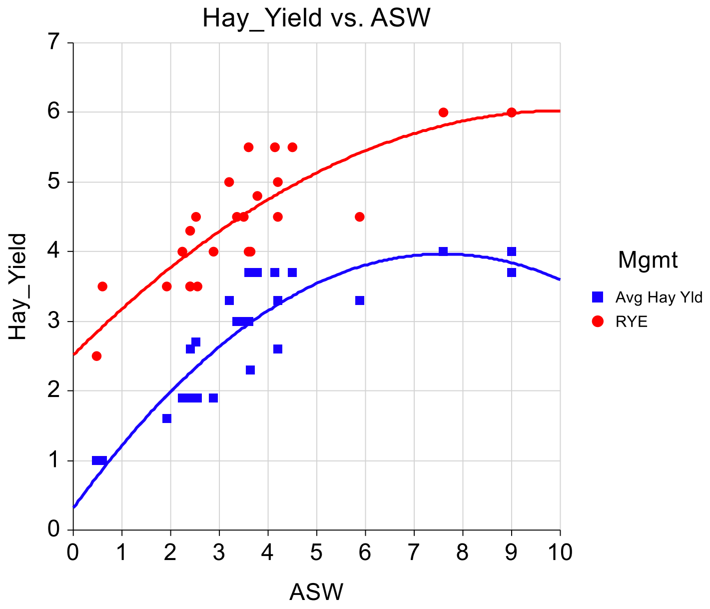

Figure 1. Plant available soil water (ASW) held within the potential rooting zone of the soil (depth to seasonal high-water table or bed rock) has a major impact on realistic yield expected (RYE) from a soil and average hay yield achieved from the soil (Avg Hay Yld).

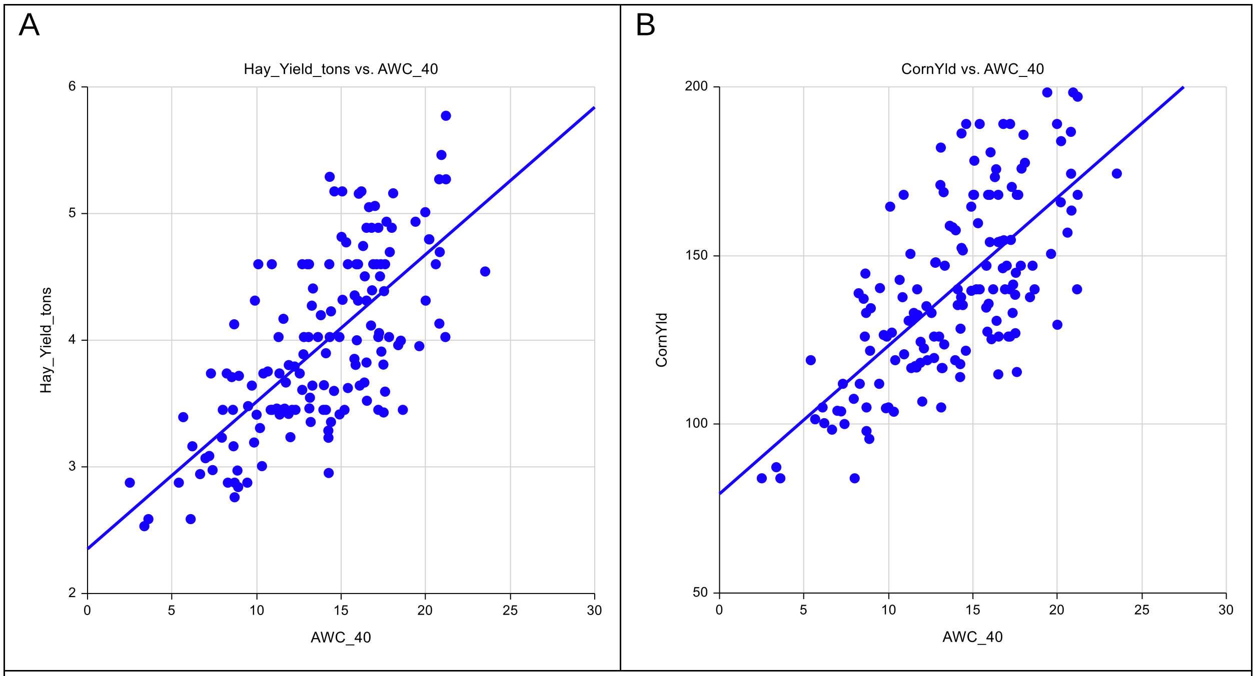

Figure 2. Effect of available soil water content (AWC, centimeters) in the top 40 centimeters (16 inches) of soil relative to expected hay (A) and corn (B) yield in West Virginia soils based on historic yield estimates adjusted to modern fertilization and management practices.

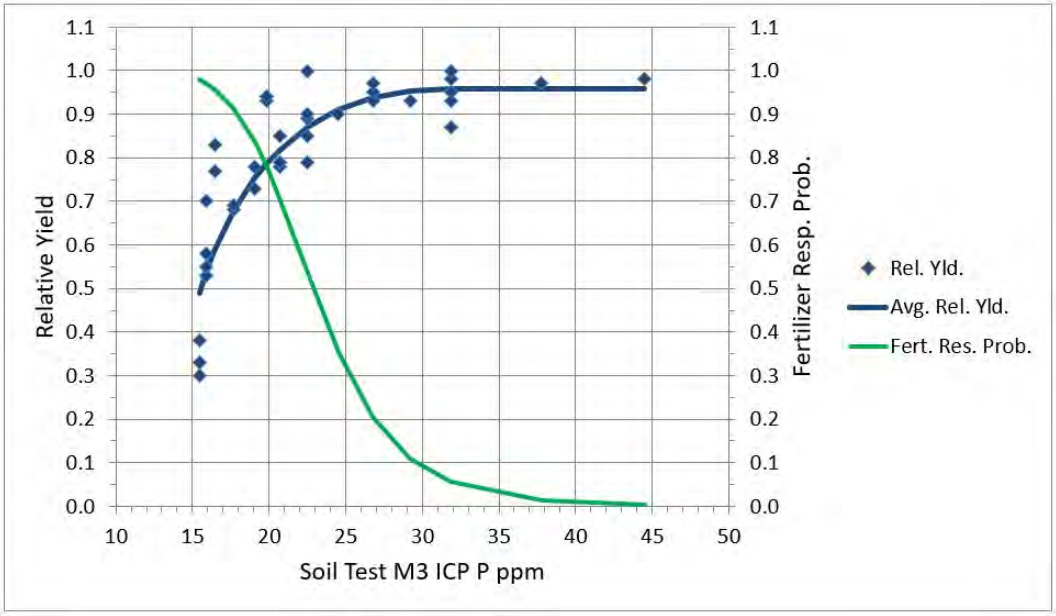

Figure 5. Yield of none fertilized crops relative to the yield of fertilized crops (Rel_Yield) grown on soils differing in Mehlich-3 soil test phosphorus (M3_P_ppm, adapted from Lathwell and Peach adjusted to M-3 ICP soil test) and probability of crops responding to P fertilization needed to bring crop yields to within 10% of maximum yield.

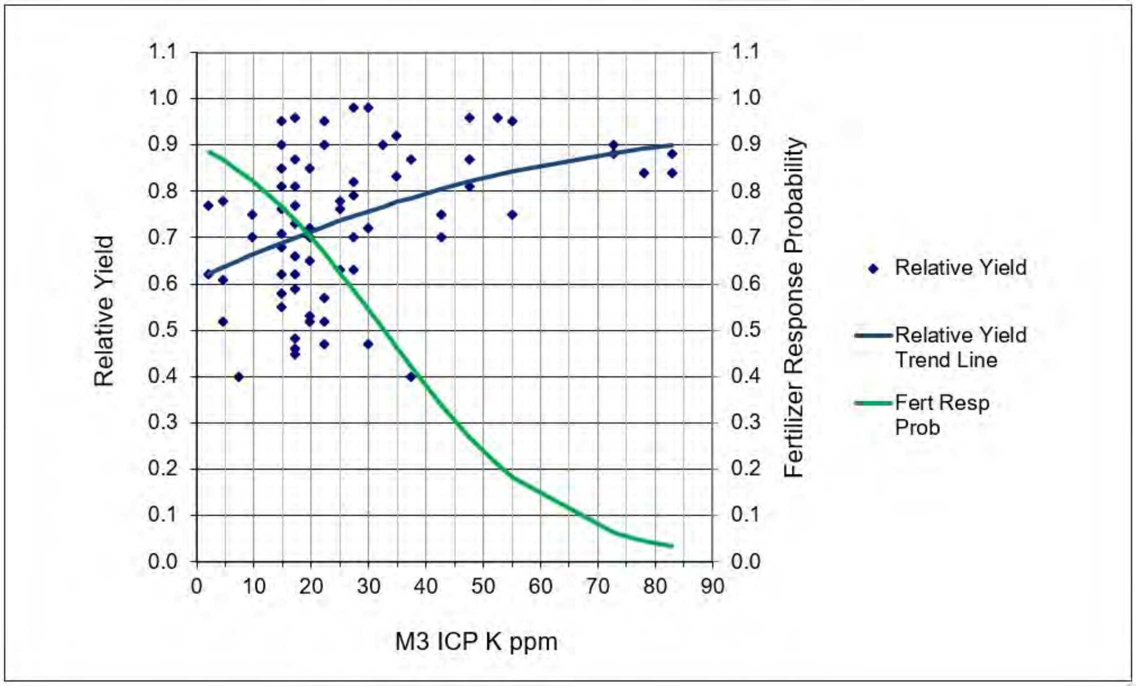

Figure 6. Yield of none fertilized crops relative to the yield of fertilized crops (Rel_Yield) grown on soils differing in Mehlich-3 soil test values for potassium (M3_K_ppm, adapted from Lathwell and Peach adjusted to M-3 ICP soil test) and probability of crops responding to K fertilization needed to bring crop yields to within 10% of maximum yield.

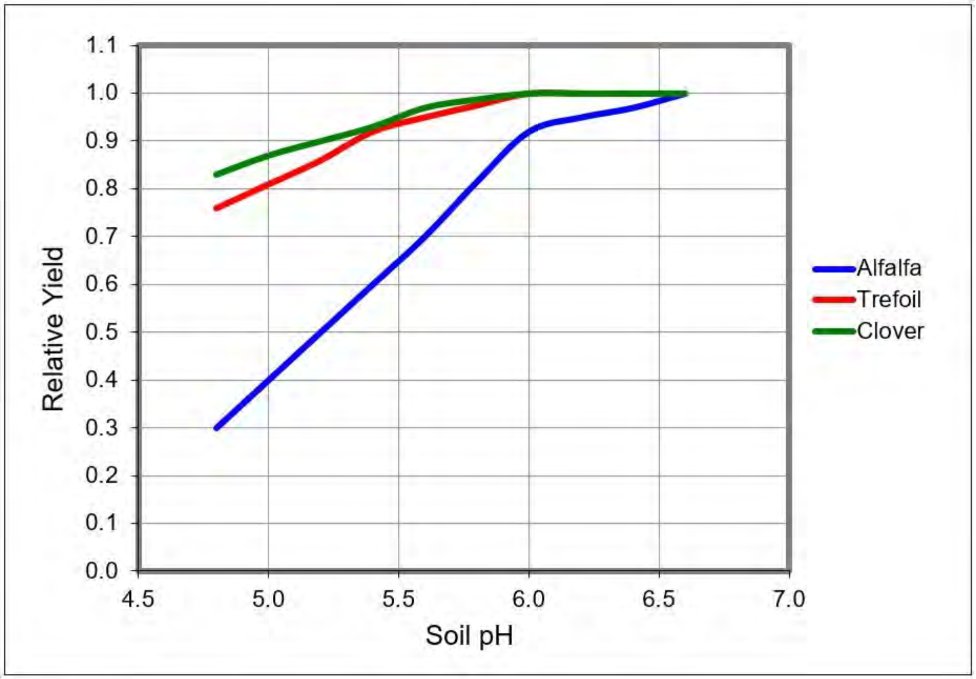

Figure 7. Yield response of forage legumes to soil pH due to nitrogen fixation by nodule rhizobia and their response to soil pH.

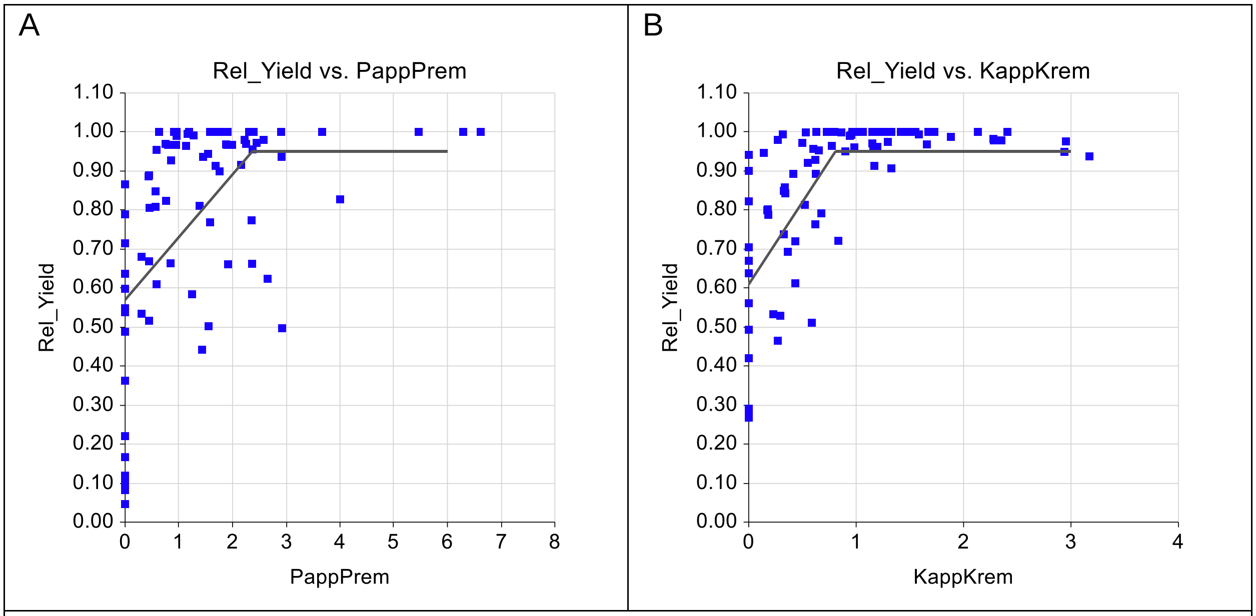

Figure 8. A. Relative yield (Rel_Yield) of crops fertilized with phosphorus (P) as P_2O_5 when application rates are measured as a multiple of crop removal rate (PappPrem = P applied as fertilizer / P removed in the crop). B. Rel_Yield of crops fertilized with potassium (K) as K_2O when application rates are measured as a multiple of crop removal rate (KappPrem = K applied as fertilizer / K removed in the crop).

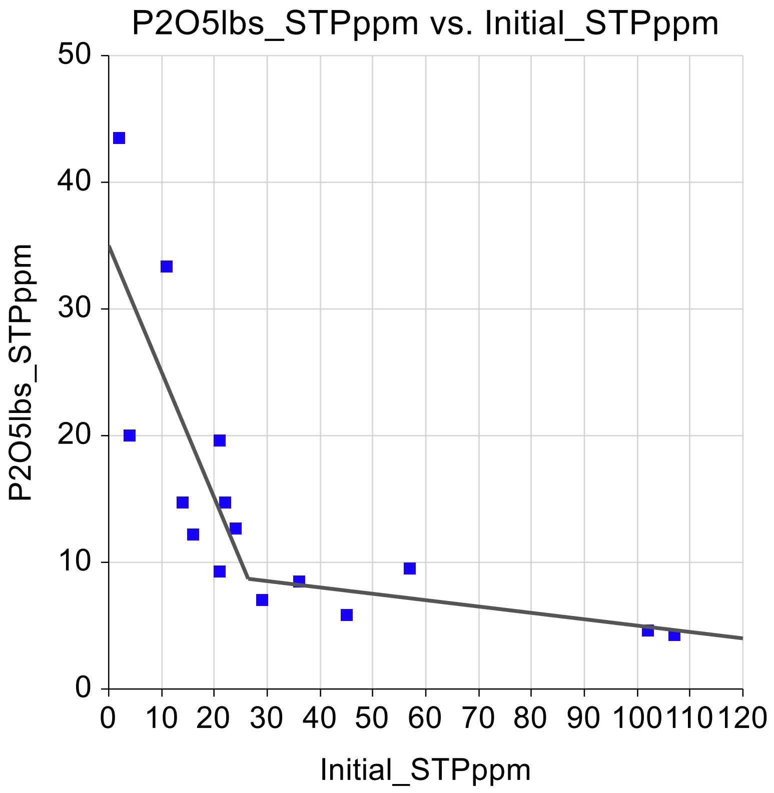

Figure 9. Phosphorus soil test (STPppm) change following the addition of phosphorus fertilizer (P_2O_5) to 16 Kentucky soils as if mixed into the top 6 to 8 inches of soil (values adjusted to M3 P ppm). (Adapted from Thom, William and James Dollarhide. 2002.Univ. KY Coop. Ext. Agron. Notes Vol 34, No. 2.).

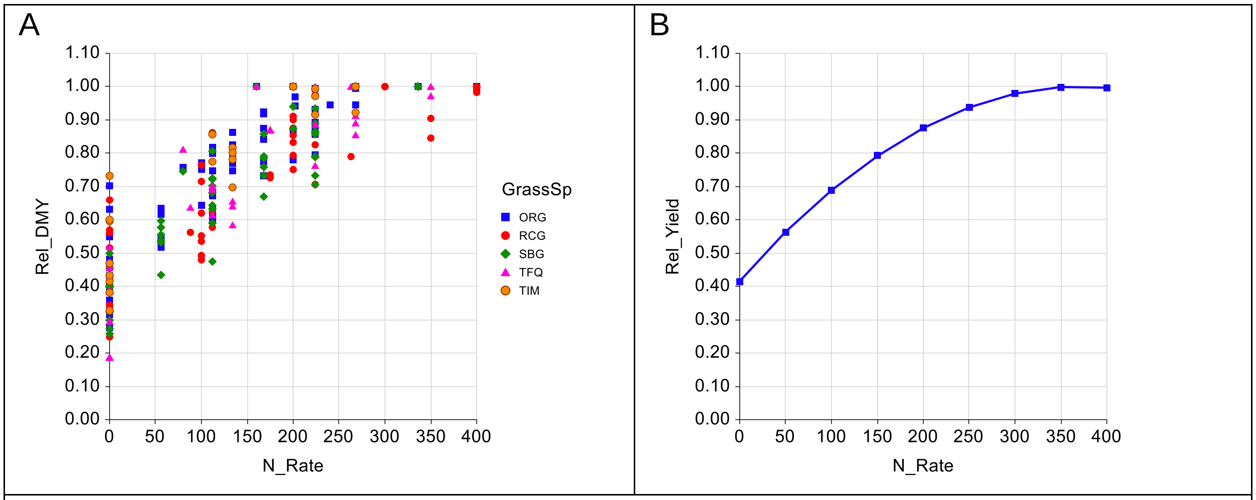

Figure 10. Grass growth reported as relative dry matter yield (Rel_DMY) response to nitrogen fertilizer (N_Rate, pounds N per acre) across different cool-season species (ORG orchardgrass, RCG reeds canarygrass, SBG smooth bromegrass, TFG tall fescue, TIM timothy) (A) and average relative yield response (B). (Based on a literature review of N trials on cool-season grasses.)

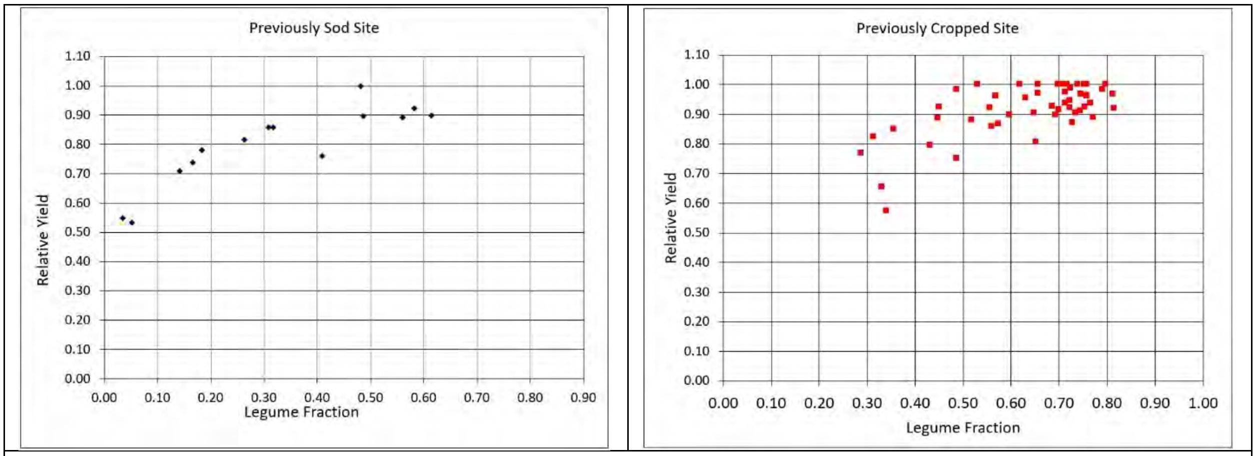

Figure 11. Effect of legume fraction in harvested forage on relative yield for a previously sod site where soil organic matter was high vs. a previously cropped site where soil organic matter was low.

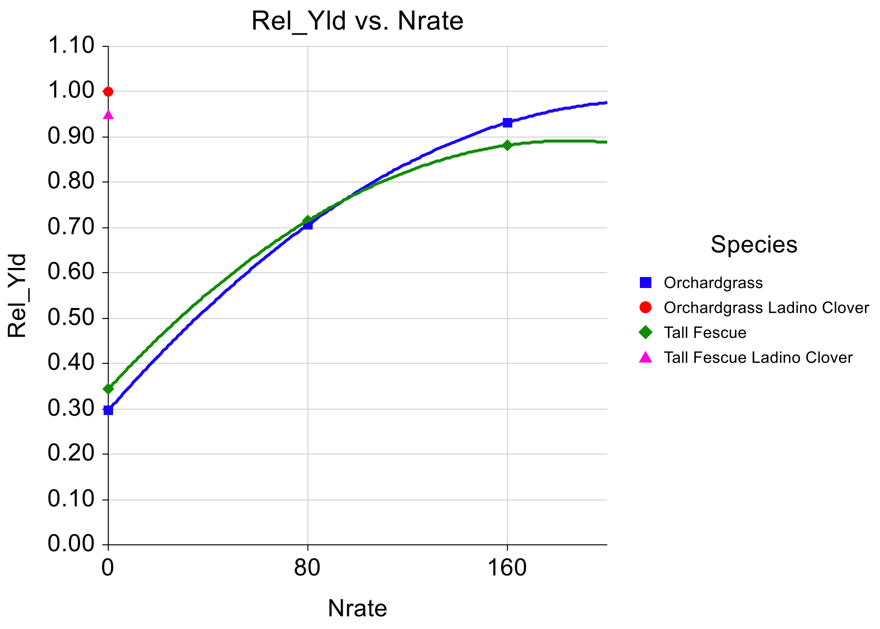

Figure 12. Orchardgrass and tall fescue response to nitrogen fertilizer versus ladino clover providing the source of nitrogen (18% to 34% ladino clover). Two-year average in Maryland. Mix yielded as much or 10% more than 160 pounds N on the grass.

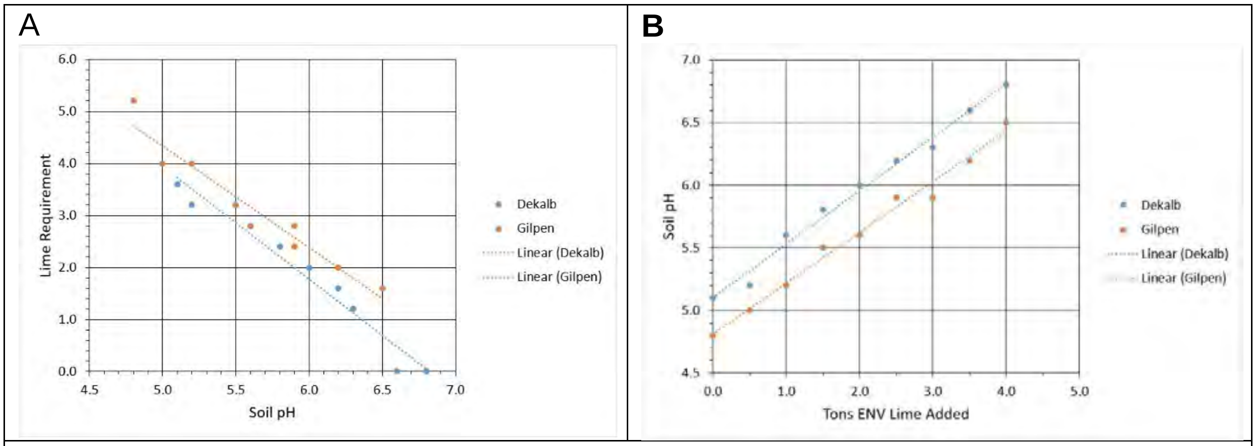

Figure 13. Influence of soil pH on lime requirement of two West Virginia soils and the resulting soil pH as 100% effective neutralizing value lime (ENV) is added to the soil.

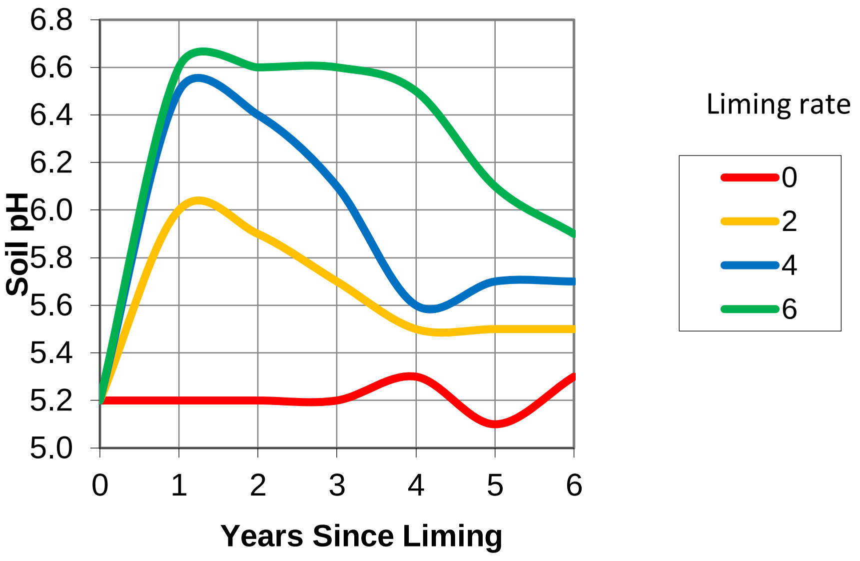

Figure 14. Change in soil pH over time when lime is incorporated into the top 6 to 8 inches of the soil and soil samples are taken to a 6-inch depth (Cornell Univ., Lime I Study, Mt. Pleasant).

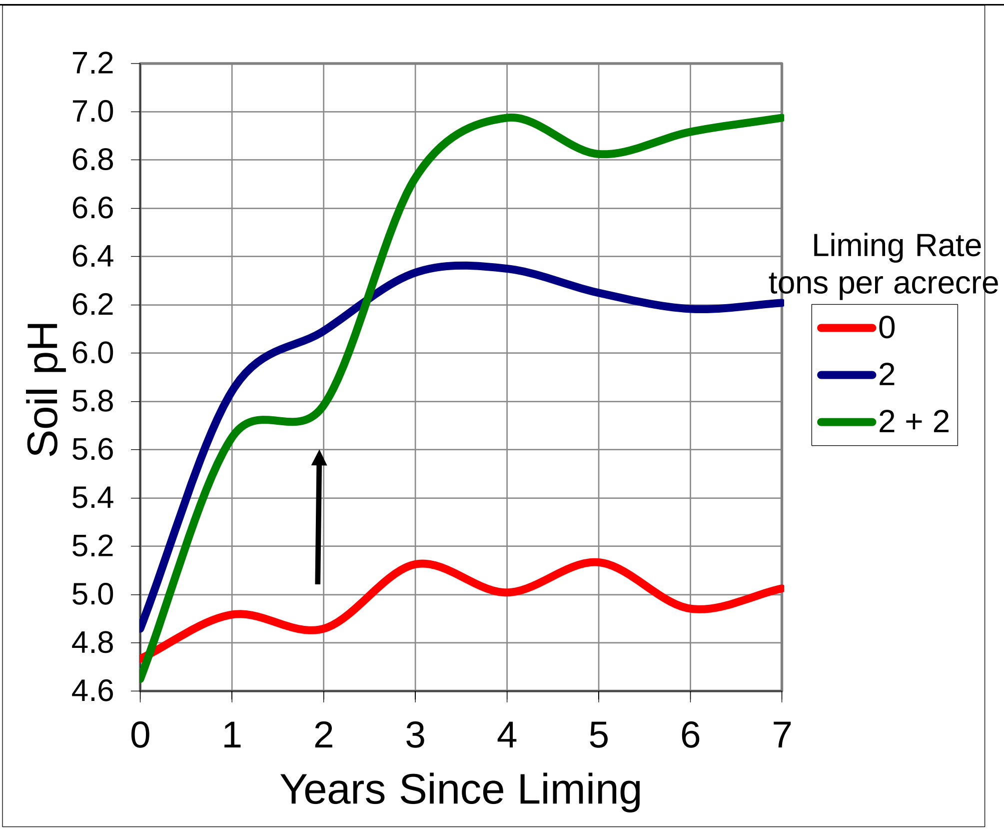

Figure 15. Change in the soil pH over time in the top 2 inches of the soil when lime is surface applied.

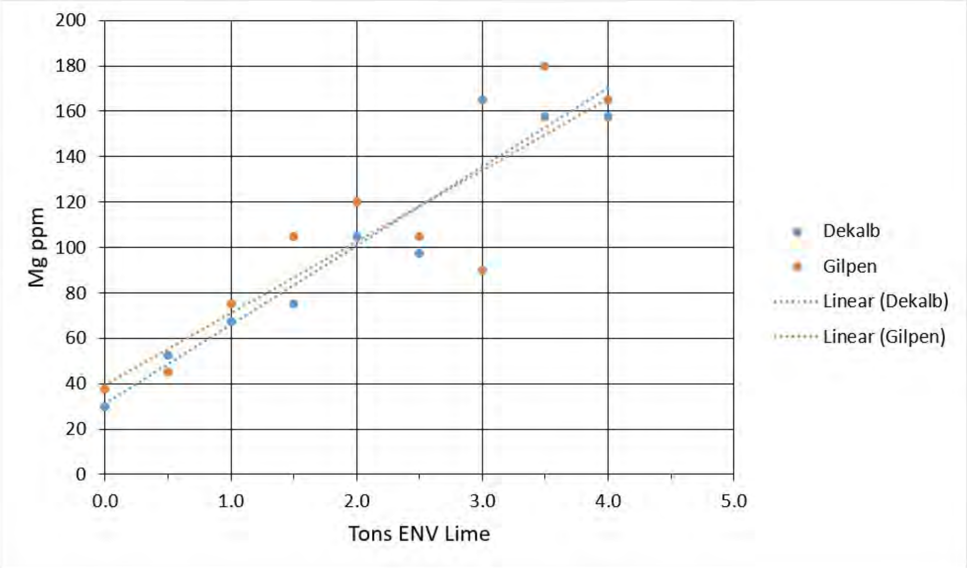

Figure 16. Impact of calcitic lime containing a small percentage Mg on the soil test Mg level in the soil (+ 32 parts per million of Mg per ton ENV lime for this source).

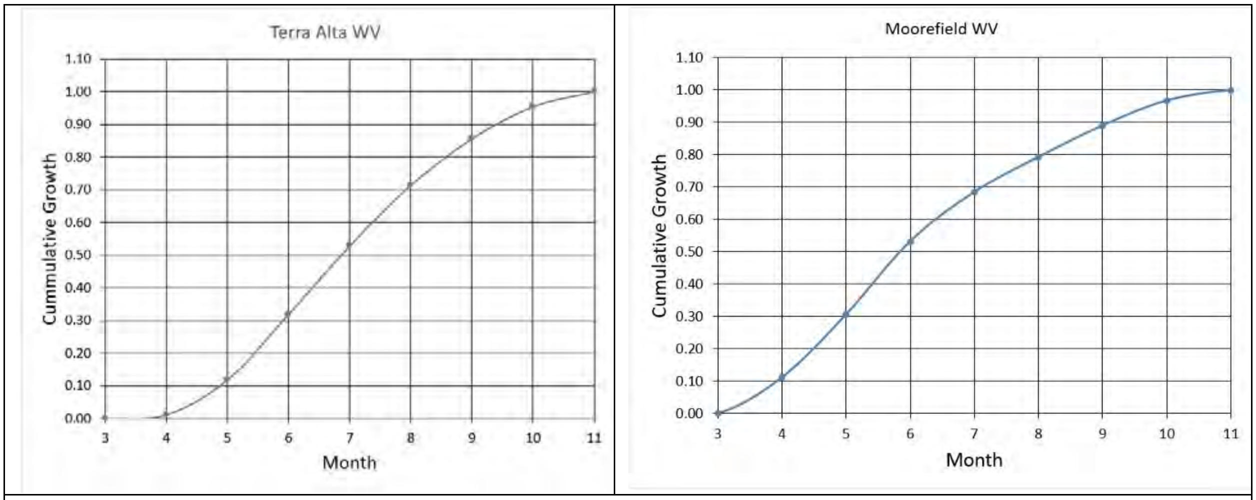

Figure 17. Average forage yield distribution at two locations in West Virginia.