Fertilizer BMPs —

Fertilizer Management Practices for Potato Production in the Pacific Northwest

By Robert Mikkelsen and Bryan Hopkins

Potatoes are grown in almost every state and province in North America. Some potatoes are grown for fresh consumption, while others are used for processing into fries, chips, or frozen products. Whatever the end use, the objective of every potato grower is to provide high quality potatoes that meet the market objectives at a price that is economically profitable and environmentally sustainable.

Potatoes are an important part of our diet. In North America, a typical consumer uses over 130 lb of potatoes each year (fresh and processed). Global consumption of potatoes continues to increase…with the largest consumers in Eastern Europe and with China now the world's largest potato producer.

Of the 40 billion pounds (400 million hundred weight) of potatoes grown in the USA in 2007, over 60% of the fall production occurs in the Pacific Northwest. A unique combination of soil, environment, and management practices has led to the success of the potato industry in this area. Production occurs primarily in the Snake River Valley of southern Idaho, the Columbia River Basin between Oregon and Washington, and smaller regions of eastern, central, and southern Oregon. Yield potential varies considerably between these regions, with the Columbia River Basin commonly measuring yields 50% greater than in the Snake River Valley of Idaho, due to a longer growing season.

Although Russet Burbank potatoes are the most commonly grown potato in the region, other varieties are also important. The major varieties grown include various Russets (Burbank, Norkotah, Ranger) and Shepody. The specific management of nutrients for potato varieties differs with factors such as their growth habit (determinate and indeterminate varieties), yield potential, irrigation practices, root patterns, and especially the length of growing season.

Advances in crop management and improved varieties have resulted in steadily increasing yields. Successful potato production requires careful attention to water, disease, pests, and plant nutrition. To maintain these high levels of intensive potato production, considerable research has been done to properly manage the crop and nutrients. Most of the information here relates to Idaho potato production. Many principles of potato nutrient management practices apply throughout the Pacific Northwest. However, local expertise is needed to fine-tune the general management practices outlined here for specific conditions and goals. For specific recommendations, it is generally best to consult with your local university or a Certified Crop Adviser (CCA).

Fertilizer BMPs for potatoes are based on applying the right source of nutrients at the right rate, right time, and right place.

This publication describes general fertilizer best management practices (BMPs) to help assure that the **Right Source** of nutrient is applied at the **Right Rate**, at the **Right Time**, and in the **Right Place**. The term "right" is defined as contributing to the productivity, profitability, and sustainability of the potato production system – all while minimizing any undesirable impact on the environment.

An understanding of the nutrient demand of high-yielding potatoes through the growing season is crucial to correct management. Knowing the total seasonal demand and the daily nutrient requirement provides a guide for fertilization and

Abbreviations and notes for this article: N = nitrogen; P = phosphorus; K = potassium; GS = growth stage; NO_3^- = nitrate.

This publication is one of a series prepared by cooperators with the staff of the International Plant Nutrition Institute (IPNI). It is part of a project in cooperation with the Foundation for Agronomic Research (FAR) toward fulfilling the goals of a 3-year Conservation Innovation Grant (CIG 68-3A75-5-166) from the USDA-Natural Resources Conservation Service to identify fertilizer best management practices (BMPs). The intent of this publication is to help develop the BMP definition process in such a way that environmental objectives are met without sacrificing current or future production or profit potential and in full consideration of the newer technologies relevant to fertilizer use. The concept of applying the right fertilizer at the "right rate, right time, and right place" is a guiding theme in this series. For additional information, visit the websites: www.farmresearch.com/CIG and www.ipni.net. Item # 30-3240

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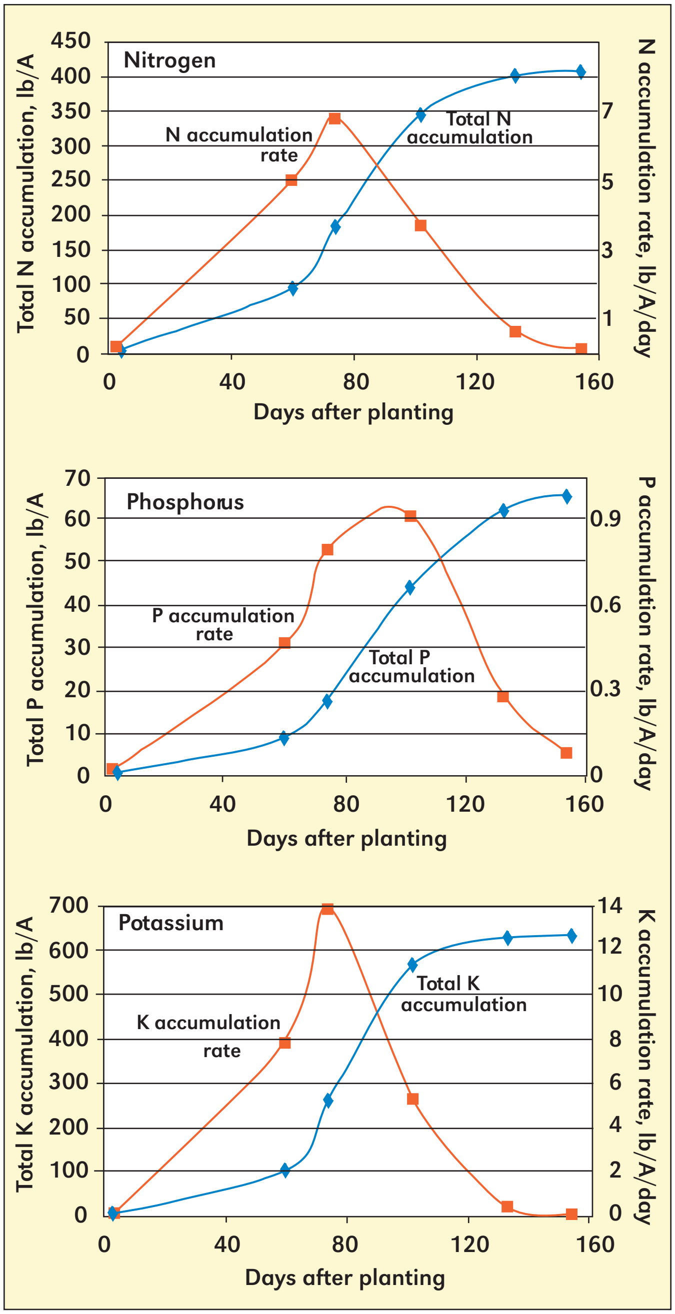


Figure 1A. Total (left axis) and daily rate (right axis) of N, P, and K accumulation by Russet Burbank potatoes grown with non-limiting nutrition and water near Hermiston, Oregon (Horneck and Rosen, 2008).

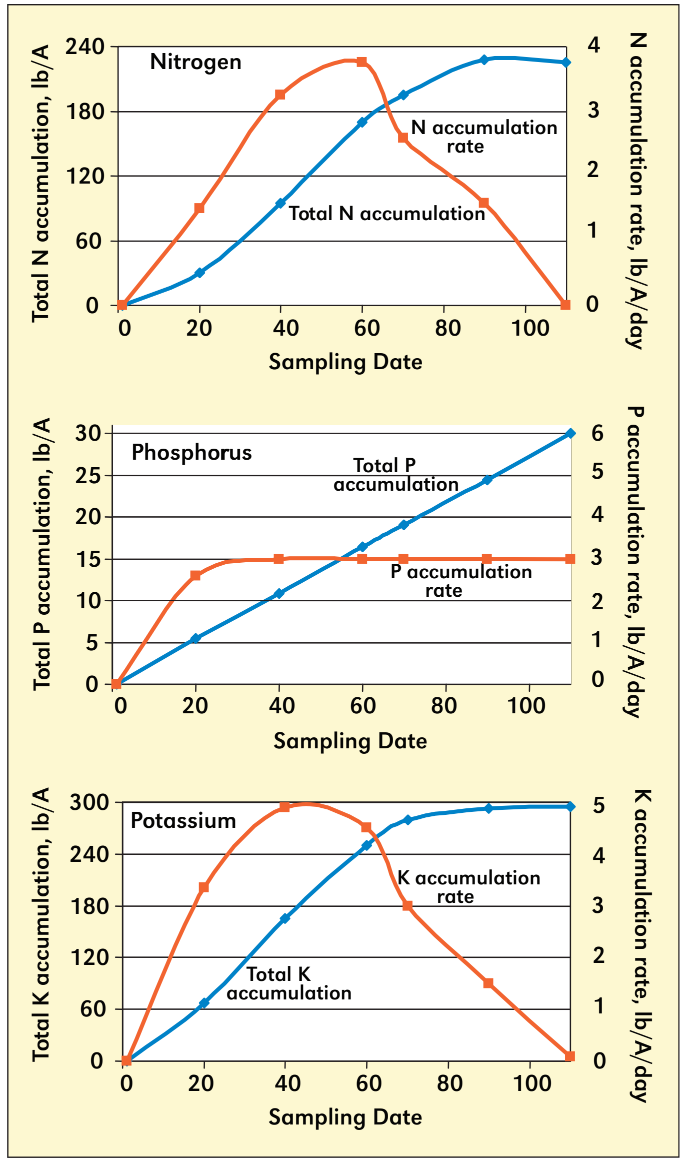


Figure 1B. Total (left axis) and daily rate (right axis) of N, P, and K accumulation by Russet Burbank potatoes grown with non-limiting nutrition and water in the Snake River Valley of Idaho (Stark and Westermann, 2008).

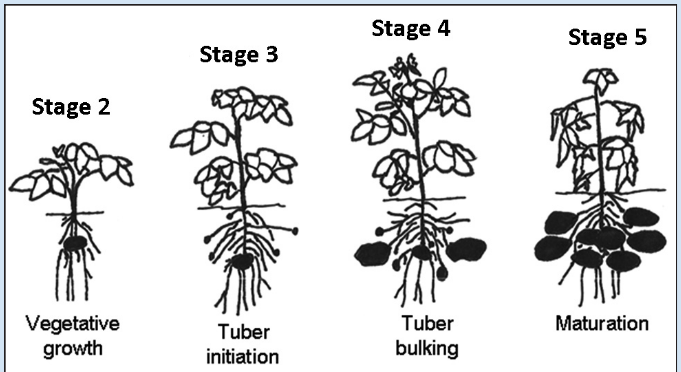
for mid-season adjustments. (**Table 1**). Nutrient uptake is generally most rapid during the time of tuber initiation (GS3) and tuber bulking (GS4), then tapering off during tuber maturation later in the growing season (GS5). Examples of nutrient accumulation from the Columbia River Basin in Oregon (**Figure 1A**) and the Snake River Valley of Idaho (**Figure 1B**) show this pattern. Differences in the two locations are due to weather conditions.

1. The Right Source

Nitrogen: Getting sufficient N to the growing plant is critical in achieving high yields. Proper N management influences almost all of the important properties related to tuber yield and quality – including size, grade, and storage quality. Both an inadequate and an excessive supply of N can have deleterious effects. Potatoes acquire N from a variety of sources – all of which should be accounted for in a comprehensive nutrient management plan. Across the region, between 200 and 320 lb N/A are required for successful potato production in southern Idaho. The N available to the growing potato crop may come from added N fertilizer, organic matter (including animal manure and cover crops), N in irrigation water, and inorganic N present in the soil

Table 1. Potatoes have distinct growth stages, each with specific nutritional requirements.

Stage 1	***Sprout Development*** No nutrients are required during this stage as the seed piece provides energy and nutrients until roots and shoots have grown and photosynthesis begins.
Stage 2	***Vegetative Growth*** Photosynthesis now provides the energy for the developing plant and rapidly expanding roots are active in acquiring moisture and nutrients.
Stage 3	***Tuber Initiation*** Hormonal changes signal the plant to channel excess carbohydrate from vegetative and root growth to begin setting tubers. An adequate supply of nutrients is important during this stage to get abundant tuber initiation. If tubers are not properly set at this stage, end-of-season yields will be limited.
Stage 4	***Tuber Bulking*** The development of tubers now occurs very rapidly as they become the major sink for carbohydrates and nutrients. Peak nutrient uptake occurs during this period, with daily accumulation rates as high as 7 lb N/A, 1 lb P/A, and 14 lb K/A. Tubers may be growing at a daily rate of 600 to 1,000 lb/A during this period.
Stage 5	***Maturation*** Further nutrient uptake largely ceases by this point, but nutrients are transferred from the vegetative portions to the tubers. The vegetative portion of the plant needs to be sufficiently healthy to continue to supply carbohydrates to the maturing tubers.



Major stages of growth and development of potatoes. The nutrient requirement of the developing potato changes during the growing season.

prior to planting. All of these potential N sources should be accounted for when making decisions related to the total fertilizer N requirement.

- Cover crops can be advantageous for a variety of reasons – including benefiting the physical properties of the soil, reducing erosion losses, preventing NO_3^- leaching by crop uptake, and providing a source of N to the potato crop after decomposition. Nitrogen scavenged by the fall-planted cover crop is stored in the plant until it is killed in the fall or spring, when it begins to decompose.

  There are a wide variety of cover crops that have been successfully used before planting potatoes – including various grasses, small grains, legumes, and other species (such as rape, mustard and radish). The cost and returns of using cover crops in a potato production system should be carefully considered before planting, but their use may be helpful in many cropping situations. The length of the fall growing season also needs to be determined in selecting a cover crop that will have sufficient time to develop before preparing the field for potato planting in the spring. There can also be considerations with pests and mineralization of excessive N late in the growing season to account for.

- There are several common forms of commercial N fertilizer used for potato production – materials containing NO_3^-, ammonium, and urea alone or in combination. When N fertilizer is applied to soil, microbiological processes rapidly convert urea to ammonium (urea hydrolysis) and convert ammonium to NO_3^- (nitrification). During the growing season, urea hydrolysis is typically complete in less than a week and nitrification is largely complete in less than 10 days. Since potatoes can use either NO_3^- or ammonium forms of N, the choice of soil-applied fertilizer is typically based on cost. During urea hydrolysis, free ammonia can be emitted – which is harmful if placed too close to seed pieces. Therefore, avoid applying high rates of banded urea in close proximity (less than 2 in.) to the seed pieces.

- Water-soluble N fertilizers are frequently added to the irrigation system to provide a mid- or late-season boost in nutrition to the rapidly growing tubers. Several N fertilizers are compatible with fertigation, including urea-ammonium-nitrate (UAN), but always check the chemical compatibility of any fertilizer with the specific water before adding it into an irrigation system. Aqua ammonia or anhydrous ammonia is sometimes added to water used for furrow irrigation.

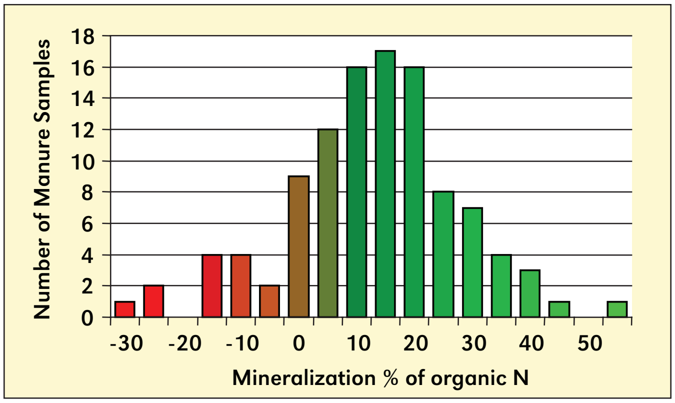


Figure 2. Nitrogen mineralization from 107 individual dairy manure samples after 8 weeks of incubation. On average, 13% of the organic N was mineralized, but 19 samples had net immobilization (negative values). Net N mineralization from the remaining 88 samples ranged from zero to 55% (from Van Kessel and Reeves, 2002).

- The growth of the animal industry provides easier access to organic N sources such as manures and composts. Much of the N present in manure is found in organic compounds that require decomposition before becoming available for plant uptake. It is important to know the nutrient content of any organic material used for crop production and not just rely on tables and book values for an average nutrient composition. Composted manure generally has a slower nutrient release rate than fresh manure and needs to be managed differently. If the N-release period from manures is excessively long, potatoes may have extended vegetative growth and delayed tuber bulking. Some manures may actually immobilize N for a period of weeks and make nutrients initially less available for potato growth (**Figure 2**). Recent research did not show additional food safety risks for potatoes associated with using manure as a nutrient source, compared with commercial fertilizer (Entry et al., 2005).

- Excellent results have been obtained from the use of controlled-release N fertilizers (CRF). There are many types of these materials, with widely varying periods of nutrient release. A general recommendation would be to apply approximately two-thirds of the total N requirement as a CRF at emergence. Any remaining N could be applied through the irrigation system as determined by frequent monitoring of the plant. This technique may reduce NO_3^- leaching since not as much soluble N is present in the soil at any one time. For best results, select a CRF that has a N release rate that matches the crop nutrient demand (Hopkins et al., 2008).

Phosphorus: Many potato production fields have need for P applications since this nutrient is especially important for early plant development and rapid tuber growth. The requirement for additional P should be determined with pre-season soil tests and in-season plant tissue monitoring.

- Both solid and liquid sources of P fertilizer are equally suitable for potato nutrition. The decision to use a particular fertilizer material is generally based on price, equipment availability, and other field operations that are occurring.

- Mid-season applications of P are common when the uptake of nutrients from the soil may be inadequate to fully meet the demand of the rapidly growing crop. Soluble sources of P are commonly applied through the irrigation system to meet peak demand periods. A number of soluble phosphate and polyphosphate fertilizers may be suitable. Check their chemical compatibility with the irrigation water since added P tends to precipitate with calcium and magnesium in water to form insoluble deposits.

- University research has documented positive responses to P fertilizer additives that may enhance P solubility and plant uptake, such as liquid polymer stabilizers and humic materials. Consider evaluating these materials on a portion of the field receiving fertilizer P.

- Many animal manures and composted materials contain considerable P. When properly managed, they can be a useful source of nutrients. Regular chemical analysis of the manure and soil testing are needed to keep nutients properly balanced.

Potassium: Potatoes remove very large amounts of K in the harvested tubers (200 to 400 lb/A), but K is taken up by the plant in the cationic K^+ form, regardless of the fertilizer material applied to the soil

- Inadequate supplies of K can result in decreased yields and quality of the tuber. There are rare reports that heavy applications KCl can result in lower dry matter percentage (specific gravity) in tubers compared with K_2SO_4 or $KMgSO_4$. This problem is not common and can be overcome with proper K management.

- There are soluble K sources that are compatible with irrigation systems. Considering that potatoes may accumulate up to 14 lb K/A/day during tuber bulking, it is essential that adequate nutrient supplies be maintained in the root zone. Although not commonly done, K can be solubilized by a fertilizer company from common K sources and delivered to the field for fertigation.

2. The Right Rate

Nitrogen: Proper N management is one of the most important factors required to obtain high yields of excellent quality potatoes. An adequate early season N supply is important to support vegetative growth, but excessive soil N later in the season will suppress tuber initiation, reduce yields, and decrease the specific gravity in many instances. Having a large supply of NO_3^- in the soil at any time leaves it susceptible to denitrification and leaching during irrigation. Applying the correct amount of N requires skill and knowledge of the entire production system.

- It is advisable to sample the soil prior to fertilizing and planting to determine the supply of pre-existing NO_3^- (to a 12-in. depth). This residual NO_3^- may be carried over from the previous crop or may have accumulated during the decomposition of crop residues and soil organic matter. Soil testing labs will assist you in adjusting your fertilizer recommendations if there is significant NO_3^- carry-over in the soil.
- Less than half of the total N requirement is generally applied prior to or by the time of planting. Additional N should be applied during the growing season after the root system has sufficiently developed to utilize the supplemental N. During peak growth periods, potato plants can require as much as 7 lb N/A/day.
- Nitrate leaching losses are minimized by keeping the amount of leachable N in the rootzone to a minimum, while still meeting the plant nutritional requirement. Nitrate leaching can result from excessive irrigation that flushes this essential nutrient from the rooting area. Over-irrigation can also result in undesirable effects on plant growth and development. The keys to minimizing nitrate leaching involve management of both fertilizer and irrigation water. Avoid over-irrigation during times when consumptive water use is low- such as early and late in the growing season.
- Plant tissue analysis can provide valuable insight into the need for supplemental N. Seasonal trends in the petiole nitrate concentration are useful for predicting the need for additional N fertilizer to avoid nutrient-limited growth. In potatoes, the nutrient concentration in the petiole taken from the fourth fully emerged leaf (counting from the plant top) has been well calibrated with plant growth and yield. It is important that the same position on the plant (fourth petiole) be consistently sampled to get reproducible results that can be used for diagnostic purposes in the laboratory.
- Nitrogen deficiencies are visible only after the plant has been limited in growth and productivity. Therefore visual symptoms should not be used as a primary guide to predict the need for additional N fertilizer. Nitrogen-deficient plants typically have a pale green appearance, with the older vegetation turning light yellow. Plants will be stunted compared with plants receiving adequate nutrition.

Phosphorus: Phosphorus plays an essential role in plant health and root development, which directly impacts yield and quality. The P requirement of potatoes is frequently higher than the P requirement of many field crops due to the high nutrient demand of potatoes and their relatively shallow root system. Some P fertilizer is typically recommended for potatoes grown in a crop rotation. The need for additional P should be established by analysis of soil samples prior to planting.

- Preplant P fertilization is generally recommended, with the application rate based on the results of soil testing. Additional mid-season applications may be useful when plant tissue testing indicates that P may limit plant growth and yield.
- The P fertilization rate should be adjusted to account for the soil properties. Since free lime (calcium carbonate) in the soil tends to react with fertilizer P to make a portion of it less available to plants, P fertilization rates are generally adjusted upwards by 10 lb/A for every 1% lime in the soil. A history of manure application may build P concentrations to a point where little, if any, additional P fertilizer is needed.
- Applications of P through the irrigation system are only useful if adequate roots are present near the soil surface. This frequently occurs after the canopy shades the hill by mid-season and if the soil near the surface does not become too dry for nutrient uptake.
- Potato plants that have insufficient P are generally smaller and may have a darker green appearance than properly fertilized plants. When deficiencies become severe, some varieties may develop a purple color in the leaf and exhibit leaf cupping.

Potassium: Potatoes require large amounts of K, since this nutrient is crucial to metabolic functions such as movement of sugars from the leaves to the tubers, and transformation of sugar into potato starch. Potassium deficiencies reduce the yield, size, and quality of the potato crop. A lack of adequate K can be associated with low specific gravity in potatoes. During peak periods, potatoes can take up 14 lb K/A each day. Excessively high K can result in its accumulation in tubers, where it may increase the water content and decrease the specific gravity.

- Potassium fertilizer is commonly broadcast across the field prior to planting. Band placement of a small fraction of K fertilizer in the beds or during row markout will also efficiently supply K to the plants. When soils are quite deficient in K, it is recommended that no more than 300 lb K_2O/A be applied in a band to prevent salt damage to the young plants. In these circumstances, the K can be applied as a combination of broadcast and banded K. Account for K that may be present in irrigation water when making K fertilizer decisions.

- Potassium-deficient plants show symptoms of yellowing and scorching on the older leaves as K is moved from older vegetation to the younger growth. The surface of younger leaves may also develop symptoms of a glossy sheen with crinkling. Pre-season soil testing and proper fertilization will prevent these symptoms from occurring.

3. The Right Time

Nitrogen: Although potatoes require a constant supply of N throughout out the growing season, the peak demand period generally coincides with rapid vegetative growth in the first 60 to 80 days after planting (with daily accumulation rates reaching as high as 7 lb N/A). After this intensive growth period, N accumulation rates gradually diminish until harvest.

The objective with N management is to maintain an adequate nutrient supply for the plant to achieve the optimal balance between vegetative and tuber growth. Over-fertilization can stimulate vigorous vegetative growth at the expense of tuber development. Excessive N can also depress tuber quality. However, a shortage of N will curtail the growth of vegetation and photosynthetic capacity necessary to support healthy roots and rapid tuber growth.

- Irrigated potatoes have the advantage of being able to rapidly supply additional N during the growing season with fertigation. However, this method should be considered as a supplement to soil-based fertilization. It is common to apply between one fourth and one half of the total N requirement before or at planting, largely depending on the susceptibility to nitrate leaching losses.
- After tuber initiation begins (GS3), it is important to maintain a constant and adequate N supply. During this stage, the plants are accumulating between 2 to 7 lb N/A/day. Assuming a 4 lb/A/day accumulation and a 60% N efficiency for sprinkler-applied N, then 65 lb of N would provide adequate N for approximately 10 days.
- The frequency and quantity of N that can be applied by fertigation will depend on the irrigation system and the water requirement of the developing crop. It is common to apply 20 to 40 lb N/A every one to two weeks during Growth Stages 3 and 4. Regular monitoring of petiole NO_3^- concentrations will assist in increasing or decreasing the rate of N application.

Phosphorus: The demand for P continues to increase until the middle of the growing season, with a daily demand peaking between 0.5 and 0.9 lb P/A/day – depending on the variety and yield potential. An adequate and constant supply of P during the entire growing season is required to support vine and tuber growth. An insufficient P supply results in reduced tuber size and yield.

- The anticipated P fertilizer requirement is best applied prior to planting, based on the results of soil testing. Since P fertilizer is not susceptible to leaching loss, it can be placed in the rootzone prior to planting where it will remain during the growing season.
- Monitoring the concentration of P in potato petioles during the growing season provides useful feedback on the current plant status. Petiole sampling for P typically begins at tuber initiation (GS3) and occurs every 7 to 10 days thereafter. The total P concentration of the petiole (the fourth petiole from the growing point) relates well with the total plant P and yield. The results from the laboratory analysis should be used with local expertise and data to determine emerging nutrient shortages.
- The concentration of soluble P in the soil is generally quite low due to its chemical reactivity. Adequate fertilization increases the soluble P concentration, but it may still be insufficient to meet the plant demand during peak periods of nutrient uptake. Sprinkler application of P may be used to increase the soil P concentration when it is no longer possible to enter the field with fertilizer equipment. Since irrigation will be occurring to meet crop water demands, it is efficient to simultaneously use fertigation as a means to optimize plant nutrition.
- Sprinkler application of P should be considered as a source of plant nutrition that supplements, not replaces, the primary soil nutrition program. Fertigation of P provides the flexibility to closely evaluate and respond to the plant's progress and perhaps eliminate some of the soil-applied P. However, this approach should be viewed as corrective monitoring, not a way to eliminate major soil nutrient deficiencies.
- Fertigation of P is most successful if there are active roots close to the soil surface and the canopy shades the hill. It often takes 10 to 14 days after P application before the petiole P concentrations increase. Therefore, do not wait until deficiencies are observed or petiole P concentrations are too low before responding with

fertigation. Charting the seasonal trends of tissue P concentration at least every 10 to 14 days will help predict when concentrations may slip below established thresholds. Allowing the petiole P concentrations to drop below these critical concentrations may result in an unacceptable loss of yield and quality. However, applying supplemental P to plants that already have sufficient supplies of soil P may not be a good investment.

Potassium: Since potatoes have a very high K requirement, it is important that an adequate supply be maintained in the rootzone at all times. Many important yield and quality parameters of the tuber are negatively affected if the K supply runs short, especially during tuber bulking (GS4). The harvested tubers may contain over 90% of the total K taken up by the plant.

- Preplant applications are the most effective way to supply K. If large amounts of K are required to supply adequate nutrition, it is advisable to split the application into two or more applications before emergence.
- Monitoring petiole K concentrations can be useful for predicting the need for mid-season supplementation. After tuber initiation, petiole K concentrations tend to continually decline for the remainder of the season. However, monitoring this rate of decline can serve as a useful guide for potential deficiencies.
- Petiole K concentrations may not increase for 2 to 3 weeks after K fertilizer application through the irrigation system. Therefore, do not wait until the petiole K concentrations are below the critical level before applying supplemental K. Monitoring the rate of K decline in the petioles will help anticipate the date when additional K may be needed. It is not useful to apply additional K within 30 days of the end of the growing season- since the likelihood for economical response is low.

4. The Right Place

Nitrogen: The goal is to supply the required N as close to the roots as practical and at the time the plants need it. This approach eliminates any potential economic losses and undesirable environmental impacts, while sustaining desired levels of production. Although this concept is simple to understand, it is not easy to effectively achieve every year as conditions continually change.

- A portion of the seasonal N requirement can be broadcast prior to planting, but this N is susceptible to leaching losses during the period when seed pieces are getting established and just beginning to take up nutrients. Large applications of N at this time are not generally recommended. Banding a portion of the N fertilizer during row mark-out or at planting is effective to meet the early season N requirement. Only one-fourth to one-half of the anticipated N requirement is applied at this time. When applied during markout, the band should be placed 2 to 4 in. to the side and below the seed piece. When applied at planting, the N is commonly placed to the side, but 1 to 2 in. above the seed piece.
- Additional N can be placed as a side-dress application when the plants are still in the vegetative growth stage (GS2). Added NO_3^- fertilizer will immediately move into the soil with the irrigation water. Ammonium-based fertilizer will have limited movement into the rootzone until nitrification is complete. If urea is left on the soil surface following application, there can be significant loss of ammonia gas if it is not rapidly irrigated into the soil. Consider injecting urea beneath the soil surface or using a urease inhibitor if the urea will be left on the soil surface for several days prior to irrigating the urea into the soil. In-season applications of side-dress N injected into the soil are very effective, but may cause root damage as the plants get larger.
- Applying supplemental N through the sprinkler system is a common and effective method to meet the rapidly increasing mid- and late-season nutrient requirement. The uniformity of water distribution will largely determine the uniformity of nutrient application. The irrigation system should be designed and maintained to allow uniform application of both water and nutrients. Both over-application and under-application of water and nutrients can have harmful effects on yield, quality, and profitability.
- Improper placement of N can result in poor utilization of the nutrients. For example, if N applied through the sprinkler lands past the ends of the rows or on roads, this N is wasted and susceptible to loss. When the supply of N is in excess of plant demand, there is a greater risk for N leaching from the rootzone.
- Since potatoes are commonly grown on well-drained soils, have a more limited root system than some other crops, and have a high N requirement, careful attention must be given to all practices that minimize the leaching of nitrate into groundwater.

Phosphorus: Since P has limited mobility in soil, it is important to place it near actively growing roots, especially during early season growth when uptake may be limited. Leaching losses of P are not significant at typical fertilization rates, but P can be lost from the surface of fields subject to erosion. Consider using a runoff water collection basin or a tailwater return system if sediment or P runoff is significant.

- Band application of P during row mark-out or at planting is generally the most effective placement of P fertilizer. The majority of the P can be applied at this time, however direct contact of the fertilizer with the seed pieces should be avoided to minimize salt damage. Placement of the fertilizer several inches to the side and below the seed piece is recommended.
- When P is broadcast, it should be applied prior to hill formation so the nutrients are concentrated where the roots will grow.
- Additional P can be added during the growing season through the irrigation system if petiole P concentrations indicate a need for supplementation. A sufficient amount of irrigation water is needed to move the nutrients into the soil and facilitate uptake by the roots.

Potassium: It is important to place fertilizer K in the zone where rapid plant uptake will be possible during times of peak demand.

- The mobility of K in soil is fairly low since it is held on cation exchange sites. However, in sandy-textured soils with a low exchange capacity, the movement of K can be greater. If applications of K are required during the growing season, roots must be present near the soil surface in order to acquire the applied nutrients. Adequate soil moisture must be maintained near the soil surface to provide conditions for nutrient uptake by the surface roots.
- Broadcast application and soil incorporation of K when preparing the seed-bed is effective. Band placement of K prior to planting may also be sufficient to meet the K requirement when applied at typical application rates. Avoid high rates of banded K in close proximity to the seed piece. A combination of broadcast and band placement may be more appropriate if K application rates are high. Broadcast application of K shortly after plant emergence is also common.

Author Information

Dr. Mikkelsen is IPNI Western North American Region Director, located at Merced, California (e-mail: rmikkelsen@ipni.net). Dr. Hopkins is Associate Professor, Plant and Wildlife Sciences, Brigham Young University, Provo, Utah (e-mail: hopkins@byu.edu).

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International Plant Nutrition Institute (IPNI)

3500 Parkway Lane, Suite 550 • Norcross, GA 30092-2806 U.S.A.

Phone: 770-447-0335 • Fax: 770-448-0439 • E-mail: info@ipni.net • Website: www.ipni.net

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