

Nutrient Management Guidelines for Russet Burbank Potatoes

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BUL 840

Efficient potato nutrient management systems are designed to ensure that all essential plant nutrients are available in appropriate amounts and at the most beneficial time to provide for optimal vine and tuber growth. Studies conducted in southern Idaho show that with proper management, growers can obtain maximum net economic return without significantly increasing the impact on environmental quality.

To optimize fertilizer use efficiency, potato growers need a good understanding of the following topics covered in this bulletin:

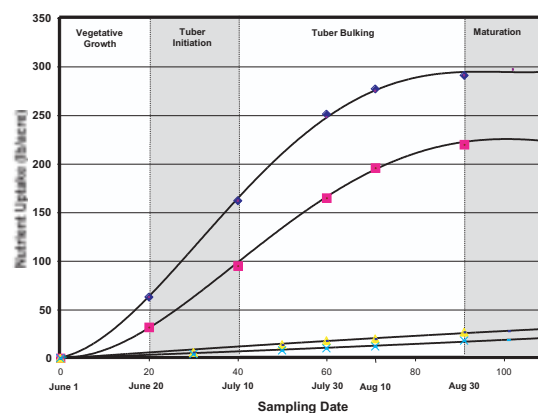
1. Potato nutrient uptake patterns and associated sufficiency levels for soil and plant tissue nutrient concentrations,
2. Cultural and environmental factors that influence plant nutrient availability, and
3. Fertilizer management practices that optimize nutrient use efficiency.

Potato Nutrient Uptake Patterns

Potatoes require optimal levels of essential nutrients throughout the growing season to ensure rapid, steady tuber growth and normal tuber development. Cumulative nutrient uptake curves for a potato crop follow an s-shaped pattern in which uptake rates increase during tuber bulking before leveling off during tuber maturation late in the growing season (Figure 1). Potatoes usually take up

about 40 to 50 percent of their seasonal nitrogen (N) and potassium (K) requirements and about 30 to 40 percent of their phosphorus (P) and sulfur (S) requirements by the time tuber bulking begins.

Figure 1. Total potato plant N, P, K and S uptake during three years of field trials at Aberdeen.



Russet Burbank potato plants with tuber yields that range from 400 to 500 cwt/acre will take up the following amounts of macronutrients per acre:

- Nitrogen (N) 200 to 240 lb/acre
- Potassium (K) 280 to 320 lb/acre
- Phosphorus (P) 25 to 35 lb/acre
- Sulphur (S) 18 to 24 lb/acre
- Calcium (Ca) 50 lb/acre
- Magnesium (Mg) 40 lb/acre

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Note The nutrient management guidelines presented in this bulletin are based on research data obtained from fertilizer management studies with Russet Burbank potatoes conducted by the University of Idaho and the USDA/ARS, as well as from on-farm fertilizer response trials conducted cooperatively with growers, crop advisers, and consultants. These recommendations are appropriate for well-managed potato production systems and account for typical levels of soil nutrient variability and nutrient use efficiency observed in commercial potato fields.

Micronutrient uptake amounts (seasonal) are much lower:

- Iron (Fe) 2.8 lb/acre
- Zinc (Zn) 0.2 lb/acre
- Manganese (Mn) 0.3 lb/acre
- Copper (Cu) 0.1 lb/acre
- Boron (B) 0.18 lb/acre

Maximum daily nutrient uptake rates also vary greatly: (Figure 2).

- Nitrogen (N) 3.0 to 4.0 lb/acre/day
- Potassium (K) 4.0 to 5.0 lb/acre/day
- Phosphorus (P) 0.35 to 0.40 lb/acre/day
- Sulphur (S) 0.10 to 0.15 lb/acre/day

Factors Affecting Potato Nutrient Requirements

Potential Tuber Yield

In late maturing cultivars such as Russet Burbank, nutrient application rates during tuber bulking should be slightly higher than those required for tuber development. This will allow for the production of new vegetative growth needed to maintain effective photosynthetic leaf area as the older leaves senesce. Nutrient deficiencies that develop during tuber bulking can reduce tuber size, yield, and quality by limiting plant physiological processes.

The potential yield of Russet Burbank potatoes increases as the length of the growing season increases as long as the plants remain healthy and supplies of water and nutrients are adequate. For a crop with an average tuber bulking rate of 7 cwt/acre/day, a two week increase in the frost-free growth period would increase potential tuber yield by about 100 cwt/acre. Crop nutrient requirements should proportionally increase to reach the higher yield.

Soil and Environmental Factors

Soil physical and chemical characteristics can have substantial

effects on nutrient availability to plants. Restrictions in root growth caused by hardpans, soil compaction, or shallow soils reduce the volume of soil from which nutrients can be extracted, thereby decreasing the available nutrient supply. Sandy soils have relatively low water-holding capacities, high infiltration rates, and a greater potential for nutrients to leach beyond the root zone.

Sandy soils also have relatively low cation exchange capacities that limit their ability to hold and exchange positively charged nutrients such as K, Ca, and Mg compared to soils with higher clay contents. High soil pH (>7.5) can reduce the availability of P and most micronutrients. Additionally,

excess calcium carbonate (lime), which is common in high pH soils, reduces the solubility of soil P and further reduces P availability.

Low soil temperatures early in the growing season reduce root physiological activity and growth, which in turn reduces nutrient uptake. This effect is particularly significant for P which moves a very short distance in soil and requires active root uptake. Banding fertilizers near roots or applying higher rates can partially compensate for low temperature effects. Cool soil conditions can also reduce the rate of N and S mineralization from soil organic matter and slow the conversion of ammonium to nitrate.

High soil temperatures can accelerate emergence and early season growth creating a corresponding increase in nutrient demand. Nitrogen mineralization rates also increase in warm soils, which under abnormally hot weather conditions can increase soil N availability causing excessive plant N uptake. However, if soil temperatures get too high (>100°F) mineralization slows considerably. Excessive N uptake caused by over-fertilization or high N mineralization rates favors vegetative growth at the expense of tuber growth.

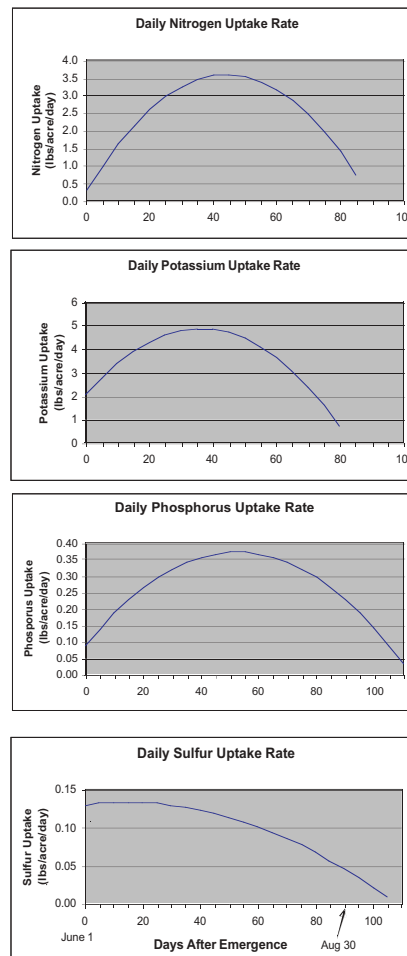
Plant Diseases

Diseases such as rhizoctonia, blackleg, and Verticillium wilt which attack potato root and stem tissue, can significantly reduce nutrient uptake and transport within the plant. Therefore, appropriate control strategies for root pathogens need to be utilized to maintain healthy roots capable of optimal nutrient uptake.

Determining Nutrient Requirements

Because of the many factors that affect plant nutrient require-

Figure 2. Daily uptake rates per acre for nitrogen (N), potassium (P), phosphorus (K), and sulfur (S) during three years of field trials in Aberdeen.



ments and availability, appropriate nutrient management strategies need to be developed for each cropping system considering the specific characteristics of each field. Soil and plant analysis are two primary tools used to develop an efficient and environmentally responsible nutrient management program.

Soil Analysis

The relative availability of soil nutrients at a specific field site can be determined by using appropriate soil testing procedures that are locally calibrated with crop yield responses.

Laboratories that accurately analyze soil, using procedures developed and calibrated for the local growing region, generally give the best recommendations.

Laboratory test results can be used by experienced crop managers in formulating fertilizer recommendations and selecting appropriate nutrient sources and methods of application.

The accuracy of a soil test result can be affected by both the laboratory analysis and the quality of the soil sample. A soil sample that is not representative of the corresponding field area will likely be misleading and cause inappropriate fertilizer application rates.

Therefore, it is essential that each field be sampled using procedures that represent the majority of the soils in the field. Preferably, areas with significant variations in soil texture, color, topography, and cropping and fertilization history should be sampled and fertilized separately.

Each soil sample should represent no more than 20 acres, even if the soil appears uniform. A composite soil sample for a field zone should consist of about 20 soil cores from the 0- to 12-inch soil depth using a soil probe that provides a uniform sample throughout the entire

sampling depth. Typically, the 20 cores are taken in a selectively random pattern such as a zigzag pattern throughout the sampling area. The samples should then be thoroughly mixed together and a two-thirds pint subsample should be collected and air dried before being sent to the lab, unless samples arrive at the lab within 24 hours of sampling. Keeping soil samples warm and moist will cause N mineralization to continue, leading to erroneously high soil test N concentrations.

Site-specific Soil Sampling

Site-specific soil sampling for variable rate fertilization can be accomplished using either systematic grid sampling procedures or some form of directed sampling based on differences in soil color, crop growth patterns, or landscape characteristics. Grid samples are typically collected from 1.0 to 2.5 acre grids using irregular sampling positions such as those used with a systematic, unaligned grid pattern. Data are then analyzed and mapped using various statistical procedures that provide an estimate of nutrient patterns within the field.

Directed sampling—also known as zone sampling—typically involves collecting soil samples from 3 to 6 management zones per field. The zones are delineated using various mapping layers including bare soil color, soil survey maps, topography maps, yield maps, soil conductivity maps, and producer experience. Ten to twenty soil cores from each zone are composited to produce mixed samples that represent each zone. The samples are analyzed separately and individual fertilizer recommendations are subsequently developed for each zone.

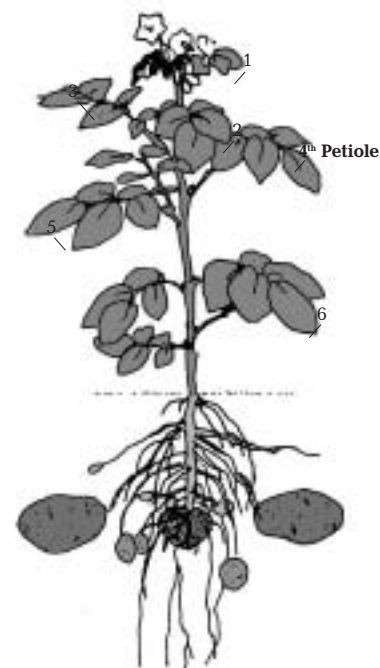
Plant Tissue Analysis

Plant tissue analysis is widely used as a diagnostic tool for

monitoring the nutrient status of potato plants. It is based on established relationships between nutrient concentrations in a standard plant part and plant growth rate or yield. In potatoes, the petiole of the fourth leaf from the top of the plant (Figure 3) is generally used to determine plant nutrient status. It is important to consistently sample the fourth petiole since analysis of samples taken from higher or lower leaf positions will produce significantly different results that are not calibrated with the crop's nutritional status. Petiole sampling usually begins at tuber initiation and continues on a weekly basis throughout most of the tuber growth period.

Approximately 50 to 60 petioles should be collected from representative areas of the field

Figure 3. Potato plant diagram shows the fourth petiole from the top of the plant. It is important to use the fourth petiole from each of many plants when determining plant nutrient status.¹



¹ Adapted with permission from Potato Health Management, 1993, Randall C. Rowe (ed.), Plant Health Management Series, the American Phytopathological Society, Eagan, MN, and adapted from R.E. Thornton and J.B. Siczka, 1980, Commercial potato production in North America, American Potato Journal 57, supplement, Potato Association of America, Orono, ME.

consistent with the soil sampling procedure. Alternatively, separate samples can be collected from selected areas or management zones differentiated by soil type, crop history, topography, etc. It is best to sample at the same time of day on each sampling day to avoid possible diurnal changes in nutrient concentrations. All leaflets should be stripped off the petiole immediately after sampling to avoid transport of nutrients from petioles to leaves. The petioles should then be placed in a clean container or paper bag and quickly dried at 150°F or kept cool (<40°F) until submitted to the lab. This procedure should minimize changes in nutrient concentrations that can occur in warm, moist tissue samples.

Petiole nutrient concentrations are divided into low, marginal, and sufficient ranges (Table 1), based on their relationship to growth and yield. These ranges can vary according to growth stage, particularly for nitrate nitrogen (NO₃N) concentrations, which can vary widely over the course of the growing season. Sufficient concentrations are generally adequate for vine and tuber growth at the time of sam-

pling. However trends observed from weekly petiole samples are more reliable in anticipating and detecting developing nutrient deficiencies.

Nutrient deficiencies can sometimes be identified from visible symptoms. However by the time the symptoms develop it is usually too late to make corrective fertilizer applications without experiencing a yield or quality loss. Diagnosis can also be complicated by multiple nutrient deficiency symptoms as well as those caused by diseases and environmental stress. Plant tissue analysis provides a more accurate and timely identification of developing nutrient deficiencies than visible symptoms.

Fertilizer Application Methods

Crop managers should adopt fertilization practices consistent with cropping system characteristics that efficiently use available equipment, fertilizer materials and other resources, and provide flexibility in responding to changing nutrient requirements. Fertilizer application methods commonly used for potatoes include:

1. Preplant broadcasting followed by incorporation
2. Banding at row markout or planting
3. Side-dressing after planting
4. Applying foliar nutrient sprays
5. Injecting liquid fertilizer through the irrigation system

Broadcasting Broadcast fertilizer applications made in the fall or spring should be incorporated into the surface 6 to 12 inches of soil to provide ready access for the potato roots. Usually, between one-fourth and one-half of the seasonal N supply should be applied in the spring prior to planting, but the bulk of all other fertilizers can be broadcast applied in the fall or spring. Preplant applications can largely eliminate the need for additional applications at planting, which generally is more cost effective and allows more time for management of the planting operation.

Banding Fertilizers can be banded at row markout or at planting. The bands should be placed close enough to the seed piece to provide early root access. However, direct contact with the seed piece should be avoided,

Table 1. Suggested ranges in nutrient concentrations for the fourth petiole of Russet Burbank potatoes during tuber bulking.

Nutrient	Low	Marginal	Sufficient
Nitrate nitrogen, ppm	<10,000	10,000-15,000	15,000-20,000
Phosphorus, %	<0.17	0.17-0.22	>0.22
Potassium, %	<7.0	7.0-8.0	>8.0
Calcium, %	<0.4	0.4-0.6	>0.6
Magnesium, %	<0.15	0.15-0.3	>0.3
Sulfur, %	<0.15	0.15-0.2	>0.2
Zinc, ppm	<15	15-25	>25
Manganese, ppm	<20	20-40	>40
Iron, ppm	<20	20-50	>50
Copper, ppm	<2	2-4	>4
Boron, ppm	<10	10-20	>20

particularly with liquid fertilizers, high fertilizer rates, or fertilizers with high salt index values. For markout applications, an effective band placement is 3 to 4 inches to the side of the seed piece and 1 to 2 inches below seed piece depth. Fertilizer bands applied at planting are best placed 1 to 2 inches above seed piece depth to provide greater early-season availability to the developing plant. Liquid formulations including N, P, and micronutrients are commonly applied in bands to enhance early season availability.

Side dressing Side-dressed N fertilizer is often applied during vegetative growth with the cultivation and diking operations. Injected or side-dressed treatments should be applied prior to tuber initiation to avoid root damage and loss of the first set of tubers. Non-incorporated side-dressed N can be applied without root pruning, but fertilizer should be incorporated into the soil with irrigation shortly after application. This is also true of aerial broadcasting of N.

Spraying Foliar nutrient sprays can be effective in treating existing or developing nutrient deficiencies and usually produce a quicker response than soil applications. This is particularly true for micronutrients such as iron, zinc, manganese, copper, and boron. Tank-mixing surfactants usually improves nutrient absorption through the leaf surfaces. However, the amount of any nutrient that can be safely applied is limited because concentrated sprays can cause leaf damage.

Irrigation injections Water-soluble fertilizers are commonly applied through sprinkler irrigation systems. Nutrients such as N, P, K, and S can be applied according to needs of the crop and partially incorporated into the root zone with irrigation water. Careful irrigation manage-

ment is essential when using fertigation because of the high potential for nutrient leaching and runoff when irrigation rates are excessive. The compatibility of fertilizer materials with irrigation water and other chemicals applied concurrently should be checked beforehand since precipitation of nutrients can reduce availability and clog nozzles (Box, p. 11). Uniformity of water application also has a significant effect on the efficiency of water-run fertilizer. In-season applications are particularly effective for N, especially on sandy soils that are prone to NO_3N leaching.

Nitrogen (N) Management

Efficient N management is an essential part of any potato fertilization program. Nitrogen management can affect vine and tuber biomass production, tuber size, grade, specific gravity, and internal and external quality. The potential for nitrate leaching is also closely related to the efficiency of the N management program.

Crop Nitrogen Uptake

Total N uptake for Russet Burbank potatoes in southern Idaho usually ranges from approximately 150 to 250 pounds N/acre, depending on growing conditions and yield potential.

At harvest, approximately 75 to 85 percent of the total plant N is contained in the tubers, while the remainder is contained in the vines and roots. During tuber bulking, Russet Burbank potatoes usually require 2.0 to 3.0 pounds N/acre/day depending on tuber growth rate.

Approximately 60 percent of the seasonal N requirement is taken up by 75 days after planting. Consequently, adequate N must be available to the crop early in the season to allow for sufficient canopy development. Research

shows that about 150 to 180 pounds N/acre from soil and fertilizer N is required by the time the rows begin to close to provide for optimum canopy development and yield. However, excessive N availability prior to tuber initiation can delay tuber bulking by up to 2 weeks, reducing tuber yields by as much as 100 cwt/acre. Excessive early-season N can also increase the susceptibility to brown center and hollow heart. Excessive late-season N applications usually reduce specific gravity and skin set, and increase the potential for nitrate leaching.

Available Nitrogen Sources

Crops can acquire N from a number of sources including (1) the inorganic soil N forms nitrate (NO_3) and ammonium (NH_4), (2) N mineralized from soil organic matter, crop residues, and animal wastes, (3) N present in the irrigation water, and (4) fertilizers.

The first step in determining the amount of N fertilizer to apply to a potato crop is to assess crop N requirements and availability from all sources. Data collected from over 120 commercial Russet Burbank potato fields in southern Idaho during the 1993 to 1996 growing seasons indicated that a total of about 300 pounds N/acre from all sources was required to produce a 400 to 450 cwt/acre crop. Total N uptake at these sites was about 180 to 220 pounds N/acre, indicating that total N use efficiency was approximately 60 to 75 percent. Although highly variable, N mineralization for these fields averaged about 60 to 80 pounds N/acre.

Nitrogen Fertilizer Recommendations

Research studies were used to validate and refine the total season N fertilizer recommendations presented in Table 2 (p. 6). The recommended rates are based on total N requirement adjusted

Table 2. Total N recommendations for Russet Burbank potatoes.

Soil test NO ₃ -N + NH ₄ -N (0-12 inch) (ppm)	Potential yield (cwt/acre)			
	300	400	500	600
0	200	240	280	320
5	180	220	260	300
10	160	200	240	280
15	140	180	220	260
20	120	160	200	240
25	100	140	180	220

for yield potential, soil test NO₃N and NH₄N in the top 12 inches and the previous crop. The recommendations assume an average of 60 pounds N/acre of mineralized N that is accounted for in the table.

Additional adjustments in the N recommendations include the following:

1. Apply an additional 15 pounds N/acre for each ton of previous grain, straw, or mature corn stalk residue up to 60 pounds N/acre. Mature cereal crop residues have relatively high carbon/nitrogen ratios and immobilize available N during microbial decomposition. Residues from non-cereal crops such as sugarbeets, onions, beans, peas, corn, and mint have lower carbon/nitrogen ratios and decompose readily without additional N applications.
2. Subtract 80 to 100 pounds N/acre from the recommendation following alfalfa. Fall incorporation of alfalfa crop residue can provide a significant amount of N to the following potato crop that effectively satisfies part of the N fertilizer requirement.
3. Subtract the N applied in irrigation water using the formula N applied (lb N/acre) = water applied (inches) x ppm NO₃N x 0.227. For example, 22 inch-

- es of 6 ppm NO₃N water equals 30 pounds N/acre.
4. Make appropriate adjustments for N contributions from animal manure applications as determined by laboratory analysis.
 5. Fields with very sandy soils typically require an additional 30 to 40 pounds N/acre to offset nitrate leaching losses.

Split Nitrogen Management

The most efficient N management systems for potatoes utilize split N management with one-half to three-fourths of the total seasonal N supply top-dressed and/or applied through the irrigation system in several small applications during tuber growth. Several liquid N fertilizers such as urea ammonium nitrate (32-0-0) and ammonium polyphosphate (10-34-0) can be applied by this method.

Nitrogen is also a component of many other liquid fertilizers containing P, K, and S that can be injected through sprinklers. When properly used, split N management can significantly increase N use efficiency and reduce N leaching potential while improving potato yield and quality.

Preplant N rates used with split N management programs determined as a percentage of the total N required (Table 2) should be as follows:

Sands	25 to 30%
Sandy loams	30 to 40%
Silt loams	40 to 50%

For example, a preplant N application for a potato crop grown on a sandy loam soil with a potential yield of 500 cwt/acre and 5 ppm soil test NO₃N + NH₄N would be about 35 percent of the total N requirement of 260 pounds N/acre (from Table 2) which is 91 pounds N/acre.

In-Season N Applications

Following tuber initiation, in-season N applications should be made to maintain optimal N concentrations in the potato crop. In-season N can be applied by sprinkler injection, foliar sprays, or broadcast aerially as dry fertilizer. Approximately 50 to 60 percent of the total N requirement should be applied to the crop by the time the rows close.

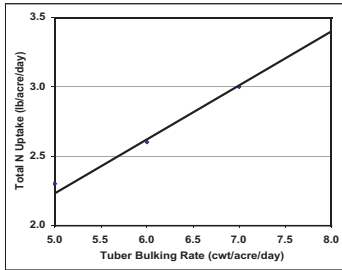
Once tuber bulking begins, weekly crop N requirements can be estimated based on the relationship between tuber growth rates and plant N uptake (Figure 4 p. 7). For example, an average Russet Burbank crop requires about 3 pounds of N per day to maintain an average daily growth rate of 7 cwt/acre/day.

Assuming 75 percent plant uptake efficiency for water-run N fertilizer, about 28 pounds N/acre would satisfy crop N requirements for a week, while

Table 3. Recommended petiole and soil (0-18 inches) NO₃N concentrations for Russet Burbank potatoes during different growth stages.

Sample	Vegetative	Tuber initiation	Tuber bulking	Maturation
		NO ₃ N (ppm)		
Petiole	—	20,000-25,000	15,000-20,000	10,000-15,000
Soil	>20	20	15-20	<15

Figure 4. Relationship between daily tuber bulking rate and nitrogen uptake rate for Russet Burbank potatoes.



40 pounds N/acre would be adequate for 10 days. Lesser amounts would be required for more frequent N applications. Adjustments to these projected rates should be based on petiole NO₃N analysis to account for contributions from soil N and N mineralization.

In sprinkler-irrigated fields, N application frequencies range from almost continuous injection on sands, to 10 to 14 day intervals on loam soils. A common approach is to apply 20 to 40 pounds N/acre every 7 to 14 days during tuber bulking, which is usually adequate to maintain petiole NO₃N concentrations in the optimal range. Petiole NO₃N analysis assists the grower in making appropriate N adjustments during the growing season.

Monitoring Crop N Status

Relationships between tuber bulking rates and daily or weekly N requirements can be used to initially estimate in-season N applications. However, weekly petiole NO₃N concentrations should be used to monitor actual plant N status. Soil NO₃N concentrations in the top 18 inches of soil can also be used to monitor

N availability. See Table 3 for recommended petiole and soil NO₃-N concentrations for the various growth stages.

Combining the two references provides a good indication of the effectiveness of N management, and the potential causes of decreasing petiole NO₃N concentrations. For example, the maintenance of adequate soil NO₃N concentrations when petiole NO₃N concentrations are falling indicates that other factors are limiting NO₃N uptake and/or translocation.

During cool springs, petiole NO₃N concentration may not provide an accurate indication of crop N status. Frequent soil fumigation also reduces the activity of nitrifying bacteria, decreasing the conversion of ammonium (NH₄N) to NO₃N and increasing the relative proportion of NH₄N in the soil. Consequently, cool soil conditions and repeated soil fumigation slows the conversion of ammonium to nitrate and increases the proportion of ammonium absorbed by the roots. As a result, petiole NO₃N concentrations may be low while plant N status is actually adequate. Measurement of soil NO₃N and NH₄N early in the season helps provide a more accurate picture of plant N availability.

Irrigation Management

Nitrogen leaching losses due to over-irrigation can be substantial, especially on sandy soils. The potential for over irrigation is usually greatest during the early and late season periods when crop water use rates are relatively low.

Southern Idaho research shows that over-irrigating by 20 to 30 percent during the growing season can reduce potato yield, quality, and fertilizer use efficiency and decrease net economic return by more than \$150/acre. It is important to closely match irrigation amounts with crop water use rates throughout the growing season while maintaining available soil water content above 65 to 70 percent.

Winter Cover Crops

Appreciable amounts of NO₃N can accumulate in the soil at the end of the growing season due to reduced late-season plant N uptake efficiency, continued mineralization of soil organic matter and plant residues, and N applied in excess of that required by the potato crop. Planting cover crops such as winter wheat and rye following harvest provides an opportunity to capture some of the residual root zone N and retain it for use the following growing season. Nitrogen absorbed by the cover crop root system is stored over winter in the plant biomass until spring when the cover crop is tilled into the soil and begins to release the stored N. Conserving soil N in this manner prevents it from leaching during winter months, and reduces potential for groundwater contamination. Winter cover crops also reduce wind erosion and can increase soil organic matter content and improve soil tilth.

Phosphorus (P) Management

Potatoes commonly respond to

phosphorus fertilization, particularly on soils with high pH and large amounts of free lime. Adequate soil P availability is important for early crop development and tuber initiation. It also enhances tuber maturity. Phosphorus deficiencies, however, significantly reduce tuber yield and size as well as specific gravity. Phosphorus moves very short distances in soil and needs to be adequately incorporated into the soil to facilitate plant uptake. Phosphorus is not readily leached, but can be lost in runoff from field areas prone to soil erosion.

Phosphorus Uptake

The amount of P in the soil solution at any given time is usually less than 1 pound per acre (0.01 to 0.3 ppm) and therefore needs to be constantly replenished from labile soil P sources during the growing season. Labile soil P consists of mineral and organic P sources that dissolve or mineralize readily. Daily potato P uptake requirements are only 0.3 to 0.5 pound P/acre/day, but serious deficiencies develop if available soil P concentrations are inadequate. Soil test P concentrations determined by sodium bicarbonate extraction provide a good relative measure of soil P availability to potatoes in alkaline, calcareous soils.

Phosphorus Fertilizer

Recommendations

The primary factors used in determining potato P recommendations are the soil test P concentration (STPC) and the amount of free or excess lime. Research shows that significant amounts of free lime (calcium carbonate) increase the precipitation of soil solution P, reducing P availability to plants. The relative reduction in soil P availability is directly proportional to the amount of free lime in the soil.

Phosphorus fertilizer may be broadcast in either the fall or spring or may be banded at markout or during planting. Banding generally improves early-season P availability by concentrating the fertilizer in a narrow zone near the seed piece.

Banding fertilizers containing ammonium may also increase P availability by reducing soil pH in the band. For full season P availability, it is important to raise the STPC in the root zone to adequate levels by broadcasting P to provide the entire root system with ready access to available soil P. Liquid fertilizers such as ammonium polyphosphate (10-34-0) and dry fertilizers such as monoammonium phosphate (11-52-0) are equally effective P sources for potatoes as long as they are managed properly.

Phosphorus recommendations

for potatoes are presented in Table 4. Rates presented represent amounts of P₂O₅ that should be broadcast in the fall or spring to raise the STPC to adequate levels. In addition, 40 to 80 pounds P₂O₅/acre should be applied in a starter or markout band to improve early P availability. Starter bands placed slightly above seed piece depth are most effective in enhancing early P uptake. Apply an additional 40 to 80 pounds P₂O₅/acre as a starter at planting for soil test P levels below 30 ppm. Add 25 pounds P₂O₅/acre to the broadcast application for each additional 100 cwt/acre above 400 cwt/acre.

In-Season Phosphorus Applications

Sprinkler application of P fertilizer is effective for correcting in-season potato P deficiencies as long as active roots are near the soil surface. Potato root density increases near the soil surface once the canopy starts to shade the hill. This is important since P applied by sprinklers only moves about 1 to 2 inches into the soil. Petiole P concentrations usually respond within about 10 to 14 days after application. Consequently, the P fertilizer should be applied through the sprinkler system before P deficiencies develop.

Petiole P Responses

Petiole P concentrations can provide a good indication of potato P status. Total P concentrations in the fourth petiole from the growing point should be maintained above 0.22 percent to provide sufficient P to satisfy both vegetative and tuber growth requirements. Petiole sampling for P should begin at or shortly after tuber initiation and continue at weekly intervals through most of the tuber bulking period.

Table 4. Broadcast phosphorus fertilizer recommendations for Russet Burbank potatoes.

Soil test P (0-12 inch depth) (ppm)	% free lime			
	0	4	8	12
	(lb P ₂ O ₅ /acre)			
0	320	360	400	440
5	240	280	320	360
10	160	200	240	280
15	80	120	160	200
20	0	40	80	120
25	0	0	0	40
30	0	0	0	0

Potassium (K) Management

Potatoes have a relatively high K requirement, removing over 240 pounds K/acre in a 500 cwt/acre crop. Extractable K concentrations in southern Idaho soils have declined over the last few decades from over 400 ppm in the late 1960's to about 100 to 200 ppm today. As a result, potato yield and quality responses to K fertilizer are common and the intensity of K management in potato cropping systems has increased.

Yield and Quality

Potassium availability influences tuber yield and size as well as a number of tuber quality factors including specific gravity, blackspot bruise susceptibility, chip and fry color, and storage quality. Potassium deficiencies decrease photosynthesis, reducing dry matter and starch formation. When K uptake is excessive, surplus K is translocated to the tubers causing increased tuber water absorption and decreased specific gravity.

Potassium Uptake

The optimum tuber K concentration for maximum dry matter production is 1.8 percent. At this concentration, about 0.5 pound K₂O is required to produce 1 cwt of potatoes. A potato crop bulking at 7 cwt/acre/day requires about 4 pounds K/acre/day to maintain

optimum dry matter production, while higher bulking rates will require proportionally higher K uptake rates. Potassium fertilization programs should be designed to provide sufficient K to maintain optimum plant concentrations throughout the tuber bulking period.

Preplant Potassium Fertilizer Recommendations

Fertilizer recommendations for Russet Burbank potatoes are based on sodium bicarbonate-extractable K, which provides a good estimate of K availability in alkaline, calcareous soils (Table 5).

Research shows that a soil test K concentration (STKC) of 175 ppm in the top 12 inches of soil is required to produce maximum potato yield and quality. On average, it takes about 4 pounds K₂O/acre to raise the STKC 1 ppm. Recommendations presented in Table 5 are based on these relationships and also include an adjustment for potential yield to account for differences in K uptake at different yield levels.

The probability of obtaining a positive yield response to K fertilization generally increases as the sand content of the soil increases in order: loamy sands>sandy loams>loams>silt loams. In general, K source has relatively little effect on total yield, although K₂SO₄ tends to produce slightly higher percentages of large No.

1 tubers and higher specific gravities than KCl, particularly when K fertilizer is applied at high rates shortly before planting.

Banded K fertilizer is generally not as effective as broadcast K when the bulk of the seasonal K requirement is applied at or prior to planting. If banded near the seed piece, K rates should be kept below 50 pounds K₂O/acre to avoid crop damage due to fertilizer salt effects. Fertilizer rates exceeding 300 pounds K₂O/acre should be split between fall and spring applications to avoid yield losses. Yield reductions have been observed with spring applications of 400 to 600 pounds K₂O/acre.

In-Season Potassium Applications

Applying all K preplant is usually more effective than applying most or all of the seasonal K supply via fertigation. Idaho and Washington studies show that applying over 50 percent of the seasonal K requirement during tuber bulking reduces tuber yield and specific gravity compared to preplant applications. Studies also show there is no consistent difference between the effectiveness of the K sources KCl, K₂SO₄, and KTS when applied through the irrigation system. However, in-season applications greater than 50 pounds K₂O/acre should be avoided because of the increased probability of tuber quality reductions. Potassium fertilizer should not be applied later than 30 days before vine kill.

Petiole K Responses

Petiole K concentrations generally decrease with time following tuber initiation. The rate of decrease depends on soil K availability and vine and tuber growth rates. Research with Russet Burbank shows that a petiole K concentration of 7.0 to 7.5 percent is adequate to maintain optimal tuber growth rates and yield.

Table 5. Potassium fertilizer recommendations for Russet Burbank potatoes.

Soil test K (0-12 inch) (ppm)	Potential yield (cwt/acre)			
	300	400	500	600
	————— (lb K ₂ O/acre) —————			
25	550	600	650	700
50	450	500	550	600
75	350	400	450	500
100	250	300	350	400
125	150	200	250	300
150	50	100	150	200
175	0	0	50	100

Petiole K concentrations will respond to in-season K applications when plant K levels are deficient. However, there is a 2 to 3 week lag period between the time that K fertilizer is injected and the time petiole K concentrations change appreciably. Sometimes petiole K doesn't increase in response to an in-season application but levels off instead of continuing downward. As a result, K applications should be made 15 to 20 days before the date petiole K concentrations are estimated to drop below the sufficiency level. Future petiole K concentrations may sometimes be estimated by plotting the previous test results against time and fitting a trend line to the data points. This procedure should be done separately for each field since the relationship between petiole K concentration and time is highly variable.

Sulfur (S) Management

Application of S fertilizer is usually needed in areas where soil S levels at the 0- to 12-inch depths are below 15 ppm and S concentrations in the irrigation water are below 5 ppm. Other plant available forms of S include S mineralized from soil organic matter and crop residues and S stored as gypsum (CaSO_4) in the crop root zone.

Sulfur is applied as a sulfate source or as elemental S. Sulfate-sulfur (SO_4S) is readily available for plant uptake, but is susceptible to leaching. Elemental S, on the other hand, needs to be oxidized to SO_4S before being taken up by the plant roots. When applying elemental S, there often is a significant time delay in the conversion to SO_4S due to the initially low activity of S-oxidizing bacteria. This is particularly true for cold, wet soil conditions that further slow the oxidation process.

A preplant application of 30 to 40 pounds SO_4S /acre as ammonium sulfate, potassium sulfate, or urea-sulfuric acid should satisfy the crop's S requirement. However, potatoes do respond well to applications of soluble S sources injected through the sprinkler system during tuber growth. Total S concentrations in petioles below 0.2 percent indicate a potential need for supplemental S applications. As with other nutrient concentrations, trends in petiole S concentrations need to be monitored weekly to provide a reliable estimate of plant S status.

Calcium (Ca) and Magnesium (Mg) Management

Both calcium and magnesium are essential for plant growth, but are usually present in adequate amounts in calcareous, alkaline soils and in irrigation waters. Some deficiencies have been observed in very sandy soils or in acid soils where supplemental applications of Ca and Mg were needed to meet tuber growth requirements. This is more likely to occur with surface irrigation water low in Ca and Mg salts.

Exchangeable soil Ca concentrations that are less than 300 ppm indicate a need for supplemental Ca, which can be met with preplant applications of 200 pounds Ca/acre.

Magnesium deficiencies can develop at exchangeable soil Mg levels below 100 ppm. Broadcast applications of 100 pounds per acre as magnesium sulfate or potassium-magnesium

sulfate, or band applications of 20 pounds Mg/acre should satisfy crop requirements. Calcium and magnesium can be applied as dolomitic lime when increases in soil pH are desired.

Some tuber quality disorders such as internal brown spot are associated with Ca deficiencies. To improve tuber Ca uptake, Ca fertilizer should be placed in the zone of tuber formation to facilitate uptake by the stolon roots. Fertilizers such as calcium nitrate, calcium-ammonium nitrate, and calcium sulfate can be used to supply Ca without significantly increasing the soil pH.

Calcium applied to foliage is not translocated to the tubers but may help satisfy some Ca requirement of leaves when deficiencies develop. Immobility of Ca in soils and plants also limits the effectiveness of sprinkler-applied Ca. Foliar sprays of magnesium sulfate can be applied to correct Mg deficiencies when petiole concentrations are less than 0.3 percent.

Micronutrient Management

Micronutrients are largely supplied to plants from soil mineral and organic sources.

The elements zinc (Zn), manganese (Mn), iron (Fe), and copper (Cu) are positively charged ions that are exchanged with the negatively charged surfaces of soil clay particles and are also released as soil minerals and organic matter decompose. Boron (B) is also contained in soil minerals and organic matter and can be present in significant

Table 6. Adequate DTPA-extractable soil micronutrient concentrations for potatoes.

Zn	Mn	Fe	Cu	B
ppm				
>1.5	>6.0	>4.0	>0.2	>0.5

amounts in irrigation water. The availability of each of these micronutrients decreases substantially as the soil pH increases from 7.0 to 8.0 and above. Critical soil micronutrient concentrations for potatoes are presented in Table 6.

Zinc (Zn) Zinc fertilization may be required on calcareous soils, particularly in areas where topsoil was removed by erosion or land leveling. For soils with Zn concentrations of less than 1.5 ppm, a broadcast application of 10 pounds Zn/acre should be applied and incorporated prior to planting. Compared to broadcast rates, banded Zn rates can be reduced by up to 50 percent due to higher fertilizer uptake efficiency. Zinc fertilizer sources with high percentages of water-soluble zinc, such as ZnSO₄, ZnDTPA, and zinc lignosulfate, should be used to maximize uptake efficiency. Zinc will move through the phloem tissue from the leaves to the tubers, and foliar sprays of Zn sulfate or chelates are effective in correcting Zn deficiencies. The maintenance of adequate Zn availability is particularly important when high P rates are applied because of the potential for P-induced Zn deficiencies.

Manganese (Mn) On neutral to acid soils, manganese can be broadcast and incorporated prior to planting at 5 to 10 pounds Mn/acre to correct Mn deficiencies. On calcareous soils, Mn should be banded or applied as a foliar spray to minimize soil fixation. Applying 5 pounds Mn/acre in a band near the seed piece has been effective in providing adequate Mn to potatoes when soil concentrations are low (<6.0 ppm). Manganese will also move from the leaves to the tubers when applied as a foliar spray. Manganese chelates and MnSO₄ are effective Mn sources

Compatibility of Phosphorus Fertilizer with Irrigation Water

Irrigation waters with appreciable Ca concentrations (>50ppm) have the potential to form insoluble calcium phosphate deposits when liquid phosphate fertilizers are injected through sprinkler systems. These deposits can plug nozzles and reduce the effectiveness of sprinkler heads. As the Ca concentration in the irrigation water increases, the potential for sprinkler problems increases proportionately. The liquid P source can also influence the potential for calcium phosphate precipitation.

Compatibility can be tested by adding a proportional amount of the specific liquid P fertilizer to a gallon of fresh irrigation water. For center pivots, the amount of fertilizer solution that can be safely added to the irrigation water can be estimated using the following relationship:

$$X = \frac{0.0283 \times F}{D \times P}$$

where,

X = teaspoons of fertilizer solution per gallon of irrigation water

F = fertilizer application rate (lb P₂O₅/acre)

D = depth of water application (inches/acre)

P = P₂O₅ concentration in the fertilizer solution (lb P₂O₅/gal)

If a fine, white precipitate forms after the calculated amount of fertilizer solution is thoroughly mixed with the irrigation water, the P fertilizer application rate should be reduced. The testing procedure should continue until there is no visible precipitate formation.

For wheel-lines, hand-lines, and solid-set irrigation systems, the relationship is:

$$X = \frac{0.0283 \times F}{W \times T \times P}$$

where,

X = teaspoons of fertilizer solution per gallon of irrigation water

F = fertilizer application rate (lb P₂O₅/acre)

W = water application rate (inches/hr)

T = injection time (hr)

P = P₂O₅ concentration in the fertilizer solution (lb P₂O₅/gal)

If precipitates form after mixing, the P application rate should be reduced or the length of the injection period should be increased and testing repeated.

Irrigation waters with high Ca and Mg concentrations or a high pH can be partially acidified to improve compatibility with P fertilizers. Phosphoric acid or urea phosphoric acid can be injected through the sprinkler system in appropriate amounts. Alternatively, sulfuric acid or urea sulfuric acid can be injected along with ammonium polyphosphate (10-34-0) to minimize calcium phosphate precipitation.

Achieving an irrigation water pH between 5.0 and 7.0 can substantially reduce the potential for nozzle plugging. However, the final pH should be kept above 5.0 to prevent corrosive damage to the irrigation system and nozzles.

for foliar applications.

Boron (B) Boron fertilizers may be needed where soils and irrigation waters have naturally low B concentrations. Broadcast applications of 1 to 2 pounds B/acre should be made prior to planting when soil test B concentrations are below 0.5 ppm. Band applications should be avoided due to the increased likelihood of B toxicity. Sodium borates, Solubor and boric acid can be applied as foliar sprays, but B is not translocated from the leaves to the tubers in appreciable amounts.

Iron (Fe) Most soils in Idaho do not require iron applications for potatoes. Band applications of chelated Fe on calcareous soils may be beneficial when soil Fe concentrations are low. Iron is relatively immobile in soils and in plant tissue. Consequently, multiple applications of Fe sulfate or chelates to the foliage may be required to correct Fe deficiencies.

Copper (Cu) Copper concentrations in mineral soils are usually sufficient for adequate plant growth. Copper has intermediate mobility in plant tissue, and foliar sprays of Cu sulfate or chelates applied during tuber bulking are effective in increasing petiole Cu concentrations. Copper is a common component of certain potato fungicides that can provide significant amounts of Cu to the plant.

Chloride (Cl) There is generally enough chloride present in irrigation water or potassium fertilizer (KCl) to provide adequate chloride for a potato crop. Deficiencies may occur when irrigation waters contain little Cl and when all of the K is applied as a

non-chloride source such as K_2SO_4 or KTS.

Additional Reading

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