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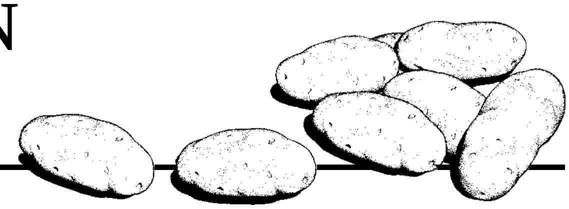
NUTRIENT MANAGEMENT GUIDE: CENTRAL WASHINGTON IRRIGATED POTATOES



The goal of all nutrient management should be to follow Best Management Practices (BMPs), which avoid applying nutrients in excess of plant needs. Nutrient availability decisions should be made on the basis of plant demand. Plant demand is a function of growth rate, growth stage (Table 1), climatic conditions, and cultivar. The amount of nutrients required by a potato crop are also related to a realistic yield potential for the selected cultivar and land farmed. BMPs include the use of soil and tissue (petiole) analysis. Proper sample collection and selection of a testing laboratory which maintains high analytical standards increase the potential for obtaining reliable values for coordinating fertilizer management. The amount of fertilizer recommended in this guide is the amount needed to produce optimum yield of the current crop. Recommendations should be modified and refined to fit each potato management unit to optimize yield, quality, and environmental protection at each location. Excess fertilizer application should be avoided at all growth stages for both short and long season cultivars to increase fertilizer efficiency and minimize potential leaching or erosion losses of nutrients.

NITROGEN

Potato Nitrogen Needs

Nitrogen is required in large amounts to maintain optimum shoot and tuber growth. Nitrogen may be supplied by residual soil nitrogen, mineralized soil nitrogen, nitrogen in irrigation water, and fertilizer application. Uptake of nitrogen (crop requirement) is determined by the amount a cultivar requires to produce a given yield. The amount of nitrogen required in the plant/soil environment to meet this need is determined by the cultivar's nitrogen use efficiency and length of growing season.

Table 1. Plant growth stages of Russet Burbank potato.

Stage I	Plant development after planting and until tuber initiation.
Stage II	Begins with initiation of tubers at the tips of stolons (tuberization) approximately 10 to 14 days prior to flowering.[z] Tuberization is defined as an enlargement which is double the normal stolon diameter. Little or no enlargement of initiated tubers (bulking) occurs during this stage.
Stage III	Enlargement of initiated tubers (bulking); tuber growth is linear if all growth conditions are optimum; tuber dry weight increases due to translocation of plant nutrients and food reserves from the shoots and roots into the tubers.
Stage IV	Tuber maturation occurs as vines start to yellow, leaf loss is evident.

Adapted from Kleinkopf and Westermann, 1981

[z]Growers should monitor tuber initiation and flowering to determine tuber initiation under their growing conditions due to interactions of soil temperature, water, and fertility modifying the initiation of this growth stage each season. Plant stress promotes tuberization when plants are small.

Under optimum growing conditions, a 30 to 35 ton/acre crop of Russet Burbank potatoes can be produced with a season total of 300 to 350 lb N/acre.

Nitrogen supply should be adjusted approximately ± 10 lb N/acre for each ton which varies from the 30 to 35 ton/acre range (Table 2). The total plant nitrogen accumulated at a given yield is independent of soil type. Whether soils are silt loam or sand has little influence on the total nitrogen taken up by the potato plant to produce a 30 to 35 ton potato crop. Although timing and placement may differ, total nitrogen available for uptake should be the same on different soil types and irrigation systems.

Pre-season management is based on nitrogen found in the top 12 inches of soil. Residual soil nitrogen remaining from the previous crop or from organic matter release (present in the top 12 inches) is a portion of the seasonal nitrogen available for uptake and should be subtracted from total nitrogen applied. Early-season irrigation management is critical to limit the potential loss of residual and preplant applied nitrogen due to leaching. An estimate of total season nitrogen application needed in combination with residual soil nitrogen concentrations is provided in Table 2.

Mineralization, the microbial conversion of organic nitrogen to ammonium, should be considered in predicting total nitrogen fertilizer application. The amount released depends on soil organic matter present, soil texture, climate, and crop residues. Under most central Washington conditions (especially sandy soils), mineralized nitrogen may represent a small percentage of the total nitrogen available. However, if an estimate of mineralizable nitrogen is available from soil analysis, it should be considered available for uptake and subtracted from the nitrogen to be applied.

Organic residues from previous crops in the rotation or from cover crops planted prior to potatoes influence the availability of nitrogen during the growing season. Possible microbial use of nitrogen when organic residue contains >1 to 1.5% total N must be accounted for in early-season nitrogen management. Approximately 10 lb N/ton of high carbon to nitrogen ratio straw residue, such as from field corn or wheat, may be needed to supply adequate nitrogen for microbial breakdown crop residues and thus may be temporarily unavailable to the potato crop. A portion of this nitrogen will be released and can be managed with reduced in-season nitrogen applications.

Table 2. Nitrogen fertilizer rates[z] for total season application based on residual soil concentrations (0 to 12 inch depth) and potential yield of Russet Burbank produced in the Columbia Basin.

Soil test N ($NO^3 + NH^4$)	Potential yield (tons/acre)			
	20	25	30	35
(ppm)	N Application Rate (lb/acre)			
0	200	250	300	350
10	160	210	260	310
20	120	170	220	270
30	80	130	180	230

[z]Does not include N needed for microbial decomposition of previous crop residue or from mineralized soul organic matter. Assumes ppm x 4.0 = lbs/acre; may be adjusted for different bulk densities.

Cover crops commonly grown for nematode control or soil stabilization may have very low carbon to nitrogen ratios and high nitrogen concentration, which allow for rapid residue breakdown, making the nitrogen from these sources available for plant uptake early in the growing season. Increases in soil nitrogen availability have been found as early as 2 to 5 weeks after incorporation of the green vegetative crops. Well-established winter cover crops such as wheat, rye, and brassicas which are incorporated into the soil in the spring, can reduce overwinter nitrate leaching and reduce total nitrogen fertilizer application required by 75 to 150 lb N/acre, as nitrogen is released through microbial breakdown. Frost-killed cover crops such as sudangrass begin to release inorganic N in late fall and early spring, so careful irrigation management is required to retain this nitrogen in the root zone. Optimum utilization of this nitrogen released from cover crops requires the use of in-season soil sampling.

In some production areas, irrigation waters may contain a significant amount of nitrate. The amount of nitrogen being applied with irrigation water should be calculated and subtracted from fertilizer applications needed to meet total nitrogen requirement.

Components of plant nitrogen supply:

\+ Residual inorganic N from previous crop (0 to 12 inches)

– N use by high C:N crop residues (~ 10 lb N/ton of residue)

\+ Release from cover crops with low C:N (75 to 150 lbsN/ac)

\+ Release from soil OM (slow 25 to 50 lbs N/ac/% OM)

\+ Nitrate in irrigation water

\+ Fertilizer addition

– Leaching below root zone

– Gaseous losses

= Total plant supply of nitrogen

Timing Nitrogen Applications

Nitrogen applications which are split between pre-plant and in-season provide opportunities to increase nitrogen use efficiency and minimize leaching by preventing excess availability. Avoiding excess nitrogen availability during growth stages I and II also favors a balanced proportion of roots and shoots, resulting in enhanced tuber set. Maximizing early tuber initiation and set increases the potential **duration** of tuber bulking phase of development. Delay of tuberization by two weeks can decrease yields by 5 tons/acre. The addition of a set daily or weekly nitrogen application rate throughout the growing season is not an effective nitrogen management strategy, due to differences in shoot and tuber growth rates which have different nitrogen demands.

For split nitrogen applications, no more than 1/3 of the expected total seasonal nitrogen (including residual soil nitrogen) should be applied pre-plant or at planting.

Maximum early tuber production can be achieved with pre-plant application rates of 60 to 120 lb N/acre, when adjusted proportionally for residual soil nitrogen.

The first in-season application should occur prior to the end of stage II (tuberization). However, the most rapid nitrogen uptake corresponds to the beginning of tuber bulking, which occurs at the beginning of stage III, normally in early July.

Thus, the crucial time for maintaining adequate nitrogen fertility is during mid-season (stage III, Table 1) when nitrogen uptake is largely determined by tuber growth rate.

To anticipate this demand, in-season nitrogen application should be managed by monitoring nitrogen availability through soil (NO_3 + NH_4) and plant tissue (petiole NO_3) analysis. Following pre-plant applications, the balance of total nitrogen applications should take place as fertigation through sprinkler systems, as a sidedress under furrow irrigation systems, or as foliar application (using aerial sprays). Monitoring soil nitrogen availability and petiole nitrate trends aids in preventing deficiency levels during stage III, and insures maximum tuber bulking rates. Application of in-season nitrogen using petiole analysis trends should be restricted to the amount of nitrogen which can be taken up and utilized by the potato plant prior to the next application.

Typical uptake rates of 3 to 4 lb N/acre each day for stage III can be supported by applications of 5 to 7 lbs N/acre each day (factoring in the 65% efficiency rate).

Generally, the total period of in-season application will be from row closure to 100 DAP for a 120 to 130 day crop because approximately 95% of the total nitrogen uptake is completed by the end of stage III. The majority of shoot and tuber nutrient accumulation has been completed and a significant decline in root length during bulking reduces nutrient uptake capacity. Nitrogen may then be subject to leaching after harvest if high fertilizer application rates are maintained. Late-season applications can adversely affect tuber quality and yield by stimulating re-growth of deteriorating vines, resulting in a reduced tuber dry matter accumulation and internal defects observed as heat necrosis. Termination of in-season fertilizer application (beginning of stage IV) allows for normal senescence of foliage and maturation of tubers.

Late-season soil sampling can be used to determine when soil nitrate levels begin to increase while petiole nitrate levels continue to decline, indicating soil nitrate availability is not limiting plant nitrate supply.

Seasonal optimum petiole nitrogen values are at the highest concentration during early stages of growth and decrease through the season, with greatest declines occurring during tuber bulking (Table 3). Decreases in petiole nitrate concentrations can indicate a decreased nitrogen supply or a reduced ability for nitrogen uptake by the plants; thus, in-season nitrogen application must take both possibilities into consideration.

Petiole sampling areas should be selected to represent the **major** conditions found in the field. The recommended petiole nitrate levels shown in Table 3 reflect field variation. Overall nitrogen field management must optimize nitrogen utilization and crop production for the majority of field conditions. Areas with extreme production problems can be adequately managed only with site specific management techniques. Average Russet Burbank petiole NO_3 can be maintained with soil nitrogen (NO_3 + NH_4) concentrations of 10 to 15 ppm in the top 18 inches of soil.

In-season soil samples need to be taken from the area of greatest nutrient uptake. This area will depend upon soil texture, bed shape, growth stage, and irrigation management. A specific sampling protocol should be developed for each cropping system. Based on growth stages, adequate seasonal soil NO_3-nitrogen in the top 18 inches should be within the following values.

Developmental Stage	Soil NO_3-N + NH_4-N Concentration **(18-inch depth)**
Stage I	15 ppm
Stage II	> 10 to 15 ppm
Stage III	10 ppm
Stage IV	< 10 ppm

Total yield, percentage of #1's, specific gravity, blackspot index, and chip color are the same regardless of the form of nitrogen applied. Ammonium in mixed sources may be less likely to be lost to early season leaching and may be important to consider in reducing leaching when spring rainfall may increase the risk of nutrient movement beyond the root zone.

Early and late season over-application of water represents the greatest potential for leaching of nitrate below the rooting depth. To manage irrigation effectively scheduling must be adjusted during the season to equal crop water use. Scheduling irrigation frequency and rate such that irrigation is within 0 to 6 inches of the potato crop's seasonal evapo-transpiration rate maximizes yield and specific gravity potential. Exceeding the optimal irrigation level can reduce yield up to 1.5 tons/acre and cannot be overcome by increasing nitrogen application rates.

Table 3. Recommended optimal petiole nitrate concentrations, based on survey of industry consultants[z] and research[y], for the developmental growth stages of Russet Burbank potato produced in the Columbia Basin.

	Petiole NO_3-N Concentration (ppm)		
Developmental Stage	Consultant Ranges	Research Plot Ranges	Recommended Ranges
Stage I	– – – –	– – – –	– – – –
Stage II	20,000 to 30,000	15,000 to 22,000	15,000 to 26,000
Stage III	12,000 to 30,000	12,000 to 15,000	12,000 to 20,000
Stage IV	8,000 to 15,000	6,000 to 10,000	6,000 to 10,000

[z]Lang and Stevens, 1997.
[y]Jones, 1975; Painter, 1978; Westermann and Kleinkopf, 1982.

Irrigation management information is available in the WSU Cooperative Extension publication *Irrigation Management Practices to Protect Ground Water and Surface Water Quality in the State of Washington*, EM4885.

PHOSPHORUS

The need for phosphorus fertilization in Pacific Northwest potato production is well documented. The soil solution concentration of phosphorus is low; therefore, there is little risk of leaching phosphorus under central Washington conditions. However, excessively high phosphorus application does increase the risk of phosphorus moving off fields into surface water.

Phosphorus plays a critical role in root development and overall plant health, which is directly related to yield. Once phosphorus levels are at concentrations which adequately support plant health, increases in phosphorus application rate to increase yields are unnecessary. For maximum tuber yields, phosphorus should be mixed into the seed bed prior to planting. Plant phosphorus levels in mid- and late-season (stages III and IV) may be raised by applications of phosphorus using foliar sprays, application through irrigation water, or soil applied phosphorus followed by irrigation. Phosphorus moves only small distances in the soils; thus, feeder roots must be near the soil surface to make in-season application effective.

A pre-plant soil test phosphorus value of 20 ppm (sodium bicarbonate extraction) is adequate for optimum production without additional phosphorus application on non-calcareous to slightly calcareous soils. Research indicates recommended phosphorus rates listed in Table 4 are sufficient to reach current yield goals. Soil and water conditions which require phosphorus application rates significantly higher than those listed in Table 4 include: elevated soil pH, in association with free lime (calcium carbonate) >1 to 2%, and irrigation water high in bicarbonate. All will decrease phosphorus availability, requiring increases in application rate. Elevated levels of free lime in the soil cause phosphate fertilizers to be rapidly precipitated to form slowly available calcium phosphate. Increasing application rates by as much as 120 lb P_2O_5/acre to an upper limit of 400 lbs P_2O_5/acre may be needed to supply adequate plant available phosphorus in soils with 5 to 15% free lime. Banding of acidifying nitrogen and phosphorus mixed fertilizers will increase phosphorus availability in these soils. Consult with your county extension agent to determine appropriate increases in phosphorus application rate under these cultural conditions.

Table 4. Phosphorus fertilizer rates^z for total season application based on pre-plant soil test concentrations (0 to 12 inch depth) for Russet Burbank potato produced in the Columbia Basin.

Soil test P (sodium bicarbonate)	Application Rate (lb/acre)^z	
(ppm)	P	P_2O_5^{y}
3	130	295
6	90	204
9	70	159
12	50	114
12 to 20	30	68
Above 20	0	0

^{z}Recommended application rates are for average conditions; conditions such as high soil pH, high free lime, or high bicarbonate irrigation water will restrict phosphorus availability; therefore, application rates should be increased to supply crop needs.

^{y}To convert P_2O_5 to P, multiply by 0.44.

Although limited data exists, a potential early-season benefit for placement of phosphorus at mark-out and/or planting exists. Placement at planting varies with the producer, but a common location is 4 inches out to each side and 2 inches above the seed piece. Adequate phosphorus availability in the bed in the area of early-root zone growth will promote root development in this region, thereby maximizing plant establishment, early tuber set, and reduce the potential for water and nutrient losses. In soils with low phosphorus fixation capacity and low phosphorus availability, broadcast and incorporation of phosphorus fertilizer is recommended.

High phosphorus soil concentrations do not appear to negatively impact yield; however, high concentrations have been suggested to reduce zinc availability, although this has not been documented.

Trends in petiole phosphorus concentration should be used to monitor and evaluate inseason timing and rate of application when an adjustment appears necessary. Phosphorus petiole values should be > 1000 ppm soluble P (0.22% total P) until plant maturation, or approximately 20 days prior to vine kill. Total phosphorus concentration (%) in the petiole may be converted to soluble phosphorus concentration (ppm) by the following equation:

$$P_{soluble(ppm)} = 5600\,(P_{total\,(\%)})^2 + 3620\,(P_{total\,(\%)}) - 10$$

In-season phosphorus applications of foliar sprays (aerial applications), fertigation, or as dry material followed by irrigation, are recommended to help maintain petiole phosphorus levels when poor root function, disease, or environmental stress have a negative effect on phosphorus uptake.

POTASSIUM

Potatoes require high levels of potassium in concentrations which are comparable to or greater than nitrogen. Potassium is taken up from the soil solution as the potassium ion (K^+) which is replenished predominately from the exchange sites of soil colloids; thus, soil extracted K^+ (reported in ppm) provides an index of soil potassium supplying ability (Table 5). On sandy soils K^+ quantity may test adequate; however, daily rate of supply may not be adequate to meet peak plant uptake demand.

Table 5. Potassium fertilizer rates for total season application based on pre-plant soil test concentrations (0 to 12 inch depth) for Russet Burbank potato produced in the Columbia Basin.

Soil test K (sodium bicarbonate)	Application Rate (lb/acre)	
(ppm)	K	K_2O^z
60	400	480
120	300	360
180	200	240
240	100	120
>240	0	0

[z]To convert K_2O to K multiply by 0.83.

At recommended potassium soil levels, yield does not appear to be directly related to increased application rates or source of potassium (KCl, K_2SO_4, or thiosulfate). In fact, applications in excess of recommended rates may be detrimental to potato quality causing decreases in tuber specific gravity.

Applying a major portion of total season potassium fertilizer prior to planting has been found effective in obtaining maximum yields. The practice of applying potassium in multiple split applications does provide the advantage of reducing the amount of potassium at planting, thereby reducing the potential for salt concentrations becoming a problem. Banding potassium fertilizer materials beside the seed piece at planting has the potential to elevate salt levels in the area in which sprouting of the seed piece occurs, causing detrimental results in root development. On extremely sandy soils, where potassium holding capacity is extremely low, application timing may need to be modified and split applications may be advantageous. Potassium fertigation is potentially an effective means of helping match the 3 to 7 lb K/acre daily potassium uptake rate which takes place during bulking.

Petiole analysis may be used to monitor the seasonal trends of potassium uptake. Research has defined sufficient potassium petiole concentrations in the following ranges:

Developmental Stage	Suffficient Petiole K Concentration (%)
Stage I	– – – –
Stage II	8 to 11
Stage III	6 to 9
Stage IV	4 to 6

SULFUR

Although sulfur deficiencies are not common in central Washington, sulfur is an essential element in potato growth and production.

Sulfate (SO_4^{-2}) is a mobile ion and may be subject to leaching. Thus, early season sulfur deficiency may occur where leaching has moved sulfate below the root zone. For this reason, soil samples should be taken to a depth of 24 inches to verify sulfate availability to the potato crop. Depending on source, preplant broadcast and incorporation of sulfur applications (in the available sulfate form) may occur along with application of some N-P-K fertilizer formulations. The concentration of sulfate in irrigation supplies will vary depending upon the source of the water; therefore, it should be analyzed to determine irrigation's contribution to the annual sulfur supply.

The majority of sulfur fertilizer is applied in the water soluble sulfate form, although elemental sulfur may be applied as a means to lower soil pH. When elemental sulfur is applied, a significant lag in sulfate availability occurs due to limited microbial activity which is necessary for transformation of elemental S to the plant useable form. This lag occurs particularly under cold, wet soil conditions, which are common early in the growing season.

The standard recommendation is to apply at a rate of 40 lb S/acre, if sulfur is known to be deficient from soil test information (Table 6). Sulfur deficiency can occur with soil test levels < 2 ppm SO_4^{-2}-S.

In-season monitoring of soil and petiole concentrations aid in preventing sulfur deficiencies. Sulfur petiole concentrations should be maintained within a range of 0.15 to 0.20 % to support tuber growth (stage III).

Table 6. Sulfate-sulfur soil test ranges and interpretation for east of the Cascades.

	SO_4^{2-}-S (ppm)
low	< 2
medium	2 to 10
high	>10

Adapted from Marx et al., 1996.

ADDITIONAL NUTRIENTS

Calcium and magnesium are essential nutrients required for plant growth which are seldom limiting in central Washington soils. Calcium has been implicated as a factor influencing tuber quality, although research has not established a direct relationship. Calcium is immobile in plant tissues. To be translocated to the tubers during bulking, calcium must be taken up by the stolons and/or stolon roots. Therefore, any calcium fertilization program must be designed to increase the calcium concentration in the zone of tuber formation. To maintain calcium availability in the zone of tuber formation, the solubility and potential leaching of calcium fertilizers must be considered.

Presently, limited data exist to support an economic response to the application of boron (B), iron (Fe), manganese (Mn) or copper (Cu), although the idea of applying complete fertilizer mixes which contain these nutrients is attractive to many producers. Application of individual plant nutrients should be based on soil test and petiole analysis (Tables 7 and 8).

Table 7. Critical soil test levels for micronutrient (0 to 12 in depth) for Russet Burbank potato produced in the Columbia Basin.

Nutrient	B[z]	Cu[y]	Fe[y]	Mn[y]	Zn[x]
	ppm				
Critical concentration	0.5	—	—	—	0.8 to 1.0

[z]Extracted with hot water.
[y]Insufficient research data to determine critical soil test levels Cu, Fe, Mn.
[x]Extracted with DTPA.

Table 8. Suggested nutrient ranges (ppm)[z] for the most recently matured petiole (fourth) for Russet Burbank potatoes produced in the Columbia Basin.

	ppm		
Nutrient	Low	Marginal	Adequate
Boron	< 10	10 to 20	> 20
Copper	< 2	2 to 4	> 4
Iron	< 20	20 to 50	> 50
Manganese	< 20	20 to 30	> 30
Zinc	< 10	10 to 20	> 20

Adapted from Hiller, 1993.
[z]Micronutrient levels will vary with growth stage; current research data is insufficient to give specific ranges based on growth stage.

Micronutrient deficiencies under central Washington production conditions are uncommon. However, availability of zinc can become growth limiting under high pH, high free lime, or very high phosphorus soil conditions. Zinc soil concentrations above 1.0 ppm (DTPA extraction) are considered sufficient, while soil concentrations < 0.8 ppm can cause deficiency symptoms. Applications of 10 lb Zn equivalent/acre are recommended to supply adequate zinc for optimum crop production.

Excess levels of boron can have a negative impact on growth due to plant toxicity and should be avoided. Boron should be applied in a broadcast-incorporated application and not banded.

Iron application on alkaline soils is inefficient unless a chelated formulation is applied and then response may be minimal. Lowering soil pH using soil amendments can increase the availability of iron for plant uptake. Manganese availability may also be improved by formation of an acid fertilizer band in the root zone. Foliar applications of micronutrients may be useful in correcting deficiencies.

These recommendations are based on research and therefore, should be expected to be modified as additional knowledge and understanding of nutrient management is obtained. Best nutrient management requires that all management steps be optimized. Soil preparation, planting, irrigation and disease control must be performed according to best management practices if nutrient management for optimum production is to be obtained. Minimizing leaching of nitrate and other nutrients from the root zone must become a primary management objective.

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