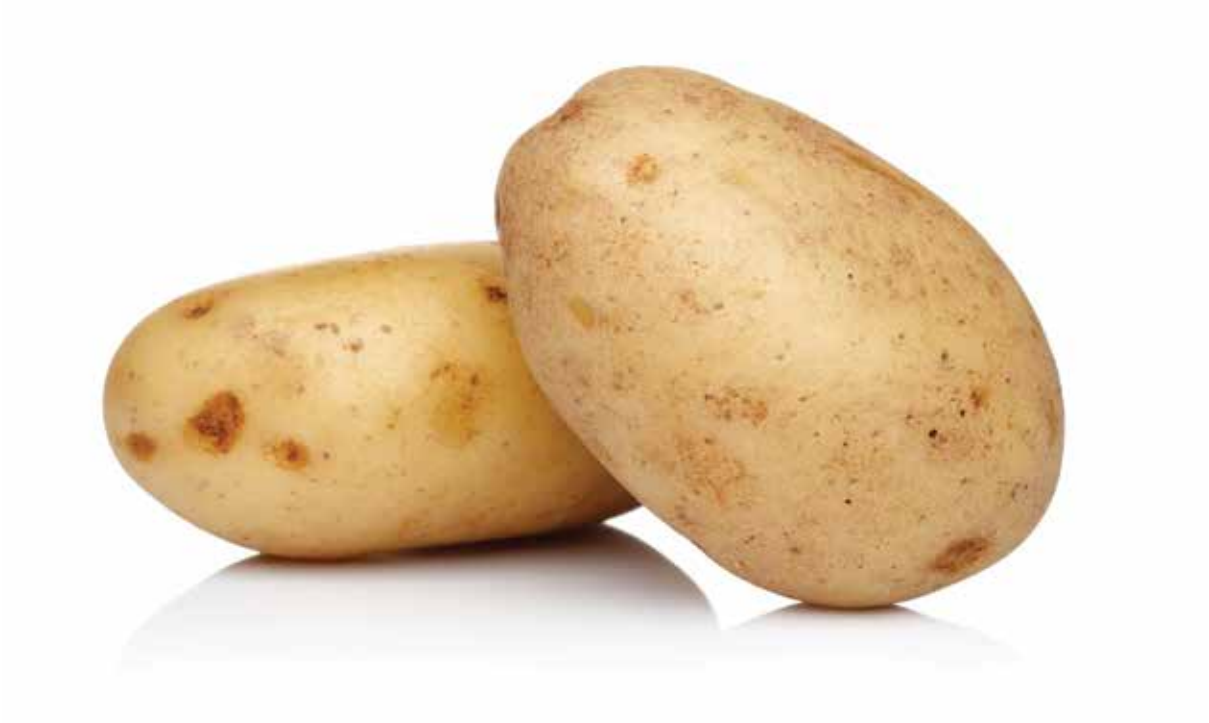
Potato

Nutrient Management Guide



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The potato is a member of the Solanaceae family. This family contains about 2,000 species, including tobacco, tomato, eggplant, pepper, horse nettle, bittersweet, ground cherry, and petunia. The potato plant, presently cultivated in North America, Europe, and widely throughout the world, is *Solanum tuberosum* (L.). It is classified as a dicotyledonous annual, although it can persist vegetatively (as tubers) in the field from season to season. Potatoes are a highly nutritious food crop and the third largest crop globally for direct human consumption after wheat and rice. Potatoes have generally high nutrient requirements and are especially sensitive to rate, timing, and placement of nutrients.



Potatoes

History

The potato is widely believed to have originated in the Andes Mountains of Peru and Bolivia at altitudes of 4,000 to 6,000 feet, where close botanical relatives are still growing today. First reports are from the Spaniards who found potatoes at the time of their conquest of Peru beginning in 1524. The name "potato" is derived from the Spanish name, "patata" (Spain). The Spanish word is a blend of the Taíno language "batata" (sweet potato) and the Quechua language papa (potato).

The potato is believed to have been first introduced into Europe via Spain as early as 1565. From there it spread to other European countries. Its introduction into England was probably independent of its spread in Europe. Exactly when is unclear due to confusion that existed among the potato, the sweet potato, and other tuber and root crops.

The Spaniards may have introduced the potato to Ireland early in the 1600s where it first became an important agricultural crop. Between 1650 and 1840, potatoes were a basic part of the food supply of Ireland. Because of its early widespread use and importance in Ireland, the potato is sometimes (erroneously) referred to as the Irish potato. When late blight devastated the crop in the 1840s, it was one factor that led to the famine that forced many Irish to immigrate to the United States.

When the potato was first introduced to the United States is not known. The first possible introduction into New England and the U.S. was from Ireland into Londonderry, New Hampshire, in 1719. Introduction into Canada was earlier; potatoes were grown in 1623 at Annapolis Royal, Nova Scotia. Acceptance of the potato as food was very slow in North America. However, 1.6 million hundredweight were grown by 1840, according to the first inclusion of potatoes in the U.S. Census.



Potato Consumption

Potatoes constitute an important part of our diet and are widely recognized today for their nutritional value. Formerly, however, it was commonly believed that potatoes were fattening, and annual consumption reached a low point in the 1950s, averaging 107 pounds per person. Educational efforts by the potato industry have bolstered the image of the potato, and consumption, in recent decades.

While total per capita consumption has been increasing, how the product is being consumed is changing. Consumption of fresh potatoes has declined to about 45 to 50 pounds annually, but this has been more than offset by the increased consumption of processed potatoes. Frozen, chips, and dehydrated products have all dramatically increased since 1960. See Table 1.



TABLE 1. PROCESSING OF POTATOES IN THE U.S.

Utilization Items/Processing	Crop Year		
	2020	2021	2022
1,000 cwt			
Chips and shoestrings	59,217	60,289	62,076
Dehydrated	44,893	40,553	37,853
Frozen french fries	155,623	159,637	156,730
Other frozen products	10,968	11,118	12,133
Canned products	1,429	1,314	1,142
Other canned products (hash, stew, soups)	1,172	862	611
Other (including fresh pack, potato salad, vodka, etc.)	6,490	7,200	8,226
Total	**279,792**	**280,973**	**278,771**

The shift in product consumption can be attributed to a number of factors, including the change in household structures toward two-income families resulting in less time for food preparation. Also, household size has been declining. Larger families tend to consume larger quantities of fresh potatoes. It is speculated that the advent of the microwave oven may have stemmed the decline in fresh consumption in recent years. Similar trends are not evident for Canada where per capita consumption is higher.

Source: https://downloads.usda.library.cornell.edu/usda-esmis/files/fx719m44h/cr56pj02j/4q77h840g/pots0923.pdf

Geographic Distribution and Productivity

Harvested potato land in the U.S. peaked in 1922 with 3.9 million acres and in Canada in 1921 with 702,000 acres. Since then there has been a steady decline in acreage. In the early 20th century, U.S. potato production was concentrated in the Northeast, Southeast, and Midwest, but acreage in these regions has dramatically declined. Equally dramatic has been the increase in acreage in the Pacific Northwest over the past several decades. See Table 2.

The overall decline in potato acreage to less than half that of its peak can be attributed at least in part to the increase in productivity that has occurred in all regions. The productivity of today's potato farmer is more than five times that of their turn-of-the-century predecessor. Canada has also experienced a decline in potato acreage due to shifts in agricultural priorities and market demands. See Table 3.

TABLE 2. HARVESTED POTATO ACREAGES, YIELD PER ACRE, AND PRODUCTION PER KEY GROWING STATES.

Region	2020	2021	2022	2020	2021	2022	2020	2021	2022
	Harvested Area (1,000 acres)			Yield Per Acre (cwt)			Production (1,000 cwt)		
California	28.9	25.4	20.9	445	435	405	12,861	11,049	8,465
Colorado	53.8	52.4	52.9	420	410	405	22,596	21,484	21,425
Florida	20.4	20	19.7	260	270	455	5,304	5,400	5,024
Idaho	299.5	314.5	294.5	450	420	410	134,775	132,090	120,745
Maine	50.8	53.3	51.9	265	345	355	13,462	18,389	18,425
Michigan	45	45	45.4	390	430	415	17,550	19,350	18,883
Minnesota	41.2	41.3	46.7	435	425	410	17,922	17,553	19,147
Nebraska	18.8	18.9	19.9	490	490	485	9,212	9,261	9,652
North Dakota	70	75	72.5	340	300	300	23,800	22,500	21,750
Oregon	45	43.8	43	600	600	600	27,000	26,280	25,800
Texas	15.3	12	12.9	465	460	575	7,115	5,520	7,418
Washington	154.5	154.5	164.5	645	595	580	99,653	91,928	95,410
Wisconsin	68.5	67.5	66.5	420	430	400	28,770	29,025	26,600

Source: https://downloads.usda.library.cornell.edu/usda-esmis/files/fx719m44h/cr56pj02j/4q77h840g/pots0923.pdf

TABLE 3. HARVESTED POTATO ACREAGES IN CANADA.

Region	2020	2021	2022	2023	2020	2021	2022	2023	2020	2021	2022	2023
	Harvested Area (acres)				Average Yield (hundredweight per harvest acres)				Production (hundredweight x 1,000)			
BC	6,500	6,300	5,000	5,790	8331.5	330	320	370	2,155	2,080	1,600	2,140
Alberta	57,937	67,800	71,325	76,440	404	363	376	420	23,407	24,614	26,813	32,063
Saskatchewan	6,300	6,800	6,500	7,200	222	223	223	247	1,400	1,519	1,450	1,780
Manitoba	71,200	78,000	79,250	80,000	337	308	330	372	24,000	24,024	26,139	29,760
Ontario	35,800	37,302	37,100	37,400	210	240	219.9	230	7,518	8,953	8,160	8,602
PEI	83,500	84,500	83,200	83,000	252	322	334	311	21,000	27,209	27,789	25,813
Nova Scotia	1,200	1,150	800	780	250	310.6	300	285	300	357	240	222
New Brunswick	48,450	52,00	51,600	50,515	237.4	350	329.5	294.5	11,500	18,200	17,000	14,879
Newfoundland	365	375	350	370	150	147	149.3	134	55	55	52	50

Source: https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3210035801&pickMembers%5B0%5D=1.11&cubeTimeFrame.startYear=2020&cubeTimeFrame.endYear=2023&referencePeriods=20200101%2C20230101



Food Value

The potato is a nutrient-dense food. This means that for each calorie eaten there is an ample return of essential nutrition. This is important because the need for calories in North America is down at least a third from 1900 because physical activity is lower, yet nutritional requirements are the same.

Per capita consumption of calories from potatoes averages a little over 100 calories per day, four or five percent of the total for most adults. Yet the potato provides substantially more than four or five percent of the daily nutritional requirements of many vitamins and minerals. The potato is especially rich in vitamin C, providing approximately half of the daily requirement. See Table 4.



TABLE 4. NUTRITIONAL VALUE OF A MEDIUM-SIZED POTATO (ABOUT ONE-THIRD POUND).

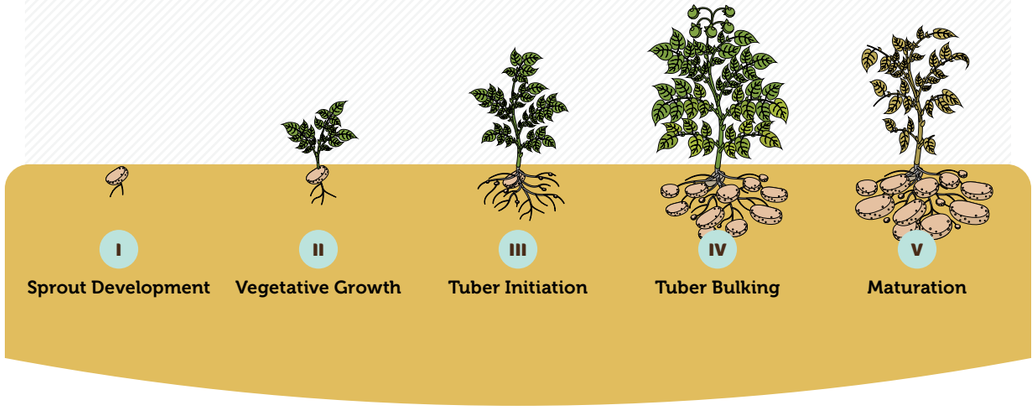
Nutrient	% U.S. Recommended Daily Allowance (USRDA)
Protein	6 (3 gms)
Vitamin A	<2
Vitamin C	50
Thiamin	8
Riboflavin	2
Niacin	10
Calcium	<2
Iron	8
Vitamin B6	15
Folacin (folic acid)	8
Phosphorus	8
Magnesium	8
Zinc	2
Copper	8
Pantothenic acid	4
Iodine	15
Values for Which USRDAs Have Not Been Established	
Calories (no.)	100
Carbohydrates	23 gms
Fat	0
Dietary fiber	2710 mg
Sodium	10 mg
Potassium	705 mg

Source: Potato Association of America Handbook

There are other nutritional advantages to potatoes beyond vitamin C. Although not rich in iron (Fe), the potato supplies needed Fe for nearly a month on an annual per capita basis but only two weeks of calories. Folic acid is scarce in foods, and therefore low in many diets, but the potato will supply a month's requirement. The potato is also an important source of vitamin B6, thiamin, and copper (Cu).

The potato is also a valuable resource in feeding a hungry world because it produces a large amount of food energy and nutrition per unit area. It is estimated the potato provides 75 percent more food energy per unit area than wheat and 58 percent more than rice. In terms of protein per unit area, the potato produces 54 percent more protein than wheat and 78 percent more than rice.

Potato Development and Growth Staging



Vegetative

I Sprout Development

Following planting, sprouts develop from eyes on seed tubers and emerge from the soil. The roots begin to develop at the base of emerging sprouts. During this stage the seed tuber is the only energy source for growth. Adequate phosphorus for early growth and root development and phosphorus starters are often applied at planting.

II Vegetative Growth

Leaves and branch stems develop from above-ground nodes along emerged sprouts. Roots and stolons develop at below-ground nodes. Photosynthesis begins. Stage I and II typically last 30 to 70 days depending on environmental factors. The latter part of vegetative growth as growth accelerates and through tuber bulking is the period of greatest nitrogen demand, but excess nitrogen can delay tuber initiation and thereby shorten the tuber bulking stage.

III Tuber Initiation

Tubers form at stolon tips but are not yet appreciably enlarging. This stage lasts about two weeks. In most cultivars the end of this stage coincides with early flowering. Adequate nutrients are needed during this time to promote abundant tuber initiation. Reduced tuber initiation will reduce yields at the end of the season.

IV Tuber Bulking

Tuber cells expand with the accumulation of water, nutrients, and carbohydrates. Tubers become the dominant site for deposition of carbohydrates and mobile inorganic nutrients. Tuber Bulking is the longest stage and usually lasts 45-60 days. This is a period of rapid nutrient uptake. During this time a constant supply of nitrogen is needed, and potassium uptake can reach as much as 14 lbs K_2O per acre per day.

V Maturation

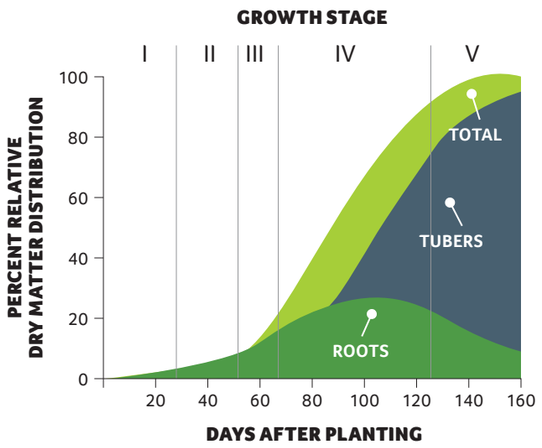
Vines turn yellow and begin to lose leaves. Photosynthesis decreases, tuber growth slows, and vines die. Tuber dry matter reaches a maximum, and tuber skins set. When growing a long season variety (i.e., Russet Burbank) in an area with a short growing season, the plant is usually killed using a herbicide to allow the tuber to grow larger before harvest. Plants should be running out of nitrogen by this time. Excess nitrogen can prolong maturation, delay skin set, and reduce quality.

Growth Stages of Potato

The growth of the potato plant follows a typical S-shaped curve similar to most annuals. However, in the case of the potato, most of the growth expressed in dry matter is produced as underground tubers. Only a small percentage, about 25 percent, is in the tops and roots at maturation. See Figure 1.

Rate of dry matter accumulation varies by growth stage and has a major impact on nutrient demand. During Growth Stage I (sprout development) photosynthesis has not yet begun. The seed piece remains the primary source of nutrients through this stage and into the next growth stage, which is a significant factor to how fertilizer application can be managed with a potato crop. Growth Stage II begins with shoot emergence and leaf development so that energy can be gained from photosynthesis.

FIGURE 1. DRY MATTER DISTRIBUTION THROUGH THE GROWING SEASON BY GROWTH STAGES OF THE RUSSET BURBANK.



Source: D.T. Westermann. 1993. Fertility Management, Chapter 9. In Potato Health Management, Randall C. Rowe (ed.). APS Press.

Roots begin absorbing nutrients from the soil in this growth stage. The rate of growth accelerates in Growth Stage III (tuber initiation). At this point the plant must supply more carbohydrates via photosynthesis than is required for growth and maintenance of leaves, stems, and roots. Tuber initiation is affected by various factors including plant hormones, nutrition, and soil moisture and temperature. Nutrient amount and balance are important determinants of timing and number of tubers initiated and affect various potato varieties and types differently.

Development proceeds rapidly and almost linearly during Growth Stage IV (tuber bulking), assuming no outside growth factor becomes limiting. The tuber is the dominant sink for carbohydrates and mobile inorganic nutrients during this stage. If carbohydrates and inorganic nutrients cannot be supplied at a sufficient rate to meet the demand of growing tubers, then these products are solubilized from vegetative parts of the plant and transported to the tubers. This causes vines to prematurely senesce, which may be accelerated further by increased susceptibility to diseases such as early blight. Most of the nutrients used during the growing season by the potato plant are taken up in Growth Stage IV. This has obvious implications in planning a fertilizer program to achieve high-yield potato production.

Dry matter production reaches a maximum during Growth Stage V (maturation). Nutrients are solubilized in the tops and roots and translocated into the tubers. An additional 10 to 15 percent dry matter may be produced in the tubers during this stage.

Nutrient Uptake Pattern

Nutrient uptake is much more rapid than dry matter accumulation with potatoes. Uptake is relatively small through Growth Stage II (vegetative growth). There is substantial uptake in Growth Stage III (tuber initiation) as well as variation among the different nutrients. Nitrogen (N) and calcium (Ca) are taken up quickly relative to the other nutrients through Growth Stage III. Phosphorus (P) and potassium (K) uptake accelerates during Growth Stage IV (tuber bulking) so that by mid-bulking, total uptake of all the nutrients is similar, approximately 70 percent of the seasonal total. See Table 5.

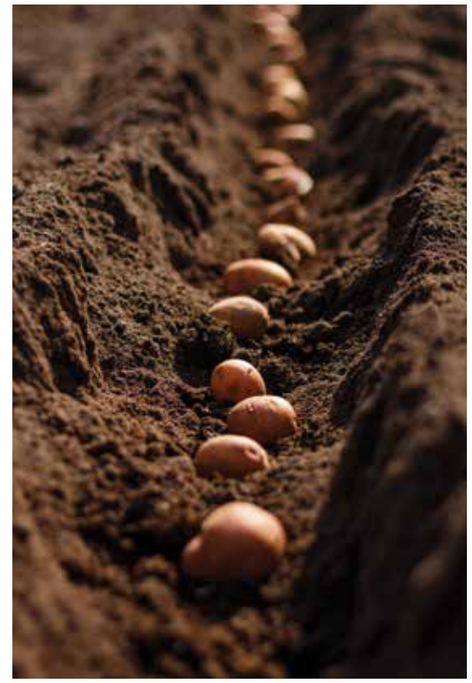


TABLE 5. TOTAL AND RELATIVE NUTRIENT UPTAKE BY GROWTH STAGES OF VINES, ROOTS, AND TUBERS (FINAL YIELD, 490 CWT/AC OF TUBERS) IN KIMBERLY, ID.

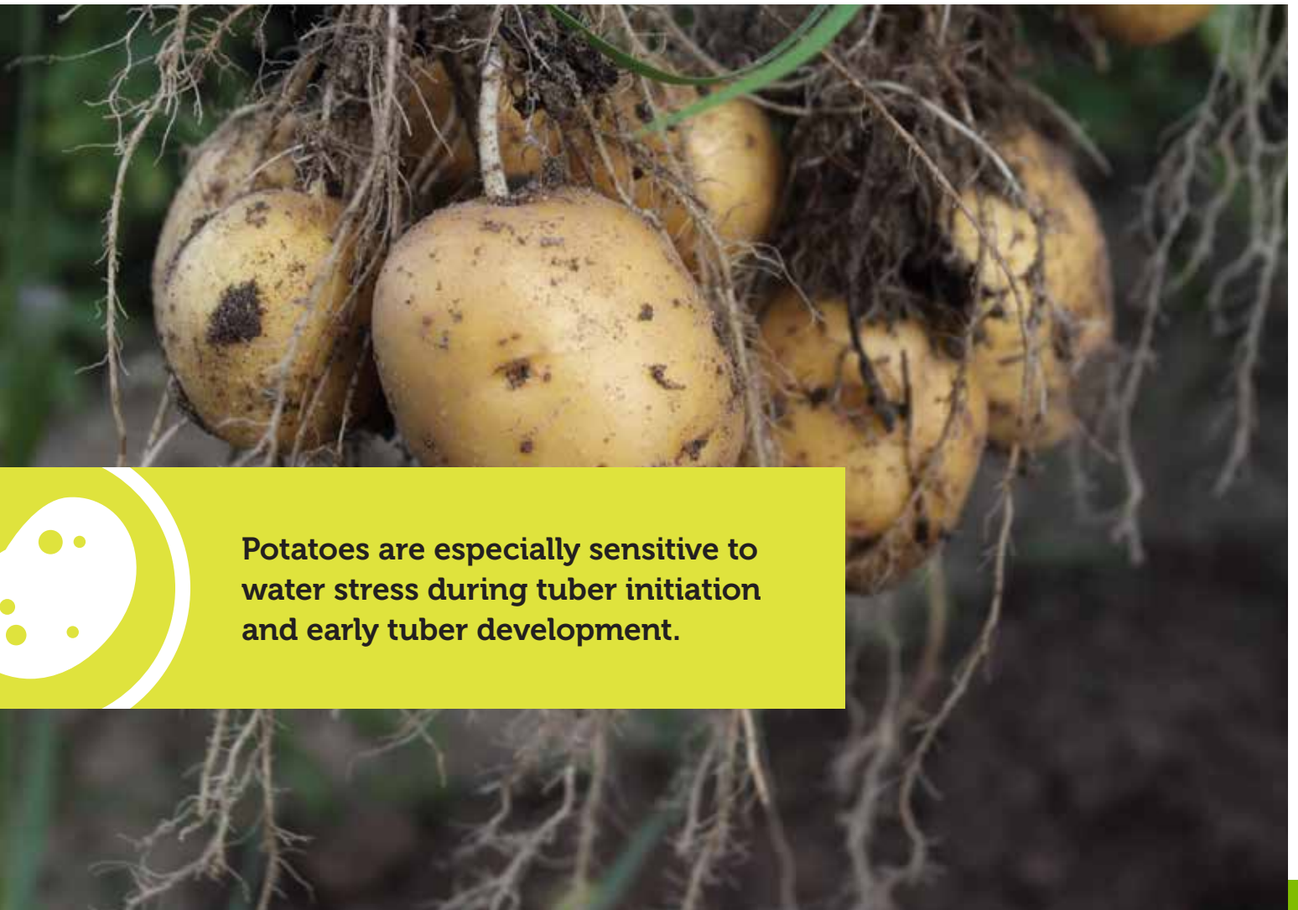
Nutrient	Total Uptake (lbs/ac)	Relative Uptake by Growth Stage (%)				
		II(l)	III(m)	IV(e)	IV(m)	V(e)
N	205	15	30	58	71	98
P_2O_5	64	7	14	36	66	99
K_2O	392	7	15	42	75	98
Sulfur (S)	20	5	11	35	68	98
Ca	81	12	29	66	73	98
Magnesium (Mg)	56	8	20	54	71	94

II(l)	Late vegetative growth stage	55 days after planting
III(m)	Mid tuber initiation	66
IV(e)	Early tuber bulking	83
IV(m)	Mid tuber bulking	111
V(e)	Early maturation	135

Source: D. T. Westermann, ARS-USDA, Kimberly, ID, personal communication.

Adequate nutrition is essential throughout the growing season to achieve a high-yielding, high-quality potato crop. Yields will be maximized within genetic limitations of the cultivar and the climate if other factors such as insects and disease are controlled. Even a few days of nutrient stress, however, can significantly reduce yield. Growth Stage IV (tuber bulking) is a critical time when nutrient demand by expanding tubers is high. See Table 6.

Values in Table 6 represent a comprehensive look at all nutrient requirements and uptakes in potatoes. It is important to keep in mind that nutrient uptake rate and requirements may change depending on the maturity of the cultivar. For example, late-maturing cultivars', such as the Russet Burbank, need for nutrient uptake to exceed requirements of bulking tubers in order to support additional vegetative growth during this stage. Yield potential of late-maturing cultivars is dependent on the length of the growing season. Stage IV may last 70 days in a 130-day frost-free season and 100 days or more in a 180-day frost season. At similar rates of growth, longer growing seasons of these cultivars will result in substantially more yield and will require proportionally more nutrients.



Potatoes are especially sensitive to water stress during tuber initiation and early tuber development.

TABLE 6. ESSENTIAL PLANT NUTRIENT UPTAKE IN 450 CWT OF POTATO, LBS/AC (DRY WEIGHT).

Element	Form Taken Up by Plants	Reported Concentration Ranges for Crop Plants (dry weight)	Amount in 450 cwt of Potato, lbs/ac (dry weight)
Non-Mineral Nutrients			
Carbon (C)	Carbon dioxide (CO_2)	~45%	4,500
Oxygen (O)	Oxygen (O_2)	~43%	4,300
Hydrogen (H)	Water (H_2O)	~6%	600
Primary Nutrients			
Nitrogen (N)	Nitrate (NO_3^-), Ammonium (NH4+)	0.5-6.4%	200-240
Phosphorous (P)	Phosphate ($H_2PO_4^-$, HPO_4^-)	0.1-1.3%	25-35
Potassium (K)	Potassium (K^+)	0.3-1.4%	280-320
Secondary Nutrients			
Calcium (Ca)	Calcium (Ca^{++})	0.03-6%	50
Magnesium (Mg)	Magnesium (Mg^{++})	0.02-5%	40
Sulfur (S)	Sulfate (SO_4^-)	0.08-1.4%	18-24
Micronutrients			
Boron (B)	Borate ($H_2BO_3^-$)	1-200ppm	0.18
Manganese (Mn)	Manganese (Mn^{++})	1-2,000ppm	0.9
Zinc (Zn)	Zinc (Zn^{++})	5-400ppm	0.11
Copper (Cu)	Copper (Cu^{++})	1-60ppm	0.09
Iron (Fe)	Iron (Fe^{++}, Fe^{+++})	2-1,820ppm	1.8
Molybdenum (Mo)		0.01-20ppm	0.03
Chlorine (Cl)	Chloride (Cl^-)	0.05-3%	40
Nickel (Ni)	Nickel (Ni^{++})	1.0-10ppm	0.03

Source: Hopkins B.G., Stark J.C., and Kelling K.A. 2020. Nutrient Management. ***In*** Stark J., Thornton M., Nolte P. ***(ed) Potato Production Systems***. Ch. 8:155-202. New York, New York: Springer, Cham. DOI: https://doi.org/10.1007/978-3-030-39157-7_8 (ISBN978-3-030-39157-7) Hopkins B.G., Stark J.C., and Kelling K.A. 2020. Nutrient Management. ***In*** Stark J., Thornton M., Nolte P. (***ed) Potato Production Systems***. Ch. 8:155-202. New York, New York: Springer, Cham. DOI: https://doi.org/10.1007/978-3-030-39157-7_8 (ISBN978-3-030-39157-7).

Water Management

Irrigation is required for profitable potato production in most of North America. Potatoes are sensitive to water stress in comparison to many crops, have a shallow root zone, and are often grown on coarse-textured soils characterized by low to medium water holding capacity. These conditions require frequent light and uniform irrigations throughout the growing season.

Both under- and over-irrigation by a relatively small amount results in yield loss. Yield reductions due to excess water are largely due to poor soil aeration, disease problems, and leaching of nitrate from the shallow root zone.

The root system of the potato plant generally reaches 18 to 24 inches deep, with most of the roots concentrated in the upper 12 inches. This is due to a weak root system that has difficulty penetrating restrictive layers, including those caused by tillage pans and wheel traffic.

Potatoes are especially sensitive to water stress during tuber initiation and early tuber development. Water deficits during these periods can significantly reduce high-quality yield. Growing #1 grade potatoes is significant because they command the highest market prices owing to their superior quality, size, and appearance, resulting in better returns for growers. Such deficits interrupt normal tuber expansion and may cause malformations, such as pointed ends, bottlenecks, dumbbells, and knobs. These problems are accentuated when soil water contents are allowed to fluctuate widely. The main effect of water stress during tuber bulking is reduced total yield more so than effects on quality. During harvest, soil water content can influence mechanical damage.

The available soil water (ASW) of the root zone should average 65 to 85 percent (70 to 80 percent at planting) of field soil capacity. This is best accommodated by drip irrigation systems and solid-set, center-pivot, and linear-move sprinkler systems that can be operated to apply light, frequent irrigations that will minimize soil water fluctuations. It is more difficult to minimize fluctuations with set-move sprinkler systems and furrow irrigation systems.

Irrigation water quality is generally not an issue in most potato growing regions simply because the potato is a very high cash value crop and growers cannot afford to utilize questionable water. However, this could change as better land and water resources continue to be diverted to urban and other non-agricultural uses. In general, potatoes will experience a 10 percent yield reduction if the salinity of the irrigation water is approximately 1.7 dS/m (1 dS/m = 1 mmho/cm), which can create soil salinity of about 2.5 dS/m, if not properly managed. Additionally, potato plants may suffer from leaf burn caused by absorption of sodium (Na) and chloride (Cl) deposited by sprinkler systems if their concentration exceeds 5 to 10 mEq/l. Bicarbonate ions in sprinkler-applied irrigation water will "whitewash" leaves, but not affect plant growth nor harm the underground tubers.

Field preparation should result in soil that provides unrestricted root growth and drainage and reclamation from salinity issues if needed (see page 50 and 51). Soil pH can also be corrected at this time if needed (see page 50 and 51). This will encourage good initial growth of the seed piece and support optimum yield as the season wears on.



Soil and Plant Sampling

Soil and tissue (petiole) analyses are essential tools in potato production. Understanding variability and proper sampling techniques is essential to take full advantage of these important BMPs.

Soils are not homogenous. Their properties, including fertility, can vary naturally from location to location and also among horizons of a given profile. When sampling potato fields for fertilizer recommendations, the greatest concern is to obtain a sample that accurately reflects the fertility status of that field.

There are several ways to obtain a representative sample. The simplest is to take random soil cores from throughout the field. Each core is selected separately and drawn randomly and independently from the others. The cores are then mixed into a composite sample and submitted to the lab for analysis. A composite sample works well but does not provide any indication of field variability. Submitting individual cores is more costly but provides important information about field variability that can impact fertilizer recommendations. Other sampling plans, referred to as "zone sampling," involve dividing the field into subunits of similar soil types, landscape position, or management or nutrient needs, from which random soil cores are taken and composited.

This type of sampling increases the precision, or reproducibility, without substantially increasing the cost.

The best way to measure the variability in a field is grid sampling. Cores are taken at regularly spaced intervals in all directions. Grid sampling has been widely accepted because it increases the accuracy of soil tests and provides invaluable information about soil variability. The use of Global Positioning Systems (GPS) makes grid sampling easy and allows areas in the field to be precisely determined.

The best sampling plan will be the minimum area the grower is prepared to treat as a separate management unit. This kind of "zone sampling" can capture many of the benefits of managing field variability at a lower cost than grid sampling.

In addition to selecting a sampling plan that reduces field variability, sampling error can be minimized by following proper technique. Sampling equipment should be clean, free of rust, and chrome plated or made of stainless steel, especially when testing for micronutrients. Samples are best collected with a soil probe or auger. It is important the equipment allows for a uniform slice of the soil profile for the entire depth sampled.



Timing, frequency, and sampling depth depend on the nutrient. Preseason soil tests determine residual nutrients and provide the basis for fertilizer recommendations. In-season soil analysis allows the grower to monitor nutrient availability and complement petiole testing.

Potatoes have an effective rooting depth of about 2.5 feet, but most of the uptake of immobile nutrients occurs from the first few surface inches of the hill. Mobile nutrients like nitrogen and sulfur should be estimated annually by sampling to depths of 2 feet. Sampling to a depth of 3 to 4 feet can help determine the effectiveness of in-season nitrogen management and if mobile nutrients are being leached below the root zone. Soil samples should be taken in the spring prior to seeding or in the fall when soil temperatures have decreased to less than 41°F (5°C). Immobile nutrients like phosphorus and potassium do not change dramatically from year to year unless high rates of manure or fertilizer have been applied. Periodic samples every two to three years are sufficient for these nutrients, and a sampling depth of 12 inches is recommended.

Following sampling, soil should be kept cool or shipped to laboratories immediately. Some laboratories ask that soil be air-dried by spreading the sample out in a thin layer. Whether air-dried or shipped cool, the purpose is to prevent microbial action, which could alter the level of some nutrients. Consult your local soil testing laboratory for complete sampling guidelines.

Petiole sampling during vegetative growth and tuber bulking is a useful management tool for high-yield production. All plant nutrients can be analyzed, but most often only nitrogen, phosphorus, and potassium are tested in-season.

The petiole is the part of the potato plant connecting the leaf blade with the stem. The sampling procedure involves taking petioles from 30 to 40 representative plants. The leaves are stripped from the fourth petiole from the growing tip of the plant and discarded. Plants should be sampled every seven to 10 days beginning approximately four weeks after emergence and continuing until about three weeks before vine-kill. The petioles should be free from soil, stored in a clean paper bag, and kept cool until sent to the laboratory for analysis. Detailed guidelines for handling petioles should be available from your local testing laboratory.

Petiole analysis should be interpreted on the basis of trends in nutrient values during the growing season, not on individual sampling dates. A single sampling date is not recommended for interpretation because it may not be directly related to plant or soil fertility. A variety of factors affect the nutrient status of the plant on any given day (e.g., climatic conditions, plant stress, disease pressure, age, or even the time of day the sample was collected). Soil samples should also be taken in the same area and in conjunction with the petiole samples for best results.

PETIOLE SAMPLING PROCEDURE FOR POTATOES.



Results of the laboratory analysis will be reported in percent (%) or parts per million (ppm). One percent is equal to 10,000 parts per million. Nutrient concentrations in plant tissue change with the age of the plant. The highest concentration of most nutrients in petioles occurs during tuber initiation (Growth Stage III) and then gradually declines until late maturation (Growth Stage IV) unless additional nutrients are applied during the growing season. Tissue concentrations of nitrogen, phosphorus, potassium, sulfur, copper, and zinc decrease with increasing plant age if no additional nutrients are applied, while calcium, magnesium, boron, iron, chloride, and manganese increase in concentration. Petiole nutrient concentrations during Growth Stage IV for Russet Burbank potatoes are shown below in Table 7.

TABLE 7. SUGGESTED RANGE IN NUTRIENT CONCENTRATION IN THE FOURTH PETIOLE DURING GROWTH STAGE IV.

	Low	Marginal	Sufficient
Nitrate-N, ppm	< 10,000	10,000-15,000	> 15,000
Phosphate-P, ppm	< 700	700-1,000	> 1,000
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	0.15-0.30	> 0.3
Sulfur, %	< 0.15	0.15-0.2	> 0.2
Sulfate-S, ppm	< 200	200-500	> 500
Zinc, ppm	< 10	10-20	> 20
Boron, ppm	< 10	10-20	> 20
Manganese, ppm	< 20	20-30	> 30
Iron, ppm	< 20	20-50	> 50
Copper, ppm	< 2	2-4	> 4

(Idaho data)
The above nutrient ranges will vary for different cultivars.

Source: https://objects.lib.uidaho.edu/uiext/uiext25485.pdf

Site-Specific Management

Site-specific management has generated considerable interest in the U.S. and Canada in the past several years. High-tech tools like yield monitors, GPS technology, geographic information systems (GIS), and remote sensing allow growers to identify variability and manage it in small areas within fields.

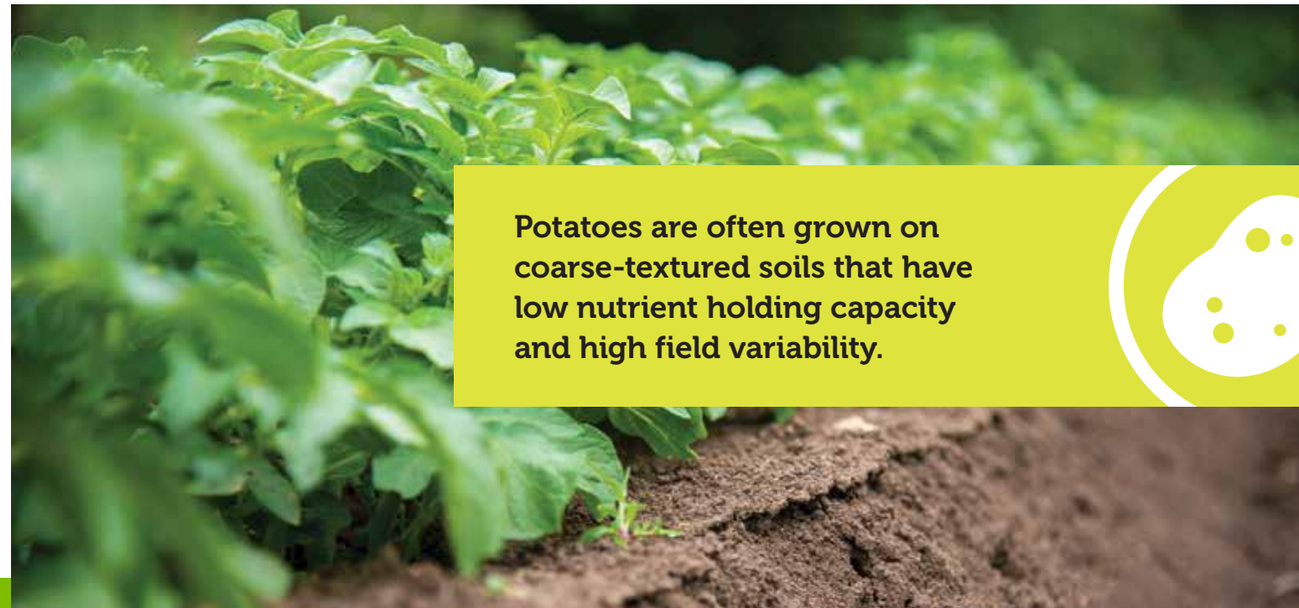
Potatoes are a high-input, high-value crop. They are often grown on coarse-textured soils that have low nutrient holding capacity and high field variability. That makes them an ideal crop for site-specific management.

The objectives of site-specific management include recognizing field variability and then managing that variability to improve production. The first step is to document a field's history and past management practices. This includes identification of areas in the field that were leveled, that had previous manure applications, that have drainage or salinity problems, etc. Any anomalies in the field, like an old feedlot or fence line, need to be identified as well as any known problem areas. The objective is to collect as much historical information about the field as possible and use it to help develop management zones.

In addition to historical information, assemble or begin keeping data on varieties, seeding dates, rates, weed, insect and disease control, fertility and fertilizer use, and yield. It's important to track all production practices during the growing season and to keep a record of irrigation practices, soil temperature and moisture conditions, and crop growth. Examples of records to maintain are days from planting to row closure, flower initiation, tuber initiation, and bulking. Monitoring potato growth, water applications, evapotranspiration, and soil nutrient levels regularly throughout the season provides the necessary information to make management decisions about in-season fertilizer applications and diagnostics for disease and insect problems.

New technology can aid in data collection, whether it's diagnosing problems or intensive soil sampling or yield mapping and decision making, but much can be done without the use of these new tools. The key is to assemble as much data as possible and then use that data to improve production practices in the management zones identified for a field. New remote sensing tools such as crop canopy sensors and satellite or other aerial imagery can be useful tools in evaluating or diagnosing crop nutrient status or other plant health conditions.

New proximate soil technologies (e.g., Veris and DualEM sensors) can measure field level variability, and site specific variable rate fertilizer prescriptions can be built from data.

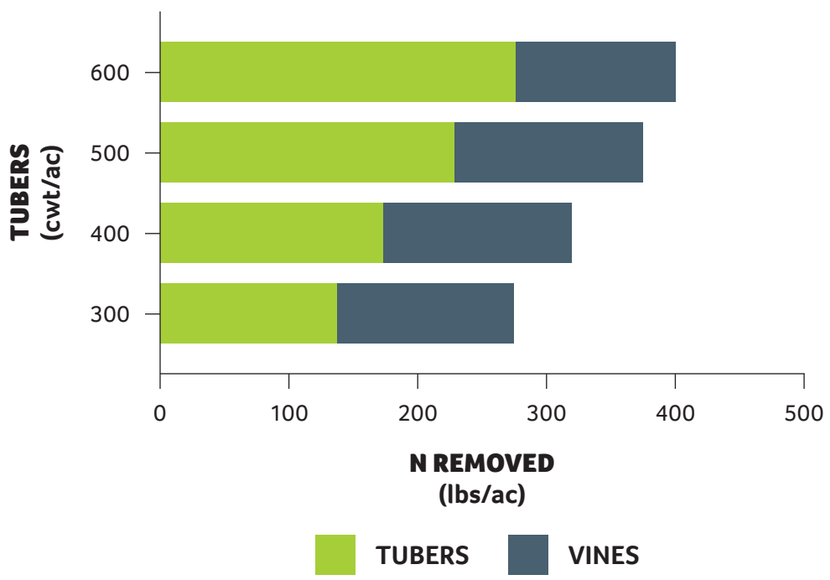


Potatoes are often grown on coarse-textured soils that have low nutrient holding capacity and high field variability.

Nitrogen

Potatoes have a large demand

for nitrogen. Like other crops, nitrogen is needed for chlorophyll, photosynthesis, vitamins, and uptake of other plant nutrients.



Potatoes remove large amounts of N from the soil.
(Idaho data)



The nitrogen taken up from the soil by potatoes depends on the yield of vines and tubers. Vines can have as much as 3 percent nitrogen and tubers 2.1 percent on a dry matter basis. Uptake in high-yielding crop can exceed 250 pounds per acre of nitrogen. One-third to one-half of the nitrogen taken up is found in the vines. When nitrogen is not limiting, vine growth and its nitrogen content tend to be similar for a 300 or a 600 cwt crop. In other words, the relationship between nutrient removal and tuber yield is linear. For example, Idaho data shows that a 600 cwt per acre crop removes about twice as much nitrogen in the tubers as a 300 cwt per acre crop.

Nitrogen (N) deficiency begins when the entire plant turns light green. As the deficiency increases, the older leaves turn a deeper yellow to light brown, and the oldest leaves dry out. Under severe deficiency, leaves cup upward and become necrotic. Nitrogen deficiency will also reduce tuber size and protein content. Excess nitrogen results in succulent, weak stems and delays maturity.

Nitrogen Fertilizer Requirements

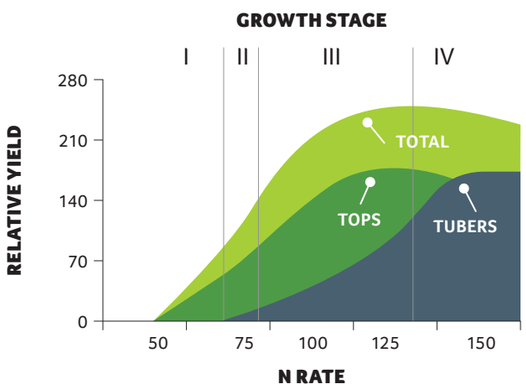
The amount of nitrogen needed to meet the uptake demands of potatoes varies with the cultivar and management practices. Using today's management systems, nitrogen uptake efficiency in 450 cwt of potato (dry weight) is about 200-240 pounds per acre of soil plus fertilizer nitrogen. The reported concentration ranges of potatoes (dry weight) of nitrogen is around 0.5-6.4%.

Nitrogen fertilizers are used most efficiently when applications are split, with about one-third to two-thirds of the total nitrogen requirement applied after plant emergence. Splitting nitrogen between pre- and in-season applications minimizes leaching opportunities and increases fertilizer efficiency.

Timing of Application

Nitrogen applications should coincide with nitrogen demand of the potato. Figure 2 shows a typical nitrogen uptake pattern in Russet Burbank potatoes as it occurs during the growing season. Growth Stage I ranges from 30 to 70 days after planting, during which plants use 10 to 15 percent of their total seasonal nitrogen requirement. Pre-plant nitrogen rates of 60 to 120 pounds per acre, depending on residual soil nitrogen levels, provide adequate nitrogen for early growth. Growth Stage II lasts about 10 to 14 days. By its end, the potatoes have taken up approximately 60 percent of their total nitrogen. The first in-season nitrogen application can occur near the end of Growth Stage II. The most rapid nitrogen uptake occurs at the beginning of Growth Stage III as tubers start bulking. This is the most critical time to ensure nitrogen fertility is adequate. An average Russet Burbank crop needs about three pounds of nitrogen per acre per day to maintain a daily growth rate of 700 pound tubers per day. However, nitrogen utilization can vary from two to five pounds per acre per day depending on the variety of potatoes. At the end of Growth Stage III, the plant will have taken up 98 percent of its total nitrogen.

FIGURE 2. NITROGEN UPTAKE PATTERN IN RUSSET BURBANK POTATOES.



In-season nitrogen applications are determined by monitoring available soil nitrogen and petiole nitrate-nitrogen levels during the growing season. Petiole nitrate-nitrogen should be about 25,000 parts per million at the end of Growth Stage I and will decline as the potato matures. Petiole nitrate-nitrogen levels need to be maintained at a minimum of 15,000 parts per million during Growth Stage III (tuber bulking) to ensure rapid, uniform growth and to prevent early leaf dying or senescence. By the time the crop is killed, petiole nitrate-nitrogen should have declined to less than 10,000 parts per million. Available soil nitrogen levels in the top 18 inches should be maintained at the following levels to provide adequate nitrate-nitrogen in the petiole (Table 8).

TABLE 8. AVAILABLE SOIL N LEVELS REQUIRED TO PROVIDE ADEQUATE PETIOLE NITRATE-N.

Growth Stage	Soil $NO_3^-N^+$ NH_4^-N, ppm
Stage I	15
Stage II	> 10 to 15
Stage III	10
Stage IV	< 10



Nitrogen Application Methods

Pre-plant nitrogen may be broadcast and incorporated or banded at the time of planting. However, high rates of banded urea, or diammonium phosphate, can cause ammonia toxicity, particularly in calcareous soils. If these materials are placed with the seed pieces, rates should be less than 150 pounds per acre. Higher rates can be used if applied at least 2 inches from the seed pieces. Varieties can vary widely in their early season demand. Too much nitrogen can delay tuber initiation and shorten the tuber bulking stage, while too little nitrogen can reduce vegetative growth and yield potential. Consult local experts for needs of specific varieties in your area.

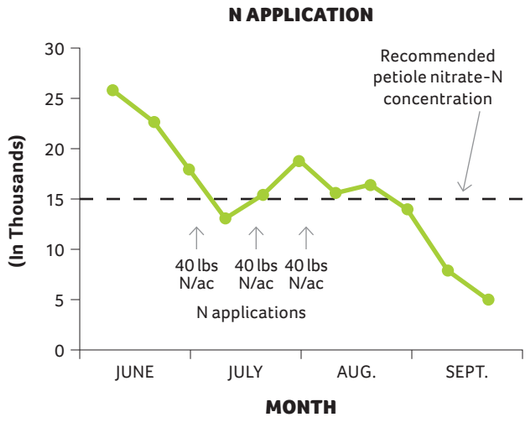
Side-dressing is commonly used for in-season nitrogen application during Growth Stage II, up to about 60 days after planting. However, late side-dress applications increase the risk of root pruning during the operation.

Injecting soluble nitrogen into irrigation water (fertigation) is another effective method for in-season application. With sprinkler irrigation, 20 to 40 pounds of nitrogen per acre is commonly applied every 10 to 14 days during tuber bulking (Growth Stage IV) to maintain petiole nitrate-nitrogen concentration in the desired range (Figure 3). Fertigation is advantageous in that it allows "spoon feeding" of the crop according to its needs as determined by regular soil and petiole analysis. However, careful irrigation scheduling and management are required for this method of application. The uniformity of the nitrogen applied with irrigation water is no better than that of the water, and applying excess water can result in leaching losses of nitrogen.

Nitrogen Sources

There is no one best nitrogen source for fertilizing potatoes. Anhydrous ammonia, aqua ammonia, urea, ammonium nitrate, ammonium sulfate, and nitrogen solutions are all effective when managed properly. Washington state research has found that yield, percent U.S. No. 1's, specific gravity, blackspot index, and chip color are the same regardless of nitrogen source. (https://s3.wp.wsu.edu/uploads/sites/2742/2014/11/nutrient-central-wa.pdf) However, ammonium sources may have greater efficiency if leaching is a concern. Regardless of the nitrogen source, water and nitrogen best management practices must be considered to reduce nitrogen losses and maximize environmental protection.

FIGURE 3. PETIOLE NITRATE-N CONCENTRATIONS FOLLOWING IN-SEASON N APPLICATIONS (40 LB/ACRE).





Best Management Practices for Nitrogen

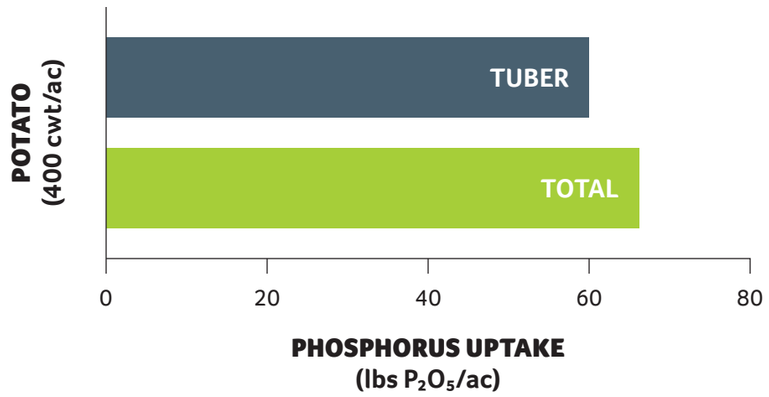
Nitrate-nitrogen is easily leached by irrigation or rainfall, especially in coarse-textured soils suited for potato production. Groundwater protection requires that nitrogen be carefully managed both during and after the potato crop.

Best management practices for maximum protection of groundwater include:

- Soil test to determine pre-plant nitrogen application rates.
- Use in-season soil testing and petiole analysis to determine nitrogen needs during crop growth.
- Apply nitrogen in split applications and time applications to coincide with plant demands.
- Avoid late-season nitrogen application.
- Base irrigation on crop water use and avoid excessive irrigation, especially early and late in the growing season.
- Recover residual nitrogen following potato harvest with cover crops.
- Balance nitrogen with phosphorus, potassium and other nutrients to ensure optimum crop growth and nitrogen use.

Phosphorus

Potato plants with an adequate supply of phosphorus are capable of higher yields, early crop development and tuber development, and hastened tuber maturation.





Reactions of Phosphate in Soils

Phosphorus can be taken up as the anions $H_2PO_4^-$ and $H_2PO_4^{-2}$. Organic matter decomposition, pH, mineralogy, soil moisture, and fertilizer additions affect the supply of phosphorus to the plant.

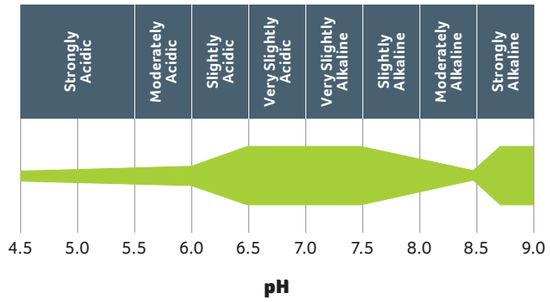
Phosphorus can be readily fixed, or "tied up" in most soils resulting in low soil-solution P. For this reason, phosphorus does not generally leach down the soil profile with water. This phenomenon has been observed, however, in sandy soils in high rainfall areas.

Phosphate losses due to erosion can be a major loss pathway in hilly areas and over heavily texture soil. These losses are largely associated with soil erosion, but soluble organic phosphorus compounds can also be lost during spring run-off events.

There are two primary ways in which phosphorus is retained, or fixed, by soils. The first is through an adsorption reaction, in which phosphorus becomes bound to the surfaces of soil minerals. Second, phosphorus may form insoluble compounds (precipitation) with other minerals or dissolved ions. The extent of these reactions depends in part upon soil pH. Generally, phosphorus is most available to plants in the pH range of 6.5 to 7.5 (Figure 4).

As plants take up phosphorus, they deplete the levels of phosphorus in the soil solution. A portion of both adsorbed and precipitated phosphorus replenishes the phosphorus supply to the plant. These reactions cause phosphorus to be slowly released over time. Consequently, the phosphorus available to potatoes in any one season is a result of the current year's application plus a portion of residual phosphorus from past years' applications.

FIGURE 4. AVAILABILITY OF P TO PLANTS AT VARIOUS SOIL PH VALUES. THE WIDER PARTS OF THE BAR INDICATE GREATER AVAILABILITY.



Adapted from R.J. Cook and R.J. Veseth. 1991. Wheat health management. American Phytopathological Society. St. Paul, MN.



Role in Plants

Phosphorus has many important functions in potato plants:

- Phosphates form the backbone of DNA and RNA, both are essential in the production and growth of crops.
- Energy storage and transfer. This is the most important role of phosphorus. Phosphate containing compounds provide the energy plants need for growth and reproductive processes.
- Structural component of biochemicals critical to metabolic processes.

Potato plants with an adequate supply of phosphorus are capable of higher yields, early crop development and tuber development, and hastened tuber maturation. Potatoes are generally known to need greater soil phosphorus concentrations than many grain crops. Careful attention to phosphorus supply is critical to growing high yields of quality potatoes.

Potato plants deficient in phosphorus are stunted, and leaves may be dark with margins that are rolled upward. A purple color may be apparent in some leaves as well. The severity of leaf roll increases with increased deficiency. The lower surfaces of leaves may also be a gray-green color.

Fertilizer Sources

Both liquid and dry sources of fertilizer phosphorus are effective for potato production. The preference of form depends upon cost, grower preference, available equipment, and whether or not fertilizer will be applied through irrigation systems. Some of the more commonly used phosphorus fertilizers are:

- Monoammonium phosphate (11-[48-55]-0). This source contains ammonium nitrogen and dihydrogen phosphate. Both have an acidifying effect on soils.
- Diammonium phosphate (18-46-0). This fertilizer contains ammonium nitrogen and monohydrogen phosphate. Immediately after application, the soil around the fertilizer becomes basic. This can cause the ammonium nitrogen to convert to free ammonia.
- Ammonium polyphosphate is available as a liquid fertilizer. There are a variety of analyses possible. The two most common ammonium polyphosphate solutions are 10-34-0 and 11-37-0. This source contains both polymeric (chain of multiple phosphorus anions) and ortho (individual anion) forms of phosphorus. When this fertilizer is added to soils, the ortho forms are immediately available for plant uptake. The polymers must first break down before they are plant available. This process, however, occurs rapidly in soils and does not limit the supply of phosphorus to the plant.
- Triple super phosphate (0-[44-52]-0). This fertilizer contains monocalcium phosphate, which has an acidifying effect upon soils.
- Urea phosphate (17-[43-44]-0).
- Phosphoric acid (0-55-0).

Sources which are suitable for applications in irrigation systems are urea phosphate, ammonium ortho and polyphosphates, and phosphoric acid. Phosphorus levels in irrigation water should be tested to adjust applied phosphorus rates. It is important to be sure that dissolved minerals in the irrigation water will not precipitate phosphorus compounds that plug nozzles. Water high in calcium or magnesium salts may not be suitable for phosphorus fertigation.

Fertilizer application

Placement

Proper placement of phosphorus depends upon the soils in which potatoes are grown. In soils that fix significant amounts of phosphorus, band applications will be most effective. This concentrates phosphorus into a smaller area than broadcast applications, allowing less contact of phosphorus with the soil. When soil/phosphorus interactions cause potatoes to use phosphorus inefficiently, phosphorus may need to be included in a starter, even at high soil test phosphorus levels. On other soils, broadcast applications are more effective than banded applications. Because potatoes are shallow-rooted, with most of the nutrient uptake occurring in the surface few inches of the potato hill, phosphorus placement in the surface soil of the hill has been shown to be most effective. Proper placement, therefore, depends upon local conditions, and regional recommendations based upon sound research should be followed.

Diammonium phosphate (DAP) should not be placed near the seed piece on calcareous soils. The reaction of DAP with such soils can lead to the formation of free ammonia, which can damage potato seedlings.

Timing

Pre-plant and fall applications of phosphorus are both effective. When phosphorus deficiency is detected, midseason applications can significantly improve potato yield and quality. Dry and liquid fertilizers can be used to meet phosphate needs, depending on logistics.

Environmental Concerns

Phosphorus is limiting in many freshwater bodies. When phosphorus enters these systems, algal growth can occur. When these algae die, microorganisms that decompose the algae consume oxygen. This can lead to reduced oxygen levels in the water bodies.

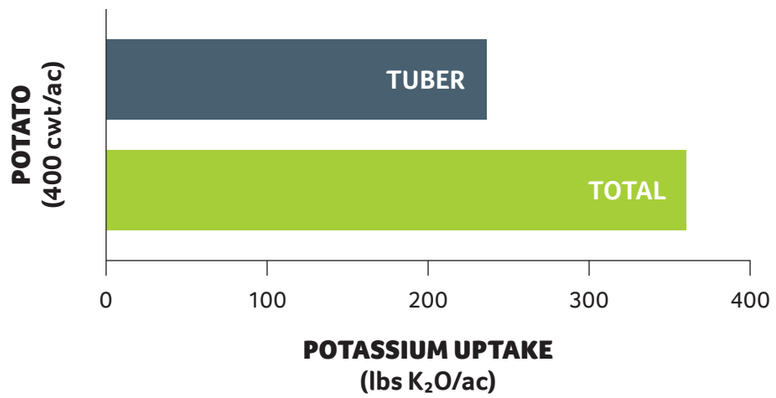
Phosphorus enters surface waters through runoff and erosion. At the soil surface, phosphorus can be washed away with heavy rains. For this reason, broadcast applications should be incorporated. Phosphorus bound tightly to soil moves with soil as it erodes. Once in a body of water, a portion of the bound phosphorus will be released. If phosphorus levels become high enough, eutrophication can occur. For this reason, controlling erosion is essential for controlling the movement of phosphorus into surface waters.

Proper placement of phosphorus depends upon the soils in which potatoes are grown.



Potassium

Potassium is essential for potatoes, as it activates enzymes crucial for tissue development and starch synthesis, aids in water uptake and distribution, boosts photosynthesis and energy production, facilitates the translocation of sugars, and supports nitrogen uptake.





Reactions of Potassium in Soils

Potatoes take up large quantities of potassium, as shown in Figure 5. Potassium is taken up from the soil solution by plants as the cation, K^+. The supply of potassium to the plant is affected by fertilizer additions, weathering of minerals, wetting and drying cycles, freezing and thawing cycles, and organic matter and residue decomposition.

The potassium cation is just the right size to fit between structural layers of certain clay minerals. It is attracted to the negative charges in the interlayer regions (Figure 5). Once potassium moves in between these layers, it is much less available to plants. This process is termed fixation. The quantity of potassium fixed by clay minerals is affected by clay type, wet/dry cycles and freeze/thaw cycles. Fixed potassium is considered slowly available to plants over time. The quantity of potassium fixed by different soils depends upon their mineralogy. Local research has identified such soils, and fertilizer recommendations are usually higher.

Potassium is also attracted to the surfaces of clay minerals and organic matter (exchangeable potassium). As plants take up potassium from the soil solution, solution levels drop. Exchangeable potassium is then released and readily replenishes the potassium in the soil solution.

Role in Plants

The amount of potassium required by potatoes is directly related to yield. Potassium has many important functions in the plant:

- **Enzyme activation.**
  Enzymes are an important part of new tissue development and synthesis of starches.
- **Water uptake and distribution in the plant.**
  Potassium helps potato plants take up water from the soil and helps keep water from being lost from the plant.
- **Photosynthesis and energy production.**
  Potassium is needed for the production of high-energy phosphate molecules, and it also speeds photosynthesis rates.
- **Translocation of sugars.**
  Potassium plays a role in the translocation (or movement) of sugars from source cells (i.e., mature leaves, storage roots, etc.) to sink cells (i.e., roots, tubers, developing fruit, etc.) by aiding in maintaining a pressure gradient in the phloem.
- **Nitrogen uptake.**
  Potassium is required for nitrogen uptake and protein synthesis.

Potassium deficiency symptoms appear first on younger, fully-expanded leaves as a glossy sheen with crinkling and slightly black pigmentation. In addition, leaf margins may be rolled downward. When potassium deficiency becomes severe, leaves may exhibit marginal scorching and necrotic spots.

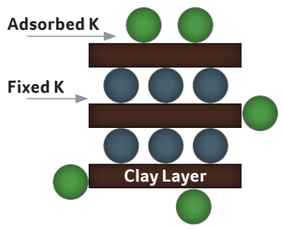


FIGURE 5. CONCEPTUAL MODEL OF K FIXED BETWEEN CLAY MINERAL LAYERS (BLUE CIRCLES) AND K ADSORBED (EXCHANGEABLE) TO OUTER SURFACES OF CLAY MINERALS (GREEN CIRCLES).

Fertilizer Sources

Commonly used potassium fertilizers are:

- **Potassium chloride (0-0-[60-62]).**
- **Potassium sulfate (0-0-[50-53]-17S).**
  This fertilizer is a source of both potassium and sulfur.
- **Potassium magnesium sulfate (0-0-22-22S-11Mg).**
  This fertilizer supplies potassium, sulfur, and magnesium.
- **Potassium nitrate (13-0-44).**
  This source supplies both nitrogen and potassium.
- **Potassium carbonate (0-0-68).**
  This fertilizer is appropriate for use with sprinkler irrigation, as are certain liquid formulations containing potassium.

When potassium fertilizers are injected into irrigation water, the potassium levels in the water should be determined to adjust fertilizer rates.

Fertilizer Application

Potassium chloride (KCl) and potassium sulfate (K_2SO_4) are commonly used in fertilization programs for potatoes. Research has shown that in soils deficient in potassium, both sources produce similar increases in tuber yield in well-managed systems. Application of potassium chloride can reduce nitrogen levels in petioles due to competition between nitrogen and chloride ions. This competition does not appear to interfere with nitrogen assimilation. However, interpretation of petiole nitrogen levels may be affected.

Potassium fertilization affects specific gravity. Some researchers have found that potassium fertilization on potassium-deficient soils increases specific gravity until excess potassium is applied. Beyond optimum rates, potassium fertilization can decrease specific gravity. In some studies, potassium fertilization decreases specific gravity, regardless of rate. Potassium chloride generally decreases specific gravity more than potassium sulfate applied at equivalent rates. However, the chloride also reduces incidences of hollow heart and brown center. In more humid regions on moderate CEC soils, growers sometimes apply potassium chloride in the fall to allow part of the chloride to leach away before spring. Some growers prefer potassium sulfate over potassium chloride because of concerns about chloride toxicity. This may be an issue in certain situations with very high potassium fertilizer rates, but, generally, research shows this concern is often not justified.

Placement

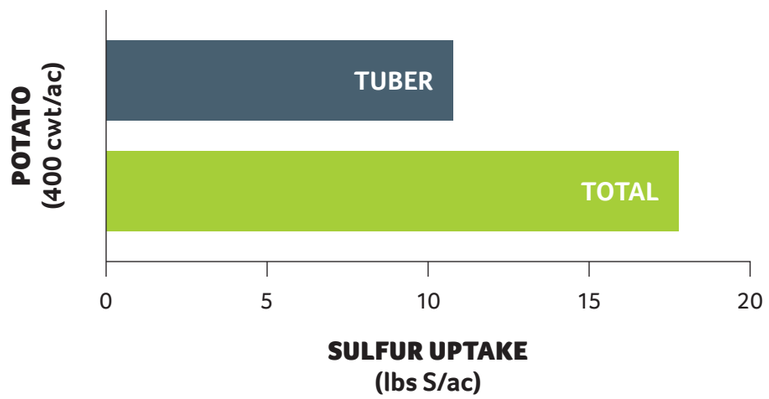
There are few constraints on methods of applying potassium. Potassium can be successfully broadcast, banded, side-dressed, or applied in-season through irrigation water. However, some researchers have observed that potassium chloride banded in a row with phosphorus and nitrogen may inhibit phosphorus uptake and reduce tuber yield and dry matter content compared to potassium sulfate. Broadcasting potassium chloride instead of applying it in a band with phosphorus and nitrogen can keep such effects from occurring.

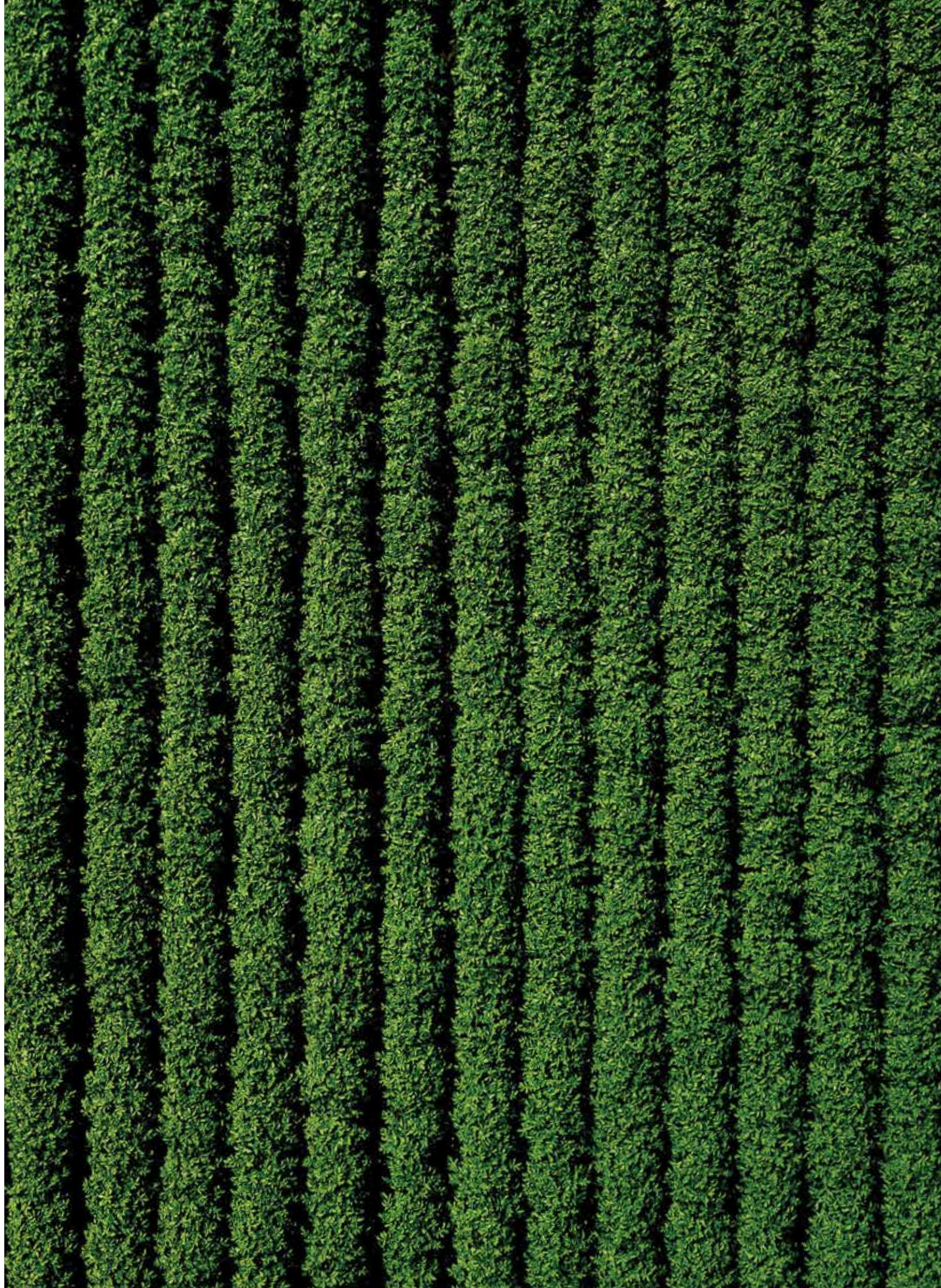
Timing

Studies examining timing of potassium fertilization indicate that there are no significant advantages in yield, quality, or efficiency from applying potassium in-season, unless potassium deficiency is observed during the growing season. Growers should test their soils and determine potassium needs in advance of the potato-growing season. Pre-plant applications based upon soil tests are considered a best management practice, but in-season applications may be needed or beneficial in some cases of high-yielding crops on low K and/or low CEC (cation exchange capacity) soils. On sandy or organic soils, potassium should not be applied in the fall, or soils subject to leaching over winter, because of increased risk of potassium loss through leaching.

Sulfur, Calcium, Magnesium

The availability of sulfur, calcium, and magnesium to growing plants is affected by fertilization practices, the weathering of minerals in the soil, and the decomposition of organic matter.





Sulfur

Potatoes take up significant quantities of sulfur. Plants take up sulfur as the sulfate anion ($SO_4^=$). The supply of sulfate available to plants is affected by fertilization, weathering of minerals, atmospheric deposition, and decomposition of organic matter. Organic matter is a significant source of sulfur for crops during the growing season.

Sulfate ($SO_4^{2=}$) behaves similarly to nitrate in many soils. It can be mobile and move with soil water (soluble sulfate). In areas high in iron (Fe) and aluminum (Al) oxides, sulfate can also become chemically attached to these oxides in a process termed adsorption (adsorbed sulfate). Adsorbed sulfate is less available to crops than soluble sulfate and may be released slowly over time. In areas of low rainfall, soluble sulfate can begin to accumulate over time when there is not enough rainfall to leach it out of the soil.

Elemental sulfur must undergo a microbial oxidation to be transformed into sulfate. Sulfur oxidation in potato fields is favored by warm, moist, well-aerated soils with higher pH levels, facilitating the availability of sulfur for optimal potato growth and development. The rate at which sulfur is converted to sulfate depends not only upon environmental and soil conditions but also upon the fineness of the sulfur material. Smaller particle sizes react more quickly.

The conversion of sulfur to sulfate can take weeks, months, or even years to complete. As sulfur is converted to sulfate, the surrounding soil becomes more acidic.

Sulfate is expected to be in short supply on soils that are coarse-textured, have little organic matter, and receive high amounts of rainfall.

Sulfur-deficient potato plants exhibit general yellowing somewhat similar to nitrogen deficiency, but appearing on youngest leaves first and progressing to yellowing of the entire plant. Nitrogen deficiency symptoms appear on oldest leaves first. Stunting may also occur. Under severe sulfur deficiency, leaf blades may remain yellowish and curl upward.

Role in Plants

Sulfur is essential for proper plant nutrition. The functions of sulfur in plants include:

- Synthesis of sulfur-containing amino acids, which are essential components of protein
- Synthesis of metabolites that are essential for many plant processes
- Synthesis of chlorophyll
- Production of enzymes that regulate the rate of chemical reactions in the plant

Fertilizer Sources

Some of the more important sulfur fertilizers are:

- **Elemental sulfur (0-0-0-90S).**
  This source may be used to lower soil pH. Sulfur must be transformed to sulfate via microbial oxidation for plant uptake.
- **Sulfuric acid (0-0-0-32S).**
  This source may also be used to lower soil pH.
- **Ammonium thiosulfate (12-0-0-26S).**
  When applied to soil, this source decomposes into elemental sulfur and sulfate. The transformations of elemental sulfur to sulfate and of ammonium to nitrate lowers soil pH.
- **Ammonium polysulfide (20-0-0-[40-45S]).**
  In the soil, this material is changed to colloidal sulfur and sulfide. The colloidal sulfur can oxidize fairly rapidly to form sulfate.
- **Ammonium bisulfite (8-0-0-17S).**
  The sulfite oxidizes to sulfate in soils.
- **Sulfate of potash magnesia (0-0-22-22S-11Mg).**
  This source contains potassium and magnesium sulfate salts.
- **Ammonium sulfate (21-0-024).**
  Provides a highly soluble source of sulfates and a significant nitrogen source to the crop, making it widely used in potatoes, where its acidic nature also benefits the crop.
- **Gypsum (0-0-0-18.6S-32.6CaO), hydrated.**
  This source contains a calcium sulfate with moderate solubility.
- **Potassium sulfate (0-0-50-17.6S).**
  This fertilizer is often used as a potassium source in potato fertilization.

Sulfuric acid, ammonium thiosulfate, ammonium polysulfide, and ammonium bisulfite are fertilizer sources suitable for application in irrigation water. The concentration of sulfur in the irrigation water should be tested to adjust sulfur fertilizer rates.

Fertilizer Application

Sulfur responses are most likely to occur on sandy soils where irrigation water has low levels of sulfur.

Sulfate sources of sulfur can be applied immediately preceding planting or at planting. Because sulfate is mobile in soils, it should not be applied in the preceding season in environments subject to overwinter or early spring leaching conditions/loss. Elemental sulfur should be applied the year before a potato crop. Sulfur with a small particle size should be used to speed soil reactions. Applying a year ahead of the potato crop gives elemental sulfur time to react and convert to plant-available sulfate.



Calcium

Total amounts of calcium (Ca) in the soil range from less than 0.1 percent to as much as 25 percent. Arid, calcareous soils contain the highest levels of calcium. At pH levels typical for potato production, calcium normally occupies 60 to 90 percent of the sites on the soil's cation exchange complex. Clay soils usually contain more calcium than sandy soils. Like other cations, calcium is also present in the soil solution. It is part of the structure of several soil minerals, such as dolomite, calcite, apatite, pyroxenes, amphiboles, and calcium feldspars. Gypsum is present in some soils in semiarid regions.

Calcium is taken up by plants as the divalent cation, Ca^{++}. It improves the root absorption and translocation of other nutrients, activates growth-regulating enzyme systems, is needed for cell wall formation and normal cell division, and contributes to improved disease resistance. Along with magnesium and potassium, calcium also helps to balance organic acids, which form during cell metabolism. Since calcium movement within the plant is unidirectional, a continuous supply is required. Symptoms of calcium deficiency appear first at growing points of the potato plant. Leaf blades cup upwards, growing points of the shoots wilt and die, and root tips swell and darken. Petiole levels of less than 0.3 percent calcium (dry weight basis) indicate a severe deficiency.

While tubers contain little calcium, it plays an important role in tuber development. A 300 hundredweight per acre potato crop takes up about 150 pounds per acre, but only about 4 pounds per acre is removed in the tuber at harvest. Most of the tuber calcium is concentrated near the skin. Internal brown spot, often called heat necrosis, and other internal tuber disorders occur when calcium is deficient. Applications of calcium can also increase resistance to bacterial soft rot. The severity of common scab increases as the pH of the soil increases from 5.2 to 8.0. Such pH increases are usually accompanied by increases in available calcium, but it is more likely the pH and not the calcium that increases the incidence of common scab. Applying gypsum does not always increase yield, but in very sandy soils there may be a small yield response as indicated by Florida data shown in Table 9.

TABLE 9. POTATO YIELD RESPONSE TO GYPSUM (CALCIUM SULPHATE) SOIL AMENDMENT. MEAN OF 3 YEARS, FLORIDA. SOIL PH 6.0 TO 6.4, SOIL CA 440 TO 860 PPM, SOIL CEC 3.0 TO 3.5.

Gypsum (tons/ac)	Marketable Yield (cwt/ac)
0.0	227
2.3	237
4.6	234

The tuber does not appear to absorb much calcium directly from the soil. See Table 10. The potato plant takes up calcium primarily through the roots. Adequate calcium is very important for maintaining tuber quality in storage, however.

Choice of calcium sources will depend on whether or not the soil needs liming. If liming is needed, the common sources would be calcitic limestone (calcium carbonate, ~32% Ca), dolomitic limestone (~22%), and hydrated lime (~46%). Note the actual calcium content can vary by lime source. If soil does not need lime, one should use a soluble calcium fertilizer such as calcium nitrate (CN), calcium-ammonium nitrate (CAN), calcium chloride, or gypsum. Calcium nitrate and calcium-ammonium nitrate are frequently used for potatoes, but one must consider their nitrogen contribution as part of the crop nitrogen budget to avoid excess N supply.

TABLE 10. SUFFICIENT LEVELS OF CA AND MG IN POTATO TISSUE AT DIFFERENT GROWTH STAGES.

Plant Part	Calcium	Magnesium
	Percent	
Petioles pre-bloom	0.6-2.5	0.26-1.1
Petioles mid-bloom	0.6-2.5	0.26-1.25
Whole leaf, tubers half-grown	1.5-2.5	0.7-1.0
Tubers at harvest	0.028-0.049	0.11-0.14

Clay soils usually contain more calcium than sandy soils.

Magnesium

Soil magnesium (Mg) comes from the weathering of rocks containing such minerals as biotite, hornblende, dolomite, and chlorite. Being a cation, Mg^{++} is subject to cation exchange. It is found in the soil solution and is adsorbed by clay and organic matter surfaces. Soils usually contain less magnesium than calcium because magnesium is not adsorbed as tightly and is more susceptible to leaching. Also, most parent materials contain less magnesium than calcium. Deficiencies of magnesium frequently occur on coarse-textured, acidic soils developed under high rainfall conditions. Deficiencies can also develop on calcareous soils where irrigation water contains high bicarbonate, or on sodic soils.

Magnesium, as the central atom in the chlorophyll molecule, is vital for photosynthesis in the plant. It is also required for cell division, protein formation, phosphorus metabolism, plant respiration, and the activation of several enzyme systems. Magnesium is taken up by the plant as the divalent cation, Mg^{++}. A 500 hundredweight per acre potato crop takes up about 50 pounds per acre, with about 12 pounds per acre removed in the tuber at harvest.

Deficiency symptoms appear first on young mature leaves as a slight yellowing (chlorosis) between the veins. As the symptoms progress, brown spots and finally leaf scorch appear between the veins, in contrast to the scorch on the leaf outer margins seen with potassium deficiency. Petiole analysis results of less than 0.26 percent magnesium (dry weight basis) indicate deficiency. Early foliar applications of magnesium often produce a visual response, deepening the green color of the leaves, but yield responses are less consistent.

If soil test magnesium levels are below 50 parts per million, extractable magnesium is usually considered low, and application of a magnesium source is warranted. For soil test magnesium levels between 50 and 100 parts per million, need for magnesium depends on soil potassium status and level of potassium application. High amounts of available potassium tend to depress magnesium uptake, while high phosphorus levels promote it. When it is necessary to add large amounts of potassium, use of sulfate of potash magnesia can avoid antagonizing magnesium uptake. In soils with pH below 6.0, addition of dolomitic lime or magnesium oxide will supply magnesium. However, in soils of higher pH, the magnesium in dolomitic lime does not dissolve, and a soluble source such as sulfate of potash magnesia or magnesium sulfate (Epsom salt) must be used.

Common magnesium sources and their magnesium content are: dolomitic limestone (3 to 12 percent), magnesium oxide (55 to 60 percent), magnesium sulfate (9 to 20 percent), and sulfate of potash magnesia (11 percent). Several industrial byproducts also contain magnesium, often in the form of magnesium oxide. Note magnesium oxides have very low solubility in neutral to alkaline soils and would not be a preferred source for these soils.





A 400 cwt/ac potato crop takes up about 50 lbs/ac of magnesium, with about 12 lbs/ac removed in the tuber at harvest.

Micronutrients

Micronutrients in potatoes play vital roles in processes such as chlorophyll synthesis, enzyme activation, and growth regulation, ensuring optimal plant health and yield.



Functions of Micronutrients in Plants

A listing of the specific functions of each micronutrient helps to illustrate why the detection of a deficiency is often difficult (Table 11). The listing also helps to target the plant part where a deficiency symptom is most likely to occur. For example, iron (Fe), manganese (Mn), and copper (Cu) are each involved with chlorophyll formation, and a shortage will likely trigger a visible yellowing of plant tissue. Zinc (Zn), boron (B), and molybdenum (Mo) are each involved with protein formation, which is less likely to trigger a visible symptom.

Availability of Micronutrients in the Soil

The total concentration of a micronutrient in the soil is usually a poor indicator of its availability to the potato plant. Tons of iron and molybdenum might exist in a soil but be limiting to plant growth because they exist in a form unsuitable for absorption by roots. The content of boron, zinc, copper, or chloride (Cl) in soils might range from a few to several hundred pounds per acre and adversely affect plant growth as either a deficiency or toxicity. Thus, micronutrient management should include consideration of the conditions regulating their availability: soil acidity, soil temperature and moisture, genetics, and/or interactions with other potato production inputs. In addition, many fungicides commonly used on potatoes contain one or more of the micronutrient elements.

The Need for Micronutrient Fertilization Programs

The potato is considered a highly demanding crop for nutrients because its rooting system is shallow while its growth rate is very high. Few crops accumulate carbohydrates as fast as the potato crop. Considering this, it is surprising that micronutrient responses in potatoes are not more common.

Liming a strongly acidic soil impacts the availability of all micronutrients except chloride. Iron, zinc, copper, boron, and manganese become less available, while molybdenum availability actually increases as pH increases. Alkaline soils that are also high in phosphorus tend to be responsive to applied zinc. Sandy soils are more likely to be in need of micronutrients than soils high in clay content. Land leveling or removal of higher organic matter surface soils often triggers a shortage of zinc. Low chloride deposition with precipitation and limited use of potassium chloride fertilizer have created low chloride soils in parts of the Great Plains and Canadian Prairies, leading to potential yield response to applied chloride in this region. Such conditions justify the existence of a strong micronutrient component for many high-yield nutrient management programs.

TABLE 11. FUNCTIONS OF MICRONUTRIENTS IN POTATO PLANT DEVELOPMENT.

Plant Growth Function	Boron	Chloride	Copper	Iron	Manganese	Molybdenum	Zinc
Enzyme systems			X	X	X	X	X
Protein formation	X		X	X		X	X
Hormones and cell division	X						X
Chlorophyll formation			X	X	X		
Disease resistance		X			X		
Photosynthesis		X		X	X		
Nitrogen, iron, and/or phosphorus metabolism	X		X	X	X	X	X
Sugar/starch translocation	X	X					X

Determining Micronutrient Needs

Micronutrients differ from macronutrients because plants take up much smaller amounts. Typically, micronutrient concentrations in the plant are measured in parts per million rather than percent. Careful diagnosis is important and relies on a combination of scouting for visual symptoms, soil testing, and plant analysis.

Boron deficiency, like calcium deficiency, affects the growing points. Root tips become swollen and darken, immature center leaves become deformed, and the growing point dies. Boron has a particularly narrow "window" between deficiency and toxicity. Although potatoes have a relatively high boron requirement, they are particularly sensitive to excess boron. When deficiencies are suspected, careful trial applications on a small scale are recommended. Boron is usually soil-applied pre-plant but may also be side-dressed. Sources of boron include sodium borate (borax), with 11 percent boron. Several other water-soluble forms are available with boron contents up to 20 percent.

Chloride differs from the other micronutrients in that it is often available in much larger amounts in the soil, and its concentration in plant tissue can be much higher (greater than 3800 parts per million). Chloride has long been known to reduce specific gravity of potatoes, and for this reason sulfate sources of potash have often been preferred. While potatoes may be sensitive to chloride deficiency (J.B. Jones, 1991), deficiencies are not common because of the frequent use of potassium chloride fertilizer in potato production, or rotational crops, soil chloride levels, and the chloride content of many irrigation waters. Oregon research has shown reductions in hollow heart with potassium chloride compared to potassium sulfate and accompanying increases in yield and grade.

Copper deficiency in the early stages produces symptoms similar to those of sulfur, molybdenum, manganese, and iron: Young, immature leaf blades turn a uniform light green. Later, the young leaves cup upward and roll inward. The young leaves remain large, in contrast to a zinc deficiency where they become small and narrow. Copper toxicity can be a problem where copper-based fungicides are used. There is very little information on potato responses to copper application. In other crops, copper responses are obtained on some organic soils and on some prairie soils in western Canada.

Iron deficiency produces a yellowing of young leaves near the growing point. The yellow color may change to white before the leaves turn brown and die. If the plants begin to recover after a mild deficiency, green veining will appear as the iron is used in chlorophyll formation near the vein first. On acid soils, iron deficiency is very unlikely. When symptoms appear on calcareous (high-lime) soils, foliar sprays of chelated iron solutions can help overcome the deficiency. Most soil iron treatments are quite ineffective on high-pH soils, although there are some certain iron chelate products that are effective.

Manganese deficiency produces symptoms of yellowing and slight cupping of younger leaves. As the deficiency progresses, dark spots develop between veins, along large veins, and on the leaf midrib. Deficiency is most likely on calcareous soils, while toxicities are more likely on acidic soils. Potatoes are particularly sensitive to excess manganese. For this reason, when deficiencies are suspected, apply small-scale test applications of foliar manganese sulfate or manganese chelate solution, then observe the response for a few days. Where toxicities occur, apply lime to raise soil pH.

Molybdenum deficiency appears similar to nitrogen and sulfur deficiencies. Leaf blades yellow uniformly. Plants deficient in molybdenum will usually have high levels of nitrate in the petioles. The critical level of 0.15 parts per million in leaf blades was based on research done on sugar beets. Liming soil usually increases molybdenum availability. Legumes and cole crops are more sensitive to molybdenum deficiency than potatoes.

Zinc deficiency is often known as "fern leaf" or "little leaf" in potatoes. Young leaves turn yellow, become narrow, and cup upward, often with tipburn. As the plants grow, the petioles detach easily from the stem, giving the plant a profile similar to a palm tree. Deficiency of zinc occurs more often on calcareous soils than on acid soils. Deficiencies are most frequently and effectively corrected by soil rather than foliar applications of soluble materials like zinc chelates or zinc sulfate. Many sources, including sulfates, oxides, frits, carbonates, nitrates, and chlorides are available. Research indicates zinc and manganese fertilizers should contain at least 35 to 50 percent water soluble zinc or manganese for optimum plant response. Broadcast applications usually require higher rates than band applications. Zinc applications to the soil have been shown to reduce tuber cadmium (Cd) concentrations in areas of Australia where cadmium accumulation was a problem.

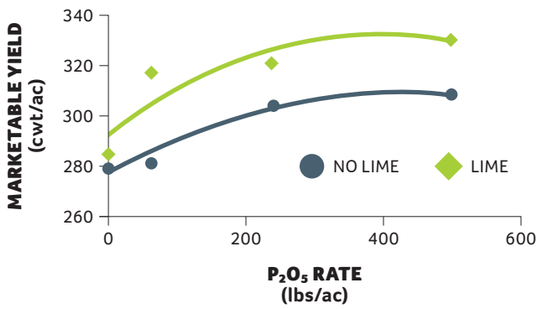
In potatoes, most micronutrient deficiencies can be corrected by applying the appropriate nutrient, such as iron sulfate, manganese sulfate, zinc sulfate, copper sulfate, boron, or molybdenum, tailored to the crop's specific requirements and soil conditions.



Soil Amendments: Lime and Gypsum

In regions with acidic soils, lime is often applied as much for the other crops in the rotation as for the potatoes. Lime additions are often made to other crops in the rotation. Potatoes grow well at a soil pH of 5.4 or above, but varieties susceptible to scab may be grown at a pH of 5.0 to 5.4 to reduce the risk of scab infection. The scab organism, Streptomyces scabies, does not thrive well in these low pH levels. Incidence of scab increases with pH in the range of 5.0 to 8.0. Overliming should be avoided, as several micronutrients (boron, copper, iron, manganese, zinc) can become deficient. Applying lime to acid soils, however, can help increase the availability of the most important nutrients (nitrogen, phosphorus, calcium, magnesium, and molybdenum). Liming to maintain an optimum soil pH reduces the risk of toxicities from aluminum and other metals, improves the physical condition of the soil, stimulates microbial activity, and increases the cation exchange capacity in some variable charge soils.

FIGURE 6. LIME APPLICATION CAN ENHANCE POTATO RESPONSE TO APPLIED P. AVERAGE OF TWO SITES, PRINCE EDWARD ISLAND, 1997. INITIAL SOIL PH WAS 5.5 TO 6.2; LIME BROADCAST AT PLANTING; VARIETY RUSSET BURBANK.



Calcitic and dolomitic aglime are the most common lime sources. Dolomitic lime is recommended where soils are low in magnesium. As aglime dissolves in soils, the carbonate reacts with the hydrogen (H^+) ions displaced by the calcium (and/or magnesium) in the limestone particles to raise soil pH. Calcium or magnesium does not directly neutralize soil acidity. This explains why gypsum ($CaSO_4$) has a calcium carbonate ($CaCO_3$) equivalence (CCE) of zero and has no direct effect on soil pH. The purity of a liming material is expressed as calcium carbonate equivalence, with all liming materials rated in comparison to pure calcium carbonate (CCE=100). The smaller the lime particle, the faster it will react in neutralizing soil acidity (Table 12). The effective neutralizing value, or effective calcium carbonate equivalence (ECCE), of a liming material is determined by both the chemical purity and the size of the lime particles.

TABLE 12. LIME PARTICLE FINENESS AFFECTS ACIDITY NEUTRALIZATION.

Mesh Size	Years After Application	
	1	4
	Percent Reacted	
Coarser than 8	5	15
8 to 19	20	45
20 to 50	50	100
Finer than 50	100	100

The effective calcium carbonate equivalence of a liming material can be estimated using the formula: ECCE = %CCE x 0.50 (% passing 8-mesh + % passing 50-mesh). Thorough mixing in the tillage zone is also necessary for the optimum lime reaction. Aglime should be incorporated to adjust the soil pH to the desired level in the entire plow layer before no-till crop production is initiated. The pH can be maintained in the desired range by surface applications afterward. Surface liming of no-till systems about every three years, based on soil tests, should be adequate.

Pelletized lime and fluid products are made from finely ground aglime and will chemically react the same as good quality aglime. Pelletized aglime is usually made from aglime ground to pass at least a 70-mesh sieve and, with the aid of clay or synthetic binders, formed into pellets in the 5-to-14-mesh range. Fluid aglime is commonly a 50 percent mixture of aglime particles that have been ground to pass a 200-mesh screen, plus 50 percent water and a small amount of clay or other suspending agent. The choice among good aglime, pelletized lime, and fluid lime is often based on cost, uniformity of application, and time permitted to raise soil pH to desired levels.

While gypsum has no neutralizing value, it can be an effective source of calcium for sandy soils low in cation exchange capacity. Gypsum can also help to improve the physical characteristics of sodic soils.

Sodic and saline soils occur in arid and semiarid regions, where salts accumulate near the soil surface as a result of evaporation of water. Salinity becomes a problem when soils do not drain well and salts are not leached. Irrigation water can be a significant source of salts in some regions. Potatoes are classified as moderately sensitive to salinity, similar to alfalfa, peanuts, and cole crops, but less sensitive than carrots, celery, and most fruit trees. Potatoes will tolerate salinity up to about 4 to 6 decisiemens per meter before yield reductions occur.

Saline soils have a saturated extract conductivity of more than four decisiemens per meter, pH less than 8.5, and less than 15 percent exchangeable sodium (ESP). If exchangeable sodium percentage is greater than 15 percent, the soil is sodic (dominated by sodium) or saline-sodic. The pH of sodic soils is usually above 8.5, while that of saline-sodic soils is less than 8.5. Saline soils are reclaimed by assuring sufficient drainage and applying water in quantities large enough to leach out the salt. Sodic soils have structural problems because of the dispersion of clay particles. These soils are more difficult to reclaim because their internal drainage is poor. Incorporating gypsum or other amendments to displace the sodium with calcium helps improve the structure and drainage so salinity can be alleviated.

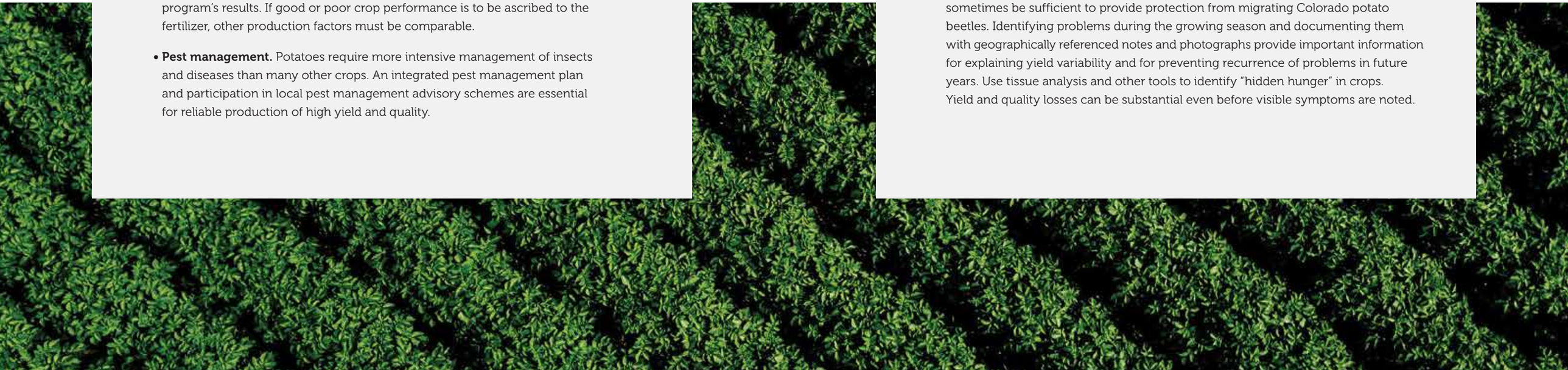


Conclusion

Fertilizing potatoes for optimum yield and quality requires both planning and monitoring. Most growers plan their fertility based on local experience or local custom. As discussed previously, it is essential to base fertility plans on a reliable soil test. Subsequently, plant-tissue analysis is useful for determining possible deficiencies and fine-tuning the fertility program. Plant-tissue analysis complements soil testing and can be considered the "barometer" of the success of the fertilizer program. In some cases, nutritional disorders identified by tissue analysis can be corrected mid-season, but in others the information is useful only in the longer term.

Growers need a strategic production plan, developed around best management practices to ensure that all important details are considered. Most important are the potential interactions among practices, since most management decisions affect other decisions that have to be made. Some of the key best management practices and their potential interactions with nutrient management include:

- **Realistic yield goals are particularly important for nitrogen.** Excess nitrogen can delay onset of tuber bulking and reduce both yield and quality. Different varieties will also require different levels of fertilization depending on their maturity and yield potential. Potatoes in irrigated production where yields above 500 hundredweight per acre are common have greater nutrient demands than those in rainfed conditions.
- **Good records.** Every growing season presents a different set of challenges. Weather, insect and disease pressure, and soil conditions vary daily throughout the growing season. Accurate records are essential for evaluation of a fertilizer program's results. If good or poor crop performance is to be ascribed to the fertilizer, other production factors must be comparable.
- **Pest management.** Potatoes require more intensive management of insects and diseases than many other crops. An integrated pest management plan and participation in local pest management advisory schemes are essential for reliable production of high yield and quality.



- **Variety selection.** Potato varieties are chosen mainly for the end use. Processing and table potatoes are grown with different quality objectives. For production of large tubers desired in processing, phosphorus inputs are critical. Timing and rate of nitrogen can influence tuber set and thus affect tuber numbers and tuber size.
- **Rotation.** Fertility does not replace all the benefits of a sound rotation. Potatoes grown following forage or cereal crops have greater yields and require less nitrogen to achieve them. Adequate control of diseases and maintenance of soil structure often require a minimum of two years of other crops between each potato crop. Diseases controlled by rotation include blackleg, wilt, rhizoctonia, common scab, powdery scab, ring rot, nematodes, and silver scurf. Rotation also can partially control Colorado potato beetles.
- **Tillage.** Many potato soils are highly susceptible to erosion. However, the potato crop generally requires intensive tillage in order to have sufficient loose soil for hilling. Successful conservation tillage strategies for potatoes usually involve deep cultivation that leaves some crop residue on the soil surface. Residue-managed potato production can be practiced on any field in which potatoes are grown in rotation with forages or cereals. In some cases, when high levels of non-legume residue are kept on the soil, immobilization of nitrogen can occur, and additional nitrogen fertilizer may be required.
- **Diagnostics.** Regular scouting for insects to accurately monitor their population development can increase effectiveness of control. For example, small Colorado potato beetle larvae are much easier to control than adults. Border sprays can sometimes be sufficient to provide protection from migrating Colorado potato beetles. Identifying problems during the growing season and documenting them with geographically referenced notes and photographs provide important information for explaining yield variability and for preventing recurrence of problems in future years. Use tissue analysis and other tools to identify "hidden hunger" in crops. Yield and quality losses can be substantial even before visible symptoms are noted.

Nutrient Deficiency Symptoms of Potato Foliage

Nitrogen



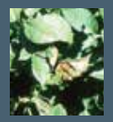
Entire plants may turn light green. Young leaves remain green; older leaves turn yellow to light brown and become senescent.

Phosphorus



Plants are stunted. Leaves are dark green and their margins roll upward. Some purpling occurs in pigmented leaves. The severity of leafroll increases as the deficiency increases.

Potassium

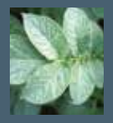


Plants may be stunted. Young leaves develop a crinkly surface, and their margins roll downward. Leaves have slightly black pigmentation. Marginal scorching with necrotic spots may occur on older leaves.

Calcium

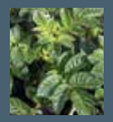
The youngest mature leaves roll upward and become chlorotic with brown spotting. Growing buds may die. In tubers, a brown discoloration develops within the vascular ring before symptoms appear on vegetation.

Magnesium



Young mature leaves are affected with interveinal chlorosis and brown spotting, which develop into interveinal scorching and necrosis. Leaves near growing buds remain green.

Sulfur



The symptoms are similar to those of nitrogen deficiency, except that chlorosis develops first in young leaves. Affected leaves turn uniformly yellow.

Boron

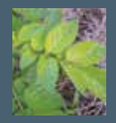
Growing buds die. Plants appear bushy, having shorter internodes. Leaves thicken and roll upward. Leaf tissue darkens and collapses.

Zinc



Young leaves are chlorotic, narrow, and upward-cupped and develop tipburn. Other leaf symptoms are green veining, necrotic spotting, blotching, and erect appearance.

Iron



Young leaves are yellow to nearly white but not necrotic. Leaf tips and edges remain green the longest. Green veining occurs in leaves.

Manganese

Young leaves are affected with interveinal chlorosis and then gray and black flecking and leaf cupping. The flecks eventually develop into small dead patches.

Copper

Young leaves develop a pronounced rolling, and then leaf tips wilt and die. Leaves remain green and are of normal size.

Molybdenum

Leaves turn yellow or greenish yellow. The symptoms are similar to those of nitrogen deficiency.

Chloride

Young leaves are light green, turn purplish bronze, and may curl upward or appear pebbled.

Source: D. T. Westermann. 1993. Fertility Management, Chap. 9. In Potato Health Management, Randall C. Rowe (ed.). APS Press.

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