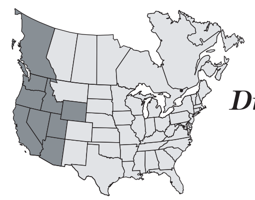
NEWS & VIEWS — Special Series

A regional newsletter published by the Potash & Phosphate Institute (PPI) and the Potash & Phosphate Institute of Canada (PPIC)

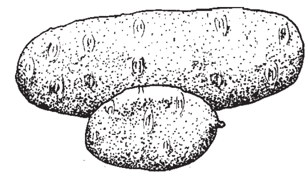
Best Management Practices for Fertilizer



Dr. Robert L. Mikkelsen, West Region Director
February 2006

This publication is one of a series on fertilizer best management practices (BMPs), prepared by regional directors of the Potash & Phosphate Institute (PPI)/Potash & Phosphate Institute of Canada (PPIC). This effort is in cooperation with the Foundation for Agronomic Research (FAR) toward fulfilling the goals of a 3-year Conservation Innovation Grant (68-3A75-5-166) from the USDA-Natural Resources Conservation Service (NRCS). The intent of these publications is to help develop the BMP definition process in such a way that environmental objectives are met without sacrificing current or future production or profit potential and in full consideration of the newer technologies relevant to fertilizer use. The concept of applying the right fertilizer at the "right rate, right time, and right place" is a guiding theme in this series.

Best Management Practices for Profitable Fertilization of Potatoes



POTATOES are an important part of our diet in North America and a very significant crop for the farm sector. A typical American consumes over 140 lb of potatoes each year (fresh and processed), far more than any other vegetable. Potato sales now top more than $3 billion each year in the U.S.

Potatoes are grown in almost every state and province across North America for a variety of purposes. Many are grown for fresh potatoes, while others are for processing into frozen products, fries, and chips. Regardless of the intended end use, the objective of growers is to provide the highest quality potato for the intended use at a price that is economically profitable.

Potato growers invest large amounts of money to grow a crop. It is not unusual for a grower to have over $2,000/A invested in the crop before the potatoes are harvested. Advances in crop management and improved varieties have led to steady increases in yields, from a national average of 150 cwt/A in 1950 to nearly 400 cwt/A in 2004. To maintain these high yield levels and because of the intensive nature of potato production, considerable work has been done to determine the best way to manage the crop and plant nutrients, referred to as "best management practices" or "BMPs".

Potatoes managed for maximum productivity have a high demand on soil nutrients. Significant quantities of nutrients are accumulated in the tops and are removed from the field in the harvested tubers (**Table 1**). Since potatoes are commonly grown on sandy-textured soils, additional challenges for nutrient management are present.

Table 1. Typical nutrient accumulation and removal in Russet potatoes in a 500 cwt/A crop (lb/A).

Nutrient	Potato vines	Removed in tubers	Total accumulation
Nitrogen (N)	139	214	353
Phosphorus (P)	11	29	40
Potassium (K)	275	240	515
Calcium (Ca)	43	7	51
Magnesium (Mg)	25	15	40
Sulfur (S)	12	22	34

Source: Oregon State Univ. Potato Information Exchange. 2004. Also personal communication, Dr. Don Horneck, Oregon State Univ.

Potatoes grown for processing are valued for yield, size, and also for dry matter content (measured by specific gravity). As the specific gravity increases, the water content of the potato decreases, improving the frying properties and flavor. Management factors, including fertility decisions, will influence potato yield, quality, and storage properties.

Potato growth is classified into four distinct growth phases (**Figure 1**). The exact timing of these growth phases depends on many environmental and management factors that vary between locations and cultivars. However, these distinct stages of growth need to be considered when managing the crop.

Plant Factors Influencing Nutrient Needs

The maturity class and growing season length are two primary factors determining potato nutrient requirements. Short-season, early maturing (determinate) potatoes

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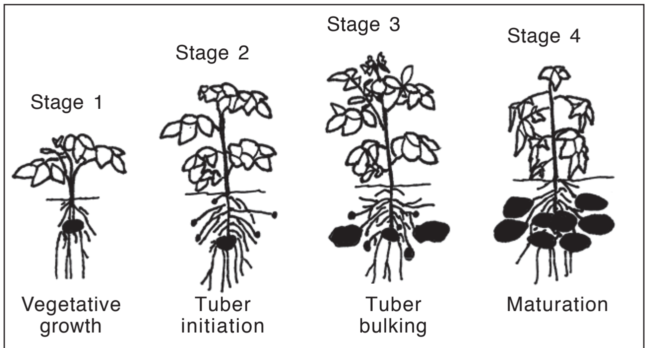

Figure 1. Major stages of growth and development of potatoes. The nutrient requirement of the developing potato changes during the growing season.

generally have a high and intense nutrient demand during the vegetative and tuber initiation stages. Long-season potatoes (indeterminate) have a longer period of nutrient uptake. The specific fertilization strategy must be adjusted for the different varieties and maturity classes or poor results will occur.

Nutrient Management

Growing healthy potatoes for maximum yield and quality requires that all the essential nutrients be supplied at the **right rate**, the **right time**, and the **right place** (**Table 2**). For potatoes, either deficient or excessive plant nutrition can reduce tuber bulking and quality. Nutrient deficiencies may limit the leaf canopy growth and its duration, resulting in reduced carbohydrate production and tuber growth. Maintaining healthy leaves is a key to producing high yields. However, excessive nutrient applications may cause nutrient imbalances or over-stimulate vegetative growth at the expense of tuber production. Some nutrients, such as S, may also have indirect yield benefits by reducing tuber disease.

Table 2. Summary of nutrient management practices for potato fertilization.

Right Rate	Pre-season soil analysis provides information that is essential for making correct fertilizer decisions. Recommendations are based on historic yields and customized for each field. Petiole N and P are monitored during the growing season to determine the need for supplemental mid-season fertilization.
Right Time	The P and K requirements are met with pre-plant fertilization. A portion of the N is applied during row mark-out or planting, with the remainder applied later in the growing season.
Right Place	Broadcast fertilizer applications are incorporated into the soil and banded fertilizer is placed in the row or within a few inches of the seed piece. Nutrients applied through the irrigation system are not allowed to runoff from the field.

The total nutrient requirement is determined by a combination of plant, soil, and environmental factors. Many of these factors can be carefully controlled, but other factors (such as rainfall, temperature, and sunlight) cannot be. The main consideration is to manage those factors that can be controlled and keep the plants in the best condition to withstand whatever environmental stresses may occur. This publication reviews some of the principles of effective potato fertilization in the West. However, due to the wide variation in growing conditions, cultivars, and production goals, it is essential that local expertise be used to customize this information.

Nitrogen

Proper N management is one of the most important factors required to obtain high yields of excellent quality potatoes. An adequate early season N supply is important to support vegetative growth, but excessive soil N later in the season will suppress tuber initiation, reduce yields, and decrease the specific gravity in some cultivars. Excess soil N late in the season can delay maturity of the tubers and result in poor skin set, which harms the tuber quality and storage properties.

Potatoes are a shallow-rooted crop, generally growing on sandy, well-drained soils. These soil conditions frequently make water and N management difficult since nitrate is susceptible to leaching losses. On these sandy soils, it is recommended that potatoes receive split applications of N during the growing season. This involves applying some of the total N requirement prior to planting and applying the remainder during the season with side-dress applications or through the irrigation system. The period of highest N demand varies by potato variety and is related to cultivar characteristics such as root density and time to maturity. Use of petiole analysis during the growing season allows producers to determine the N status of the crop and respond in a timely manner with appropriate nutrients.

There are several N fertilizers suitable for application through an irrigation system. Care should be taken to get uniform coverage through the field and to minimize runoff. Application of N fertilizer through furrow irrigation should only be done where a tailwater collection and reuse system is in place (although this method may not result in uniform application of N).

The use of controlled-release N fertilizers has been successfully tested for potato production, with the goal of reducing nitrate leaching losses of N between the time of application and plant uptake. The relatively high price of these N sources has been the main obstacle so far, but with the continuing development of more affordable coating materials, this barrier may be overcome in the near future.

Planting winter cover crops to recover residual N during the winter is attractive, but has proven difficult in many potato-production areas. The problems associated with late-fall establishment of the cover crop, timing the crop-kill in the spring, and synchronizing the release of nutrients from decomposing residues to the needs of the potato crop are all challenges that require further work.

Phosphorus

Soil Availability and Plant Uptake

Phosphorus occurs in many forms, depending on factors including pH and chemical composition of the soil. While only a portion of the total soil P is available to the crop during a given growing season, the supply of available P is constantly replenished from reserves of less available P in the soil. Some of the available P may come from this year's fertilizer application, residual fertilizer, or from the mineralization of organic residues.

Roots absorb phosphate ions only when they are dissolved in the soil water. Phosphorus deficiencies can occur even in soils with abundant available P if drought, low temperatures, or disease interfere with P diffusion to the root through the soil solution or otherwise stunt normal root development and function. Proper irrigation management and scheduling is critical for potato development and utilization of applied nutrients.

Potato plants require an adequate supply of P throughout the growing season to achieve optimum quality and yield. During the early growth stages, P stimulates the development of a vigorous root system and healthy tops. Plant demand for P peaks at tuber set and early bulking, and then slows during later bulking—when much of the nutrient demand of the developing tubers is met by translocating P from the tops of the plants down to the roots.

Distinct P deficiency symptoms are not usually visible in potatoes, even when deficiency slows growth and greatly reduces yields. Only after P deficiencies have become severe will the crop begin to develop visible signs of P stress—manifested first by stunted dark green leaves. Later, the edges of the youngest leaves may begin to fold downwards. Since P deficiency is difficult to visually diagnose and significant yield losses will have occurred when they become evident, the P status is best monitored by petiole analysis to avoid yield-robbing deficiencies.

P Fertilization

Phosphorus plays an essential role in plant health and root development, which directly impacts yield and quality. The P requirement of potatoes is frequently higher than the P required for many field crops due to the high nutrient demand of potatoes and their relatively shallow root system. Therefore, some fertilizer P is commonly recommended for potatoes grown in a crop rotation. The need for P fertilization should be established by a soil sample taken prior to planting. Since P generally moves very little in soil, it is important to place the P within the root zone to stimulate the early-season growth required for high yields. Preplant P applications (broadcast or banded) are generally preferred, but mid-season applications may be useful when needed. When petiole analysis indicates a risk of P deficiency, a soluble P fertilizer (typically 10-34-0) may be applied through an irrigation system to provide a mid- or late-season boost. This P fertigation technique is beneficial only if adequate roots are present near the soil surface, as frequently occurs after the canopy shades the hill during mid-season.

Commonly available P fertilizer sources are equally useful for potato nutrition. The selection of a particular P fertilizer is generally based on grower preference, price, and compatibility with application equipment. Recent research suggests that modifications to P fertilizer, such as polymer additives, humic substances and coatings may be beneficial in improving P uptake and potato production.

Potassium

Soil Availability and Plant Uptake

Potassium is primarily supplied to potato roots through diffusion over short distances, so K is generally considered a relatively immobile nutrient in most soils. However, in sandy-textured soils with a low cation exchange capacity, K can move as much as several inches per year. Much of the K available to the plant is held on exchange sites on clay or on the surface of organic matter, which is released to replenish the soil solution as uptake of K occurs. Consequently, soil K levels do not change rapidly during the growing season, but will steadily decline over time if harvested nutrients are not replaced.

Potatoes require large amounts of soil K, since this nutrient is crucial to metabolic functions such as the movement of sugars from the leaves to the tubers and the transformation of sugar into potato starch. Potassium deficiencies reduce the yield, size, and quality of the potato crop. A lack of adequate soil K is also associated with low specific gravity in potatoes.

Potassium deficiencies impair the crop's resistance to diseases and its ability to tolerate stresses such as drought and frost. Tubers adequately supplied with K are more resistant to blackspot bruising or after-cooking discoloration, while also experiencing less moisture loss and disease during storage.

Deficiency of K typically occurs first in the areas of the field with coarse-textured soil. As K is mobile within the plant, the lower leaves are first to display symptoms of K deficiency—yellowing of the leaves with scorching around the leaf margins. Severely deficient plants may take on a coppery appearance. Small dead spots (resembling the lesions produced by fungal disease) may form on the leaves. Obvious signs of K deficiency become visible only after potatoes are severely stressed, so the K status should be monitored by tissue testing if deficiencies are suspected.

Applying K fertilizer with a broadcast application prior to planting is most commonly recommended. If the K is band-applied, the rates should be kept below 50 lb K_2O/A to

BMPs for Potato Fertilizer Management in the West

	Best Practice	Making Progress	Improvements Required
Diagnostic			
Soil testing	Soil test for major nutrients in each field prior to soil preparation and planting.	Take occasional soil samples for analysis to represent multi-field or farm averages.	Never test or use inappropriate soil test results (too old or wrong fields).
Plant tissue testing	Begin regular leaf and petiole monitoring to check need for additional in-season fertilization.	Use plant analysis when deficiency symptoms occur or with unusual conditions.	No tissue sampling is used and supplemental mid-season fertilization is based on traditional averages.
Proper yield goals	Fertilize each specific field based on soil conditions that may limit yield potential, based on individual field history.	Use average farm yield goals to estimate need for fertilization, based on past production.	Use no yield goal or inappropriate goals for a field, resulting in under- or over-fertilization.
Tracking nutrient budgets	Account for nutrients used and removed in the crop rotation on each field.	Use the same amount of nutrient each year without considering variability.	No consideration of nutrient removal in harvested crops or previous rotations.
Fertilizer Application			
Right rate	Balanced nutrition is provided to optimize efficiency and crop recovery, based on soil and plant analysis in each field.	Average fertilizer rates are adjusted for specific fields based on historical crop performance.	Average fertilization rates are used without consideration for residual nutrients or other factors.
Right time	Appropriate fertilization is done prior to planting and the need for additional nutrients is based on analysis. Loss potential is low.	Nutrients are applied in multiple applications based on experience and visual observations of the crop. Loss potential is moderate.	Fertilizer application is based on calendar, without consideration for growing conditions and crop development. Loss potential is great.
Right place	Account for soil differences (e.g. texture and soil pH) and stage of crop development in fertilizer placement using broadcast, banding, and fertigation techniques as appropriate.	Fertilizer nutrients are primarily placed in the root zone before planting, with supplemental fertilizer added as needed.	Nutrients are broadcast across the entire field, without regard for placing immobile nutrients in the root zone.
Right form	Correct balance of nutrients provided for the crop, recognizing that all essential elements must be present for vigorous crop growth. Minimize ammonia loss and P reactions with soil and water.	Apply N only in a multi-nutrient blend without consideration for the soil condition and crop requirement.	Primary emphasis on the N requirement of the crop, resulting in inefficient crop growth and nutrient recovery.
Minimizing Nutrient Losses			
Minimize leaching losses	Sandy soils receive multiple N applications to minimize nitrate leaching losses; petiole nitrate analysis used to monitor crop development. Reservoir tillage (such as dammer diking) is used to keep water on the field.	Total crop N need applied in multiple applications with no petiole analysis to track plant nutritional status.	Nitrogen fertilizer is applied in large amounts and remains vulnerable to leaching from the root zone during irrigation and rainfall.
Minimize runoff losses	Irrigation provides adequate water without generating field runoff.	Runoff is collected in tailwater pond for removing sediment and nutrients.	Runoff from fields carries sediment and nutrients into surrounding ditches and canals.
Improve irrigation efficiency	Operation of irrigation system to provide the proper amount of water for crop health. High uniformity controls leaching and runoff to improve nutrient efficiency.	Irrigation is applied to meet the average crop requirement. Some unwanted leaching and runoff occurs on parts of field.	Irrigation water is not applied uniformly, with areas of wet and dry in the field. Poor water distribution prevents nutrients from being used properly.

avoid any salt injury to the developing sprouts. If low soil K levels require large amounts of K fertilizer, it is best to split this into two or more applications to avoid yield loss. At typical application rates, there are no significant differences in K fertilizer sources.

Proper Fertilizer Application

Fertilization of potatoes is a highly refined practice, capable of correcting potential problems before planting and reacting to changes occurring during the season. This flexibility provides many options for preparing the soil prior to planting and for addressing potential nutrition problems during the growing season. The plant nutrient status can be closely monitored and corrective action taken if conditions indicate a loss of yield or quality due to nutrient stress. Fertilizer application methods for potatoes frequently include a combination of some or all of the following, depending on equipment and management options:

- **Pre-plant broadcast application and incorporation** Broadcast applications made in the fall or the spring are generally incorporated into the surface soil where it will become available for crop growth. Fall applications of fertilizer should be protected from loss during the winter. Generally, no more than half of the N should be applied prior to planting, with the remainder added during the growing season.
- **Banded fertilizer application at row mark-out or planting** Fertilizer can be placed near the seed piece to provide nutrition during early growth. However, direct contact with the plant can cause injury. Fertilizer applied during markout is typically placed a few inches to the side and below the seed piece. Applications made at planting are typically placed 1 to 2 in. above the seed piece for early-season availability.
- **Sidedress banded application after planting** Additional N is frequently applied later in the growing season as the plants develop. This may be particularly beneficial in sandy soils that are prone to nitrate leaching. Late-season applications need to consider potential damage to the crop with field equipment.
- **Foliar nutrient spray** Mid-season correction of nutritional deficiencies can be accomplished with a variety of foliar sprays. Micronutrients are commonly applied with foliar sprays, but other nutrients and chemicals may be applied at the same time. Plant foliage can only tolerate relatively small amounts of nutrients applied in this manner, so this technique is not usually the primary way of providing most crop nutrients.
- **Fertigation through the irrigation system** Various water-soluble fertilizers are commonly applied through irrigation systems, including N, P, K, and S. These nutrients are generally applied according to the results of tissue testing that indicate potential problems. This practice must be done in a way to minimize losses through leaching or runoff in the irrigation water. The compatibility of any chemical added to irrigation water should be evaluated before introducing it through an irrigation system.

Using Soil and Plant Sampling

Soils Pre-season soil sampling and analysis can provide essential information on the starting point and residual fertility related to the growing conditions for the potato crop. In-season soil analysis can also provide information useful for monitoring nutrient availability along with plant tissue testing.

Factors to consider for getting the best information from soil analysis:

Samples must be representative of the major soil type of the site or area in the field.	Pre-season samples should generally be taken from the tillage zone (upper 8 to 10 in.).
Sampling during the growing season is best done from the same sites in the field for improved consistency.	Samples during the growing season should come from the area with the most active root growth and maintained consistently during the season.
The number of samples analyzed depends on the variability in the field and the size of the management units within the field that can be managed individually.	Intensive sampling (such as a grid-based approach) is helpful if site-specific management can be implemented based on the results.
Deep samples (>12 in.) are useful periodically to monitor mobile nutrients in the root zone.	Deep soil samples (to 3 ft.) are useful at the end of the growing season to determine the effectiveness of the N fertilization.

Plants Potato petioles are frequently sampled during the growing season to monitor the plant nutrient status. In potatoes, the fourth leaf from the top of the plant is the most commonly analyzed plant part (**Figure 2**). It is important to consistently sample the same plant part during the season because nutrient concentrations are not uniform throughout the plant and will naturally change as the plant matures. Plant analysis is most beneficial for establishing trends over the season, and not for making management decisions based on a single sampling date. Results from a single petiole analysis can be influenced by the time of day the sample is taken, the climatic conditions, and various stresses not directly related to plant nutrition.

Petiole analysis can be done for all of the essential nutrients, but nitrate determination is the most common test. A petiole is conductive tissue responsible for moving water and nutrients from the roots to the leaf blade (**Figure 3**). A petiole nutrient analysis measures the concentration of

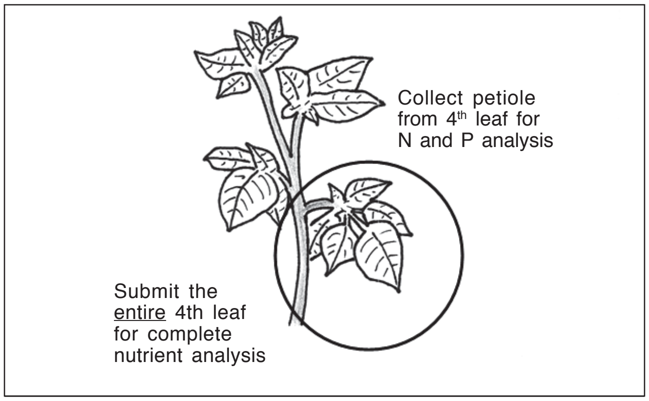

Figure 2. The entire fourth leaf back from the growing point should be analyzed for total nutrient analysis.

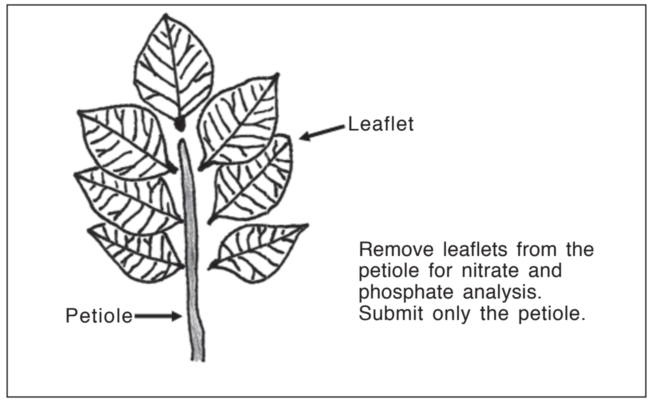

Figure 3. The petiole (with the leaflets removed) taken from the fourth leaf is analyzed for petiole nitrate and P monitoring.

elements moving through the plant at the time of sampling. The petiole nitrate concentrations will be highest during the early stages of growth and decrease through the season. Optimal nitrate concentrations vary depending on varietal and regional (e.g. soil, climate, season) differences. A local crop consultant should be used for interpretation of the results of the petiole analysis.

Petiole P concentrations are also used to measure the P status during the growing season. Petiole sampling for P should begin at tuber initiation and continue regularly during most of the tuber bulking phase. By tracking P concentrations, producers can predict if it may become a limiting factor during the season and corrective action can be taken before yield-robbing deficiencies occur. ■

Factors to consider for getting the best information from plant analysis

The petiole of the fourth leaf from the top of the plant should be collected. Be consistent through the season.	Usually 30 to 50 petioles should be collected to increase accuracy and provide sufficient material for analysis.
Plants are best sampled every 7 to 10 days beginning 4 weeks after emergence and ending a few weeks before vine kill.	Petioles should be collected at the same time of day for each sampling period when possible.
Samples should be quickly dried and sent immediately to the lab for analysis. Refrigerate samples that are not submitted immediately. Deteriorating samples cannot be used for meaningful analysis.	Leaflets should be stripped off of the petiole at the time of sampling, not in the lab.
Petiole analysis is most useful in establishing trends through the season. A single analysis must be related to the potato stage of growth.	Petioles should be shaken or wiped to remove dust. Quick rinsing may also be required, but excessive washing may remove some soluble nutrients.

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Ref. # 06039

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February 2006