3.4 Field Selection, Soil Management and Fertility

3.4.1 Field Selection (P. Haluschak, C. McKenzie, K. Panchuk)

Field selection is one of the most important contributors to high potato yield and quality. Potatoes are a high-value crop and should only be grown on the best land available. Several factors must be considered before a field is selected for potatoes. Some factors such as drainage and herbicide residues can have a significant impact on yield while other factors, such as soil texture and crop rotation, have a lesser impact.

Crop Rotation

Potatoes must be rotated with other crops to slow the accumulation of diseases and reduce the impact of insects such as Colorado potato and flea beetles. When planning crop rotation two factors must be considered:

1. The length of rotation
2. The rotational crop

The length of time between potato crops is determined by disease and insect levels (Table 3.4-1). A two or three year rotation adequately controls most diseases as well as reduces the population of Colorado potato beetles and flea beetles. Other diseases such as *Verticillium* wilt, require longer rotations. A four-year rotation is strongly recommended. Shorter rotations result in a build-up of soil borne diseases and a condition called early dying. This condition can result in yield losses as high as 30%.

Cereal grains and corn are generally the best to use in the three years between potato crops. However, the decision about which crop to use in rotation must be made considering:

- The similarity of diseases between potatoes and the rotational crop
- Soil conservation (i.e. organic matter, surface cover, trash, etc.)
- The herbicides used in the rotational crop (section 3.4.2 *Herbicide Residues and Re-cropping to Potatoes*)

Table 3.4-1 Crop rotation chart

Previous Crop	Disease Risk	Previous Crop	Disease Risk
Barley	ND	Flax	RR:L2, SP:L1
Oats	ND	Lentils	RR:L2, SP:L1, SD:L3
Fall Rye	ND	Mustard	RR:L2, SP:L1
Spring Rye	ND	Potatoes	SP:H1, VW:H4, EB:H1, RR:H3, SD:L3
Triticale	ND	Canola	RR:L2, SP:L1, SD:L3
Wheat	ND	Soybeans	RR:L2, SP:L1, SD:L3
Winter Wheat	ND	Sugarbeets	RR:L2, SP:L1
Buckwheat	RR:L1, SP:L1	Sunflowers	RR:L2, SP:L1, VW:H4, SD:L3
Canary Seed	ND	Corn	ND
Fababeans	RR:L2, SP:L1, SD:L3	Forage Grasses	ND
Field Beans	RR:L2, SP:L1, SD:L3	Alfalfa	RR:L2, SP:L1, VW:H4
Field Peas	RR:L2, SP:L1, SD:L3	Sweet Clover	RR:L2, SP:L1, VW:H4

Key:

Plant Disease
Probability [1]
No. Of Crop Seasons It Applies To
RR:L2

Plant Disease -- Code/Description

EB	Early Blight
SD	Sclerotinia Disease
SP	Seed Piece Decay
VW	Verticillium Wilt
ND	No Disease
RR	Root Rot

[1] The letters L, M and H denote risk for disease. L and M are low and moderate risk, where the crop is somewhat resistant and receives only slight damage. The probability that damage is likely to occur is less than 25%. With H or high-risk diseases, losses over 25% can occur.

The above example "RR:L2" indicates a low probability of root rot for 2 years.

Weather conditions play an important part in disease development. Most diseases are more severe in wet seasons; however, a few types of root rots are most severe under dry conditions. Very favourable conditions for disease development may cause a disease that is a low risk to become a high risk. Conversely, high-risk diseases may not materialize if conditions are unfavourable for disease development. The disease problems occurring on at least the previous four crops should be taken into consideration when planning a crop rotation. Continuous planting to the same crop can eventually cause low risk disease problems to build up resulting in severe crop losses.

Soil Texture

Mineral particles in soil are grouped into sand (2 - 0.05 mm in diameter), silt (0.05 - 0.002 mm) and clay (less than 0.002 mm in diameter). The proportion of sand (S), silt (Si) and clay (C) particles present in a soil is referred to as texture (Figure 3.4-1). The presence of larger particles in soil is recognized as gravel, cobbles or stones. Soil texture strongly influences the infiltration of water, the ability of the soil to retain moisture (water holding capacity), its general level of fertility, the tendency to form clods and ease of cultivation. The combination of similar textural classes forms textural groups (Table 3.4-2).

Well-drained soils with loamy sand to sandy loam textures are considered most suitable for potato production. These soils have an adequate capacity to retain water, provide sufficient aeration for root and tuber development and favourable conditions for planting and harvesting. Sound management practices are required to minimize the potential for wind erosion on these soils.

Farmers are successfully producing potatoes on silt loam, sandy clay loam, silty clay loam and clay loam textural classes (Figure 3.4-1) even though these soils are not considered ideal for potato production. These finer texture soils are prone to water erosion in undulating landscapes, poor to fair internal drainage and soil clod formation if tilled when wet.

A soil that contains a large amount of clay (fine textured soil with more than 35% clay) becomes sticky when wet and lumpy when dry. If this soil is too dry at harvest, it is difficult to separate the soil clods (aggregates) from the potatoes. Tubers harvested from a wet clay soil will also require washing to remove soil particles. These soils are not considered suitable for commercial potato production.

Figure 3.4-1 Diagram showing the percentages of clay, silt and sand in the main soil textural classes (Courtesy of Manitoba Agriculture and Food).

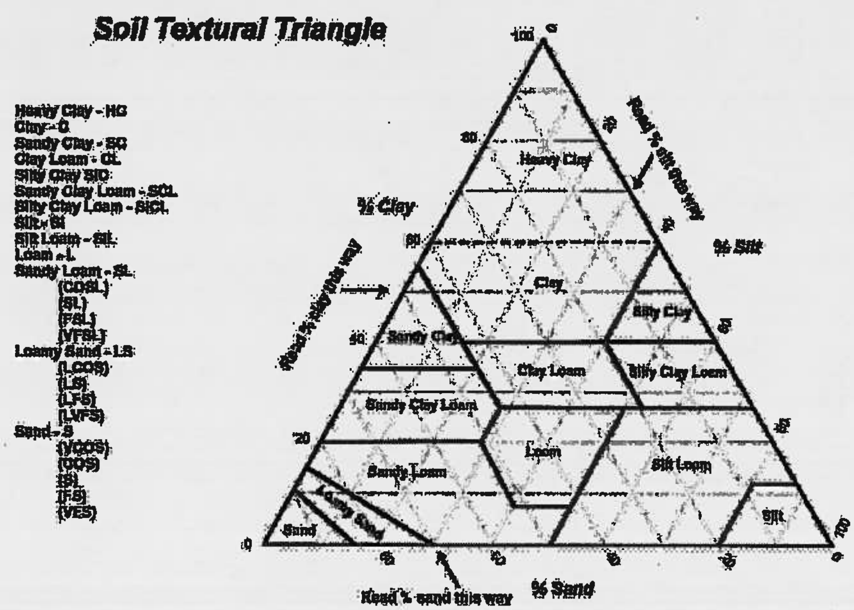


Table 3.4-2 Soil Textural Groups, Classes and Symbols.

Texture Group		Texture Class	Texture Class Symbol
Very Coarse	Light	Sand	S
Coarse	↑	Loamy Sand	LS
Moderately Coarse		Sandy Loam	SL
Medium		Loam	L
		Silt loam	SiL
		Silt	Si
		Sandy clay loam	SCL
		Clay loam	CL
		Silty clay loam	SiCL
Fine		Sandy clay	SC
		Silty clay	SiC
	↓	Clay	C
Very Fine	Heavy	Heavy clay (>60 % clay)	HC

Topography

Topography refers to the percent slope and the pattern or frequency of slopes in different directions in a field. The steeper the slope, the less suitable the field is for potato production. Surface runoff occurs when the amount of water from rainfall or an irrigation application exceeds the rate of infiltration, which is strongly influenced by soil texture. The risk of soil loss is proportional to the length of the slope and the severity of the grade. Medium and fine textured soils are most susceptible to water erosion in sloping landscapes.

Soil Salinity

Salinity refers to the presence of water-soluble salts in soil. Saline refers to a soil condition where water-soluble salts are present in sufficient amounts to affect crop growth. Salinity is measured as the electrical conductivity (EC) and is expressed as deciSiemens/metre (dS/m) or microSiemens/centimetre. The accepted standard is dS/m, however all units of measure are equal. Salinity levels range from less than 4 (non-saline), 4-8 (slightly saline), 8-15 moderately saline and >15 strongly saline. Soils with a reading of less than 4 are most suitable for potatoes. On moderately saline soils, growth and yield of potatoes can be reduced. Leaves may be darker and have burned edges. Plants growing in saline soil are unable to draw water and nutrients, particularly phosphorus, from the soil.

Moderate salinity will reduce growth and yield of potatoes.

Potato production plays a role in soil salinization. The addition of high mounts of irrigation water and fertilizer add significant quantities of salt to the soil. Early detection of salt-affected areas is critical in preventing crop damage or an increase in salinity. A field assessment determining the degree of salinity can be accomplished by soil sampling and analysis or by mapping with an EM38 electromagnetic induction meter. If salinity is a concern, assessments should be conducted every 5 years to determine if salinity is increasing over time. If salinity is detected, growers should implement appropriate water management and cropping practice strategies to improve the productivity of the soil. Prairie Farm Rehabilitation Administration and private soil laboratories provides these service.

Soil pH

Soil reaction, or pH, refers to the degree of acidity or alkalinity. A pH between 7.1 and 14 indicates an alkaline condition, a higher pH value indicating a greater alkalinity. A pH less than 7.0 indicates acidity and the lower the pH the greater the acidity. Most nutrients are readily available in soils with a pH range of 6 to 7, with a decrease in availability at soil pH above or below this range. Strongly acid soils have low extractable calcium and magnesium, a high solubility of aluminium, iron, and boron, and a low solubility of molybdenum. At the other extreme are alkaline soils. Calcium, magnesium and molybdenum are abundant in these soils with little or no toxic aluminium. Phosphorous availability may be greatly reduced at both very low and very high pH values due to phosphate fixation.

Soils below pH 5.2 (slightly acid) and above 8.3 (slightly alkaline) are not recommended for potatoes.

Soil Organic Matter
Organic matter is derived from the residues of decaying organisms such as plants, animals, insects and microorganisms. Organic matter is a very important component of soil that stores and supplies plant nutrients, holds soil particles together, improves tilth and reduces the risk of erosion. Organic matter increases soil porosity and promotes water infiltration. To maintain organic matter, the rate of addition of crop residues must equal the rate of decomposition. Continuous production of row crops such as potatoes, beans or sugar beets usually results in a rapid decline of soil organic matter because the total amount of crop residue returned to the soil is low. The level of organic matter in the soil can be maintained by crop rotations that include perennial forage crops, by adding manure, or by the production of cereal crops where residues are not removed and minimum tillage is practised.

Soil Compaction
Heavy equipment traffic and excessive tillage cause soil compaction. Soil compaction can be identified by the following symptoms:

- Excessive clod formation
- Slow water infiltration, especially in wheel tracks
- Distorted root and tuber growth and premature wilting from shallow rooting

Potatoes are sensitive to the physical condition of the soil. Dense or compacted soil interferes with root penetration as well as water and nutrient uptake. The plant will display symptoms of stress and the yield can be reduced. Compacted soil zones can be identified by carefully inspecting root growth patterns and soil texture in a 3-foot (0.9 m) deep trench.

Minimize compaction by reducing the amount of traffic or weight in the field. Avoid unnecessary vehicle traffic, tillage or hilling. The effect of compaction can be reduced by the use of tillage equipment that loosens soil to approximately 14 inches (35 cm) without inversion of soil layers. Subsoil tillage is expensive because of the high capital and operating costs of the equipment. A potato grower should confirm that compaction is causing production problems before investing in sub-soiling equipment.

Soil Drainage
Soil drainage refers to the ability of water to flow downward through soil. Well-drained soils have sufficient surface runoff and/or downward movement of water through the soil to result in relatively short periods of saturation. Poorly drained soils have a greater frequency and duration when the soils are saturated in all or part of the root zone. Soil drainage may be influenced by topography, uniformity of soil materials, proximity to the water table and climate.

Excessive water in the soil limits the free movement of the oxygen necessary for healthy root and tuber development. Excessive soil moisture increases the incidence of fungal diseases, and delays spring tillage, planting and harvesting. In extreme cases, excessive soil moisture causes tuber rot leading to the loss of the entire crop. Improved surface and sub-surface drainage can reduce the effect of excessive moisture conditions in imperfectly and poorly drained soils.

Stoniness
Soils that are free of stones or coarse fragments are most suitable for potato production. Factors such as size and abundance of stones must be considered when assessing a field for potato production. Large stones and boulders in a field make tillage difficult and can damage harvest equipment. Stones increase the chance of potato bruising during harvest. Stones cause a problem in seed production if they get into the cutter.

3.4.2 Herbicide Residues and Re-cropping to Potatoes (B. Geisel, C. Neeser)

Herbicide residues from previous crops grown in rotation with potatoes can affect yield and tuber quality factors such as size, shape and specific gravity (Figures 3.4-2, 3.4-3 and 3.4-4). The vigour of seed produced from fields with an herbicide residue can also be negatively impacted. The herbicide residue is concentrated in the tuber resulting in poor seed performance. Herbicides that could potentially harm potatoes are listed in Table 3.4-3.

Figure 3.4-2 Damage to foliage caused by herbicide residue in the soil (Courtesy of Gaia Consulting Limited)

All farmers should keep detailed records of herbicide use for each field. When leasing or purchasing new land, review the field history for potential herbicide residues.

Cultural and environmental factors, as well as the properties of the herbicide, influence the persistence of herbicide residues in the soil. These factors (discussed below) are highly variable between fields and growing seasons. Soil texture and moisture are the two most important factors affecting the re-cropping interval.

Organic Matter, Soil Texture and Moisture
The effect of soil organic matter, texture, moisture and microbial activity on herbicide residue is interrelated. Sandy soils have a lower percentage of organic matter and soil moisture, whereas clay soils have a higher percentage of organic matter and soil moisture. The interval between the application of the herbicides in Table 3.4-3 and re-cropping to potatoes is shorter in loams than sands because 1) finer textured soils have more moisture, which increases microbial activity (see below) and 2) herbicide residues bind to organic matter and clay particles in loams, causing them to be less biologically active.

Microbial Activity
Soils with a higher organic matter and clay content tend to have a higher moisture holding capacity. Generally, the population of soil microbial flora and fauna is larger and more active in soils with a higher soil moisture level, organic content and temperature. The breakdown of herbicide residues are accelerated in situations where microbial populations flourish.

Precipitation and Irrigation
The amount and distribution of moisture (precipitation plus irrigation) received during the growing season(s) between the herbicide application and re-cropping to potatoes is the most important factor determining the rate of residue degradation. Degradation is accelerated in soils with high moisture content. Higher precipitation and/or irrigation amounts increase available soil moisture, which in turn increases soil microbial activity and the rate of herbicide breakdown.

Farmers should be very cautious if the growing season(s) following the application of an herbicide known to cause injury received:

- below average precipitation, or
- average to above average precipitation, but poor seasonal distribution causing short periods of drought.

Either of these situations will prolong the persistence of herbicide residues.

Figure 3.4-3 Damage to roots and stolon caused by herbicide residue in the soil (Courtesy of Gaia Consulting Limited)

Soil pH
Degradation of residues by hydrolysis is highly pH dependent for some herbicides (i.e. sulfonylureas). A pH less than 7.0 will accelerate sulfonylurea herbicide degradation by hydrolysis in conjunction with microbial activity and should be considered in estimating the re-cropping interval. The effect of pH is minor compared to factors such as soil texture and precipitation/irrigation.

Chemical Application
The timing of chemical application, the rate at which the chemical was applied, whether any overlaps occurred during spraying and whether chemicals from the same family group were applied in consecutive years are all important factors which will influence residue persistence.

Applying herbicides later in the growing season (mid – late June) will increase the risk of herbicide damage. When an herbicide is applied late in the season, soil microbes have less time for chemical degradation before freeze-up, particularly under rain-fed crop production.

Herbicide labels often recommend different application rates to control different weed species or levels of infestation. Applying at the higher rate will lengthen the safe re-cropping interval.

Overlaps of herbicide applications at the end of the sprayer boom or at headlands and "spot" spraying of weed patches with higher than recommended label rates will increase herbicide persistence. This results in a greater risk when re-cropping to potatoes.

Applying herbicides from the same chemical family in consecutive years also increase the risk of residue damage when re-cropping to potatoes.

Figure 3.4-4 Misshapen tuber and hollow heart caused by herbicide residue in the soil (Courtesy of Gaia Consulting Limited)

Definitions of Terms Used in Table 3.4-3 List of Herbicides with Potato Re-cropping Restrictions

Re-cropping Interval refers to the length of time between the application of the herbicide and re-cropping to potatoes. One year after application refers to one cropping year. For example if an herbicide was applied in 2000 and the recommendation is to not re-crop to potatoes for one year after application then do not re-crop until 2002.

A field bioassay is a test strip of potatoes grown to maturity in a field to determine whether herbicide residues will affect a crop. For example, 10 months after a particular herbicide was applied, a test strip of potatoes could be grown to determine whether potato yield and/or grade will be affected 22 months after initial herbicide application.

Select an area of the field that mostly closely approximates the soil conditions of the entire field. Test strips should be planted perpendicular to the direction in which the site was sprayed using standard planting equipment and following normal cultivation practices. Test strips should be of sufficient length to transect several spray swaths and should be at least one planter width wide. Insects and foliar diseases, such as late blight, must be controlled in order to accurately assess the affect of residues on yield and grade. Reliability of the bioassay results will increase with the number and length of test strips planted. The test strips should be examined for possible stand reductions and other symptoms of injury such as reductions in plant vigour, yield and grade. If any injury, stand reduction or yield reduction occurs, do not plant potatoes until another bioassay is conducted the following growing season. It should be noted that yield losses within a test strip might not be measurable unless the yield can be compared to an untreated area adjacent to the treated test strip.

A laboratory bioassay is the growing of plants in a greenhouse or growth chamber to determine if herbicide injury will occur. Soil samples are collected from a field suspected of having an herbicide residue and submitted to a laboratory for a bioassay test. The lab will grow a species of plant known to be sensitive to a specific herbicide or class of herbicides in the sample soil, along with the crop to be planted. If injury occurs to the test bioassay plants, then the potential exists for significant field crop injury. Contact the Alberta Research Council for details regarding soil sampling procedure and prices:

Alberta Research Council
Crop & Plant Management
Hwy 16A & 75 Street
Vegreville, AB
T9C 1T4
Contacts: Harold Feddema at (780) 632-8238 or
Sandi Checkel at (780) 632-8217
Website:
http://www.agric.gov.ab.ca/agdex/600/609-1.html

Table 3.4-3 List of herbicides with potato re-cropping restrictions[2].

Trade Name - Manufacturer	Group	Active Ingredient	Potato Re-cropping Restriction
Amitrol 240 – Nufarm	11	amitrole	Residues may affect crops for 8 months following application.
Atrazine - Syngenta Laddok - BASF Primextra – Syngenta	5	atrazine	Sensitive crops such as potatoes may be affected 22 <u>OR MORE</u> months after application.
Curtail M - Dow AgroSciences Prestige - Dow AgroSciences Prevail - Dow AgroSciences Eclipse – Dow AgroSciences FlaxMax Ultra – BASF	4	clopyralid + MCPA	Do not grow potatoes until 22 months after application.
Lontrel – Dow AgroScience	4	clopyralid	Do not sow potatoes into fields treated with Lontrel until the third growing season after application.
Banvel II - BASF Dyvel II – BASF Dyvel DS – BASF	4	dicamba	Do not grow potatoes until 22 months following an application if greater than 240 g/acre active or if applications are made after September 1 or if dry weather persists after application.
Muster – Dupont Muster Gold – Dupont	2	ethametsulfuron methyl	Do not grow potatoes until a bioassay is conducted at 22 months after application.
Accent – Dupont	2	nicosulfuron	Do not grow potatoes until a field bioassay is performed.
Amber – Syngenta Unity – Aventis	2, 6	triasulfuron	Note: Not for use in Manitoba. In other provinces do not grow potatoes until a field bioassay is performed.
Velpar – Dupont	5	hexazinone	Insufficient information available. Velpar residues will persist for 2 or more years after application. Do not grow potatoes until a field bioassay is performed.
Attain – Dow AgroSciences	4	fluroxypyr	Do not grow potatoes until 22 months after application.
Assert – BASF	2	imazamethabenz	Do not grow potatoes until a field bioassay is performed.
Odyssey – BASF	2	imazamox & imazethapyr	Do not grow potatoes until a field bioassay is performed.
Pursuit – BASF	2	imazethapyr	Do not grow potatoes until a field bioassay is performed.
Ally Toss-N-Go - Dupont Escort – Dupont	2	metsulfuron methyl	<u>DO NOT APPLY</u> on farms where potatoes are included in the rotation.
Tordon 202C- Dow AgroSciences	4	picloram	<u>DO NOT APPLY</u> on farms where potatoes are included in the rotation.
Accord – BASF	4	quinclorac	<u>DO NOT APPLY</u> on farms where potatoes are included in the rotation.
Princep - Syngenta Simazine - United Agra Products	5	simazine	Do not sow treated field to any crop until 22 months after application.
Sundance – Monsanto Anthem – Monsanto	2	sulfosulfuron	Sundance – For use in Manitoba only. Only apply on soils with greater than 4% organic matter. Allow at least 22 months following application and conduct a field bioassay prior to planting. Anthem – For use on Brown and Dark Brown Soils of Saskatchewan only. Allow at least 22 months following application and conduct a field bioassay prior to planting.
Frontline – Dow AgroSciences Spectrum – Dow AgroSciences	2, 4	florasulam	Do not grow potatoes until a field bioassay is performed.
Reflex – Syngenta	14	fomesafen	This product is registered for use in the Red River Valley of Manitoba only. Do not grow potatoes until a field bioassay is performed.
K2 - Dupont	2	thifensulfuron methyl + tribenuron methyl	Do not grow potatoes until a field bioassay is performed.

[2] The above list may be incomplete because of the registration of new herbicides since this document was published.

Consult with the chemical manufacturers label before making re-cropping decisions.

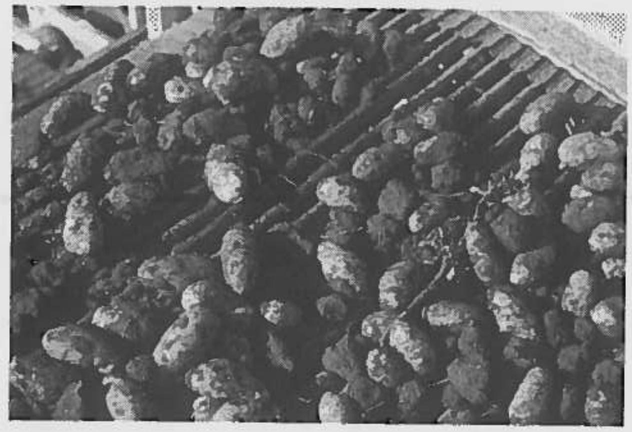
3.4.3 Field Preparation (B. Geisel, L. Delanoy)

Heavy equipment traffic and excessive tillage cause soil compaction, which reduces potato yield and quality (see *Soil Compaction* in section 3.4.1 *Field Selection*). Minimize compaction by reducing the amount of traffic or weight in the field. Do not carry out unnecessarily tillage operations.

Potato producers use a wide range of tillage equipment and techniques to prepare the potato seed bed. The variation in tillage practices results from the wide range of soil types used in potato production and the variety of tillage implements available for soil preparation. Regardless of the tillage system used, it must meet the following criteria:

- Incorporate trash – A balance must be maintained between incorporating an adequate amount of crop trash to facilitate planting while maintaining sufficient soil trash cover to prevent wind erosion. Crop residue must be incorporated into the soil to allow for trouble free planting. The amount of tillage required to do this will depend upon the soil type, the type of crop preceding potatoes and the ability of the planter to perform properly in crop residues. Tillage should not incorporate so much crop residue that the soil is susceptible to wind erosion. See section 3.4.4 *Soil Conservation* for more details regarding soil erosion.
- Produce good tilth without drying out the soil or producing soil clods - Tillage should produce enough loose soil to allow the planter shoe to penetrate to the desired depth and to provide the hiller discs with enough loose soil to construct a proper hill over the seed. Tillage that dries out the soil surface will reduce emergence and vigour. Tillage of finer texture soil types (loams) with the wrong implement or at the wrong soil moisture content will produce clods that remain intact throughout the growing season and into harvest. Soil clods are difficult to separate from the potatoes on the harvester thus reducing efficiency and increasing cost (Figure 3.4-5). Hard dry clods that come into contact with the tubers on the harvester and other handling systems will cause blackspot bruising. For more information on bruise prevention see section 3.8.4 *Bruise Prevention.*
- Herbicide incorporation - Sufficient tillage is required to properly incorporate pre-emergence herbicides. Follow the chemical manufacturers' instructions regarding the tillage method required for herbicide incorporation.

Figure 3.4-5 Soil clods on conveyor (Courtesy of Gaia Consulting Limited)



Field preparation should be performed in as few operations as possible. Excessive tillage will increase the cost of production, the likelihood of wind erosion and the amount of soil compaction. Below is a short description of three common tillage methods used on the Prairies.

Conventional

Operations such as deep tillage or discing are performed in the fall and cultivation is performed prior to planting in the spring.

Advantages:

- Inexpensive – Low capital and operating costs
- High capacity – 15-25 acres/hour (6-10 ha/hr) depending upon tractor speed and width of implement
- Preserves surface trash depending upon number of operations and shovel design

Disadvantages:

- Can produce soil clods, depending upon soil conditions at the time of tillage

Rotary Power Cultivator

In Manitoba and Saskatchewan, producers growing potatoes on loam and clay loam soils use conventional tillage (deep tiller or double disc) in the fall. In the spring, a single pass with a rotary power cultivator prepares the soil before planting (Figure 3.4-6). The rotary cultivator is a power cultivator that stirs the soil laterally rather than mixing the soil vertically like a rotovator.

Advantages:

- Clod free soil bed
- Preserves surface trash
- Preserves moisture, especially important in rain-fed production

Disadvantages
- Low capacity – 5-7 acres/hour (2-2.8 ha/hr) with a 20-foot (6 m) implement depending upon soil conditions and texture
- Costly – High capital and operating expenses
- Poor weed control – has a tendency to transplant rather than destroy weeds

Figure 3.4-6 Rotary power cultivator (Courtesy of Gaia Consulting Limited)

Fall Bedding and Reservoir Tillage

A fall bedding and reservoir tillage (diking) implement performs both the tillage and hilling operations. In the fall prior to spring planting of potatoes, the field is tilled with a deep tiller or a double disc. Next, deep subsoil tillage is performed, hills are constructed and reservoir dikes or depressions are formed between the rows (Figures 3.4-7 and 3.4-8). The reservoirs capture water from melting snow and increase soil moisture. In spite of the aggressive fall tillage, surface trash cover is preserved, reducing the potential for wind erosion. In the spring, the hills are packed with rolling wire baskets to break up soil clods that survive the freezing and thawing cycles over the winter, the hills are reshaped and the reservoirs are removed. The potatoes are planted directly into the pre-formed hills. After planting, the final hilling is carried out and new reservoirs are formed between the rows.

Advantages:
- High Capacity – 8-11 ac/hr (3-4.5 ha/hr) in fall, 15 ac/hr (6 ha/hr) in spring
- Hills warm up faster in the spring
- Increased water retention
- Reduces run-off and drown-out in low areas as a result of precipitation or irrigation
- More even moisture between high and low areas of the field
- Clod free soil preparation
- Preserves soil trash

Disadvantages:
- Costly – high capital cost
- Requires a large tractor (>300 h.p.) in the fall

Figure 3.4-7 Fall bedding and reservoir tillage implement (Courtesy of Gaia Consulting Limited)

Figure 3.4-8 Reservoirs constructed in the fall. (Courtesy of Gaia Consulting Limited)

3.4.4 Soil Conservation (B. Geisel, B. Hunt)

Soil Erosion

Wind and water erosion resulting in serious soil losses (Figure 3.4-9) can be a problem on the prairies due to a combination of climate, soil type, growth characteristics of the potato plant and management practices used in potato production:

- Most potato producing areas, especially southern Alberta, experience high winds when the fields are exposed and vulnerable to erosion.
- Potatoes are usually grown on sand or sandy loam soils, which are susceptible to wind erosion.
- The risk of wind erosion is greater when planting light textured soils to potatoes rather than cereals. Potatoes do not emerge from the soil for 3 weeks after planting and it takes an additional 2 - 3 weeks before there is sufficient vegetative growth to prevent erosion.
- Tillage, crop rotation and harvest practices used in potato production can leave fields without adequate crop trash cover for many months of the year. In the fall and spring prior to potatoes, some crop residue must be incorporated into the soil to allow for trouble free planting. Often there is too little trash cover remaining to prevent erosion. The potato harvest is similar to an aggressive tillage operation, which disturbs the soil, leaving little crop residue cover to prevent erosion.

Figure 3.4-9 Soil erosion from a potato field without adequate crop residue cover (Courtesy of Gaia Consulting Limited)

Soil formation is a natural and ongoing process, but if wind erosion is visible, soil losses are greater than the rate of soil formation. One storm that removes a 1/4 inch (7 mm) layer of soil results in the loss of 44 tons per acre (40 tonnes per ha) of top soil and will require at least 10 years to be replenished; assuming no further erosion occurs.

The loss of topsoil through wind erosion reduces yield potential by negatively affecting fertility, physical structure, tilth, permeability and water holding capacity. In addition, eroded soil from agricultural land can fill ditches reducing the effectiveness of drainage systems. In some jurisdictions, like Alberta, a fine can be imposed if a farmer fails to control erosion, and the expense of cleaning out the drainage or irrigation ditches is the responsibility of the landowner.

The erosion prevention practices listed below are discussed under three headings:

1. Potato field preparation and planting
2. Potato harvest and post-harvest
3. Long-term strategies

Field Preparation and Planting

In the fall, the combine should be outfitted with a straw and chaff spreader to distribute residue evenly across the field. Additional flailing or harrowing may be necessary to help chop and distribute the crop residue. Even distribution of the straw allows the farmer to use fewer and less aggressive tillage operations in preparing the field for planting the following spring. Fewer and less aggressive tillage operations preserve more of the trash cover reducing the potential for erosion. Tillage of light textured soils, where it is relatively easy to incorporate crop residues, should be delayed until spring. If fall tillage of a light-textured soil is carried out, it should result in no less than 65% of the ground covered with crop residue (Figure 3.4-10). The amount of residue buried by various tillage implements is shown in Table 3.4-4.

Table 3.4-4 Effect of different types of tillage implements on residue cover.

Implement	Straw Buried With Each Pass*
Field cultivator	10%-20%
Heavy duty cultivator	20%-30%
One-way disc	40%-50%
Heavy tandem or offset	35%-65%
* Residue reduction will vary depending on depth of operation, shovel type and speed of travel.	

In Alberta, fall bedding and reservoir tillage are commonly used to prepare fields for planting to potatoes the following spring. The equipment used to form the beds preserves sufficient trash cover to limit erosion. Orienting the beds at right angles to the prevailing winds reduces the impact of wind on soil erosion. The construction of reservoirs between beds prevents soil loss from water erosion caused by snowmelt and heavy spring rains.

Figure 3.4-10 Field with 65% of the soil surface covered with cereal residue (Courtesy of Gaia Consulting Limited).

In the spring, a minimum amount of tillage should be used in preparing the soil so that trash cover is maintained. The producer should choose tillage methods that incorporate just enough crop residues to allow for trouble free planting, but preserve sufficient cover to prevent erosion.

Where practical plant potatoes rows at right angles to the prevailing winds to reduce drifting in the spring. In Alberta, rows may be oriented north/south as a method of frost protection. In the north/south orientation, both sides of the hill receive equal amounts of sunlight maximizing the solar radiation captured during the day.

Strip cropping (alternating strips of potatoes with a crop less prone to erosion) can be planted to reduce the unsheltered width in erosion-susceptible fields. Crop strips should be perpendicular to the prevailing winds in May. The width of strips will depend on the size of equipment used in cropping and the susceptibility of the soil to wind erosion. Recommended strip widths vary from 76 feet (25 metres) in loamy sands to 305 feet (100 metres) in silty clay loams.

Annual crops such as corn and sunflowers can be used as wind barriers to protect the soil after harvest. Properly spaced annual barriers also trap and evenly distribute snow for effective winter cover. Annual barriers should be planted closer together than tree shelterbelts because they offer less protection. The proper width and distance between annual barriers is shown in Table 3.4-5. Plant the barriers using the seeding rates that would normally be used for crop production.

Table 3.4-5 Recommendations for planting annual barriers.

Crop	Width		Barrier Spacing		Seeding Date
	metres	Feet	metres	feet	
Corn, Sunflower	1.5 - 3.5	(5 - 12)	18	(60)	normal seeding date

Harvest
In potato production areas where there are no stones, the potato harvester should be equipped with a vine shredder, which eliminates the need for tillage to anchor potato vines. Potato vines that are not anchored in the soil can blow off the field and accumulate in ditches, fences and shelterbelts. Shredding provides even distribution of chopped vine residue improving ground cover and reducing erosion potential (Figure 3.4-11). If the harvester is not equipped with a vine chopper, a tandem disc or a chisel cultivator equipped with coulters should be used to anchor, but not completely incorporate the vines.

Figure 3.4-11 Shredded potato vines after harvest (Courtesy of Gaia Consulting Limited).

Seeding an annual cereal after the potato harvest will provide good protection from wind erosion until a new crop is established the next season. The success of this method is dependant upon the harvest date and the growing conditions after harvest. The chances of establishing a cover crop after September 15th to 20th are poor. The fall cover crop can be seeded by air just prior to harvest or with a conventional seeder just after harvest. The emergence is less even when seeding by air. In Alberta, irrigation may be required to obtain even emergence of the cover crop. Some farmers choose to use wheat, oats or barley as a cover crop because the crop will winter kill and not interfere with future cropping plans. When choosing an annual cover crop, keep in mind that you will want a crop that germinates and establishes quickly. The malting varieties of barley are well suited to quick establishment. Many farmers will use a higher seeding rate to ensure a good ground cover in the field, i.e. barley at 1.5 bu/acre (62 kg/ha). Others choose to seed fall rye or winter wheat as a cover crop. A non-selective herbicide is applied the next spring to control the rye or wheat, or the crop can be left to mature. Manure applied to the soil surface at 30-40 tons/ac (70-90 tonnes/ha) will reduce drifting. Researchers have demonstrated a link between high raw manure applications and an increase in the incidence of common scab, but this affect is rare. The nutrient content of the manure should be taken into account when planning commercial fertilizer applications the following season.

Seeding an annual cereal after the potato harvest will provide good protection from wind erosion until a new crop is established the next season.

Mulch can provide the same erosion control benefits as a well-established cover crop or well managed crop stubble. Broadcasting cereal straw with a round bale shredder onto the surface of erosion susceptible areas of the field will reduce wind erosion and add organic matter. The application of 1 to 3 tons/acre (2 to 6 tonnes/ha) will provide 65% ground cover, which is sufficient to prevent erosion.

Long-term Erosion Control Strategies
Fields susceptible to wind erosion can benefit from a systematic planting of shelterbelts. Trees should be planted perpendicular to the prevailing winds that occur in May. The prevailing winds at this time tend to have the highest velocity and fields have the least protective cover. A distance of approximately 660 feet (200 metres) between tree rows is recom-mended. The distance between green ash trees planted in the sheltebelt should be 6 to 8 feet (2.0 to 2.4 m) apart.

Fields susceptible to wind erosion can benefit from a systematic planting of shelterbelts. Trees should be planted perpendicular to the prevailing winds that occur in May.

In Alberta, there is a growing trend to reduce a soil's susceptibility to wind erosion through the build up of organic matter in the soil. The addition of composted manure on an annual basis at rates of 2.5 to 5.5 tons/ac (7 to 12 tonnes/ha) is a safe method of amending the organic matter and reducing the soil's susceptibility to erosion over time. Planting cereal and forage crops, which produce large amounts of organic matter, in rotation with potatoes helps reduce soil erosion. Care must be taken when including bean and canola crops in rotation with potatoes, as neither provides much crop residue.

For assistance with soil erosion problems, contact your provincial soil and conservation specialists or Prairie Farm Rehabilitation Administration (PFRA).

3.4.5 Fertility and Fertilizers (D. Waterer, J. Heard)

Potatoes managed for maximum productivity exert a heavy demand on soil fertility. Significant quantities of nutrients are removed from the field in the harvested tubers (Table 3.4-6), while additional nutrients are lost through erosion and leaching.

Attention should be paid to nitrogen management because of its influence on crop productivity, quality and the environment. Nitrogen management refers to placement methods, timing of applications and assessment of N status as well as N application rates.

Attention should be paid to nitrogen management because of its influence on crop productivity, quality and the environment.

Nitrogen placement and time of application
The relative efficiency of any nitrogen application varies depending on soil moisture, soil temperature, soil type, weed and crop growth. In Table 3.4.7 average efficiency of times and method of N application are compared to spring broadcast, which is given a value of 100.

Table 3.4-6 Nutrient uptake by potatoes - lbs (kg) of nutrient for every ton of crop harvested

	Nitrogen	P2O5	K2O	S
Tubers	6.5[1] (5.7)	1.1 - 3.5 (1.0 – 3.0)	9.6 - 11.2 (8.5 – 9.9)	0.6 (7.6)
Vines	3.9 (3.5)	0.7 - 1.9 (0.6 – 1.7)	4.6 - 18.3 (4.1 – 16.2)	0.3 (0.26)
Total	10.4 (9.2)	1.8 - 5.4 (1.6 – 4.8)	14.2 - 29.5 (12.6 – 26.0)	0.9 (0.8)

[1] Range in nutrient removal reflects typical variations in tissue nutrient concentrations.

Nitrogen Nutrition and Management
Of all the essential nutrients, nitrogen most often limits potato production. Consequences and symptoms of nitrogen deficiency in the crop are:

- Stunted growth
- Premature death of vines
- Poor yields
- Increased susceptibility to diseases such as early blight and *Verticillium* wilt

Likewise there are consequences of excess nitrogen:

- Negative impact on environmental – particularly due to nitrate leaching below the root zone
- Excessive vine growth, which can interfere with harvest
- Delayed tuber set leading to poor yields in regions with a limited growing season.
- More deformed tubers and hollow heart
- Tubers are physiologically immature at harvest, resulting in more harvest damage, poor storability and processing quality
- Low specific gravity

Table 3.4-7 Average efficiency of times and method of N application

Time and method	Relative efficiency value
Spring broadcast	100
Spring banded	120
Fall broadcast	80
Fall banded	100

Efficiency values are based on nitrogen uptake by plants. Broadcast values assume urea-based nitrogen fertilizers are incorporated to minimize losses through volatilization of ammonia. This incorporation step is critical on soils with a high pH or which contain free lime near the surface, particularly when rainfall is not received following application.

Banding refers to applying fertilizer in-furrow or in bands below and to the side of the seed piece. Banding the N fertilizer restricts contact between the fertilizer and the soil. This delays nitrification of ammonia forms of N fertilizer, thereby reducing losses of nitrate-N. Banding also reduces loss of N due to contact with crop residues or immobilization.

Banding the N fertilizer restricts contact between the fertilizer and the soil, thereby reducing losses of nitrate-N.

Excessive rates of banded N can impair sprouting and reduce plant emergence. In-furrow applications of N while seeding, should not exceed 50 lbs N/ac (45 kg N/ha) in the urea form, while no more than 80 lbs N/ac (70 kg N/ha) nitrogen in urea form should be applied as a sideband application. Fertilizer bands established prior to seeding should not be disturbed prior to or during the seeding operation to optimise N efficiency.

Nitrogen losses due to leaching, denitrification, immobilization and weed growth are generally higher for fall-applied than for spring-applied N. These losses are further increased if the N is applied too early in the fall (prior to mid-September) or when soil temperature at the 4" (10 cm) depth is greater than 41°F (5°C). For these reasons, nitrogen should be applied in spring or in-season. In dry soil, banding N in late fall is as effective as spring banding.

Nitrogen losses due to leaching, denitrification, immobilization and weed growth are generally higher for fall-applied than for spring-applied N.

Nitrogen is relatively mobile in moist soil and therefore need not be applied near the plant to be effectively used. However, surface application or shallow incorporation can result in reduced uptake if the seedbed remains dry during the early growing season. Nitrogen applied in a band is more effective than surface applications when the soil is dry.

Split applications for nitrogen

Splitting the total N application is an effective strategy to increase fertilizer use efficiency while limiting nitrate leaching. Part of the crop's total N requirement is supplied prior to planting or is banded at planting. This initial application of N is supplemented with one or more applications of N. The first increment of N is usually applied after tuber initiation. Additional later applications may be used if a petiole nitrate analysis indicates a N deficiency.

Several methods are available for applying N after crop emergence.

- The most common method is top-dressing which involves broadcasting granular fertilizer over the growing crop. Ammonium nitrate is the preferred nitrogen source for top-dressing because it does not require incorporation after application. Urea can be top-dressed, but hilling or irrigation must be used to incorporate the fertilizer shortly after application. Liquid N can be dribbled onto the hill at the base of the plants, but it also must be incorporated after application. Care must be taken to avoid contact between the foliage and liquid N, as it will burn the leaves.
- Nitrogen fertilizers may be banded in the soil to the side of the emerged crop row. Delaying banding increases pruning of the roots and may reduce yields.
- Fertigation, which involves the injection of liquid fertilizer into the irrigation water, can be used to apply N and other nutrients throughout the growing season. Liquid urea-ammonium nitrate (28%) is the most common source of N injected into irrigation water. Uniformity of N application depends on the uniformity of water application from the irrigation system. Centre pivot and linear irrigation systems provide the most uniform application of water. Traveling guns and side-wheel roll systems do not distribute water as uniformly over the field as centre pivots or linear systems because of overlaps between moves. These systems should only be used to apply N fertilizer when the wind is very low and no other N application method is available.

Splitting the total N application is an effective strategy to increase fertilizer use efficiency while limiting nitrate leaching.

Nitrogen Assessment

Soil testing to a depth of 24 inches in the spring is critical to planning an effective and efficient N management program. Post harvest soil samples may help growers to select succeeding crops, which will make maximum use of the residual N after the potato crop.

Commercial soil test laboratories will provide N fertilizer recommendations based upon the nitrate soil test. The recommendations may vary with the soil type, the cultivar, end use of the crop, yield goal, the previous cropping and manuring history of the field. Each provincial soil specialist can also provide rate recommendations based on the soil test results.

Nitrogen management based solely on a soil nitrate test is challenging. In intensively cultivated and irrigated potato fields, mineralization of organic matter may add significant amounts of N. Even in relatively fertile soils, leaching or very high plant demand can cause in-season N deficiencies. The nitrogen demand by the crop during tuber bulking may be 2.5 to 3.5 lbs N/ac/day (2.2 to 3.0 kg N/ha/day). Petiole nitrate sampling allows for in-season monitoring of the crop's nutrient status. Collect the 4th petiole from 30 – 50 randomly selected plants throughout the field (Figure 3.4-12). Strip the leaflets from the petiole and keep the sample cool until shipping. Tissue samples are often collected weekly to track changes in nitrate levels, and to plan supplemental fertilizer applications should levels drop below optimum. Producers should follow laboratory instructions on tissue sampling techniques and interpretation of petiole nitrate results.

Soil testing to a depth of 24 inches in the spring is critical to planning an effective and efficient N management program. Petiole nitrate sampling allows for in-season monitoring of the crop's nutrient status.

Critical petiole nitrate-levels decline as the potato crop develops and matures. Generally, petiole nitrate-N levels at tuber bulking are <10,000 ppm = low, 10,000-15,000 ppm = medium, >15,000 ppm = sufficient. (Figure 3.4-13)

Phosphorus

Soil Availability and Plant Uptake

Soil phosphorus (P) occurs in many forms depending on the pH and chemical composition of the soil. Only a small fraction of the total amount of P present in the soil is actually available to the crop within a given growing season, but the supply of available P is constantly replenished from soil reservoirs of less available P. Consequently, soil P levels are usually fairly stable over the course of the growing season and do not change much from year to year unless the field has been heavily fertilized. The roots absorb phosphorus ions dissolved in the soil water. Phosphorus deficiencies can occur even in soils with abundant available P if drought, low temperatures or disease interfere with the phosphorus diffusion to the root through the soil solution or otherwise impair development and function of the roots. Potato plants require an adequate supply of P throughout the growing season to achieve optimum yields. 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 then slows during bulking as the nutrient needs of the developing tubers are met by translocating P from the tops of the plants.

Figure 3.4-12 Diagram showing 4th petiole (Courtesy of Agvise Laboratories)

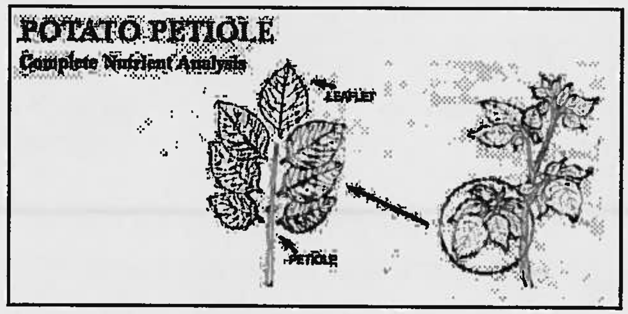
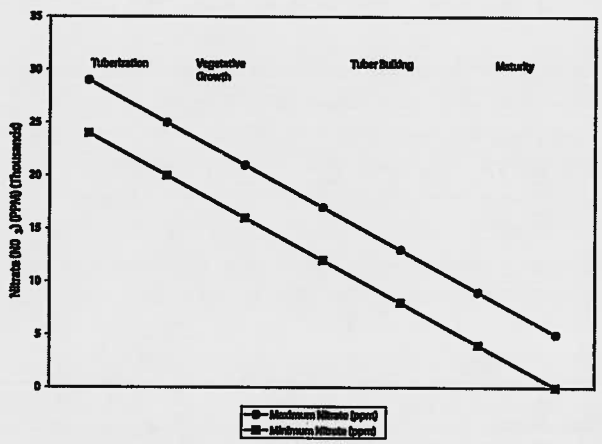


Figure 3.4-13 Target range for petiole nitrate in potato petioles



Phosphorus deficiencies slow growth and reduce yields without producing any obvious changes in the appearance of the crop. Only after P deficiencies have become severe will the crop begin to develop visible signs of P stress - stunted dark green leaves and the edges of the youngest leaves begin to fold downwards. As P deficiencies are difficult to diagnose based on the appearance of the crop, P status should be monitored by tissue testing. Optimum tissue P levels vary from 0.2-0.5%, depending on the crop growth stage (Table 3.4-8).

P Fertilizing Strategies

The P requirements of potatoes are much higher than the P levels typical of most Prairie soils and some type of P fertilizer program is usually required. Phosphorus application programs should be based on the recommendations obtained from fall or spring soil tests (Table 3.4-9). As P fertilizers are relatively expensive and the nutrient is immobile in the soil, the objective of the ideal P fertility program is to raise levels of available soil P in the effective root zone to precisely match the requirements of the crop. Band application of P fertilizer below and to the side of the seed row represents the most efficient means of meeting crop P needs with the minimum amount of P fertilizer. Placing the P fertilizer in a concentrated band adjacent to the developing root system increases the efficiency of fertilizer recovery by the roots while also reducing fixation of the applied P into forms unavailable to the crop. Banding is particularly effective in soils testing low in P or with high P fixing capacity and in situations where growing conditions may interfere with development of a healthy root system. Broadcast/incorporating P fertilizers prior to planting represents a convenient option in soils requiring only limited P amendment.

Band application of P fertilizer below and to the side of the seed row represents the most efficient means of meeting crop P needs with the minimum amount of P fertilizer.

Although P is relatively immobile in soil, timely application of P as a sidedress treatment followed by irrigation or via fertigation with P may be useful if tissue tests indicate the crop is at risk of a P deficiency. This practice is only recommended when there is risk of a yield limiting nutrient deficiency and there are no other application options available. Excess application of P as either fertilizer or manure is economically and environmentally unsound but has little potential to reduce yield or quality.

Potassium

Soil Availability and Plant Uptake

Potassium (K) is supplied to the crop root through diffusion over short distances; hence K is also referred to as a relatively immobile nutrient in soils. Much of the K available to the plant is held on exchange sites on clay or organic matter, which replenishes the soil solution as root uptake of K occurs. Consequently, soil K levels are usually stable over the course of the growing season and from year to year.

Potatoes require abundant soil K, as this nutrient is crucial to metabolic functions such as the movement of sugars from the leaves to the tubers and the subsequent transformation of those sugars into starch. Potassium deficiencies reduce both the yields and quality of the potato crop. 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. Potassium deficiencies typically first show up in the sandier or knoll areas of the field. 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 sheen. Small dead spots resembling the lesions produced by fungal disease may form on the leaves. As visible signs of K deficiency only become apparent once the crop is severely stressed, the K status should be monitored by tissue testing. Optimum tissue K levels vary from 2-5 %, depending on the crop growth stage (Table 3.4-8).

K Fertilizing Strategies

Potassium application programs should be based on the recommendations obtained from fall or spring soil tests (Table 3.4-9). As K fertilizers are relatively inexpensive, many growers opt to add a small amount of K fertilizer to potatoes even in K rich soils. Potassium fertilizer (20-40 lbs/ac [18-35 kg/ha]) applied in a band adjacent to the seed row may provide a jump-start to the emerging potato plants. To avoid salt damage to the crop, the total amount of all actual fertilizer nutrients applied as a band should not exceed 100 lbs /ac (88 lbs/ha). Broadcast/incorporating K fertilizers prior to planting represents the preferred approach in soils requiring more substantial K amendment.

To avoid salt damage to the crop, the total amount of all actual fertilizer nutrients applied as a band should not exceed 100 lbs /ac (88 lbs/ha). Broadcast/incorporating K fertilizers prior to planting represents the preferred approach in soils requiring more substantial K amendment.

Although K is only moderately mobile in the soil, timely application of KNO3 as a sidedress treatment followed by irrigation or via fertigation may be useful if tissue tests indicate the crop is at risk of a K deficiency. This practice is only recommended when there is risk of a yield limiting nutrient deficiency and there are no other application options available.

Muriate of potash (KCl 0-0-60) is the least expensive and most readily available form of K fertilizer. There is some evidence that excessive Cl associated with heavy application of KCl may reduce the specific gravity of the potato crop, but this is rarely an issue on the relatively K-rich Prairie soils.

Micronutrients

Although micronutrients (boron, chlorine, copper, iron, manganese molybdenum and zinc) are only required in relatively small quantities by the potato crop, they are no less important to the health and productivity of the crop than are the other nutrients. Although deficiencies of micronutrients are relatively uncommon in Prairie soils, growers should still have the micronutrient levels in their soil evaluated prior to planting and should confirm the micronutrient status of their crop through tissue testing (Table 3.4-8). The micronutrient needs of the crop may be met through either soil or foliar applications. As micronutrients are relatively expensive and the margins between adequate and excessive supplies are often narrow, growers should exercise caution when utilizing these products. Check strips represent a useful tool for confirming the benefits and cost efficiency of any fertilizer treatment.

As micronutrients are relatively expensive and the margins between adequate and excessive supplies are often narrow, growers should exercise caution when utilizing these products. Check strips represent a useful tool for confirming the benefits and cost efficiency of any fertilizer treatment.

Table 3.4-8 Recommended tissue concentrations of nutrients for potatoes. Check with your soil testing lab or provincial fertility specialist to obtain values appropriate for your production area, soil type, cultivar, management practices and anticipated end-use of the crop.

Nutrient	Recommended Tissue Concentration [1]
Phosphorus	0.2 - 0.5 %
Potassium	2.0 – 5.0 %
Calcium	0.4 – 4.0 %
Sulphur	0.2 - 0.5 %
Magnesium	0.2 - 0.5 %
Boron	15.0 – 40.0 ppm
Manganese	20.0 – 100.0 ppm
Copper	4.0 – 25.0 ppm
Iron	50.0 – 250.0 ppm
Zinc	20.0 – 70.0 ppm

[1] Critical tissue nutrient concentrations vary with growth stage, production

Table 3.4-9 General fertilizer recommendations for nitrogen, phosphorus and potassium for irrigated potatoes. Check with your soil testing lab or provincial fertility specialist to obtain values appropriate for your production area, soil type, cultivar, management practices and anticipated end-use of the crop.

Soil Nutrient Status	lb/acre soil N (0-24")	N fertilizer recommended (lb/acre)[1]	lb/acre soil P (0-6")	P_2O_5 fertilizer recommended (lb/acre)[1,2]	lb/acre soil K (0-6")	K_2O fertilizer recommended (lb/acre)[1]
Low	0-35	130 - 200	0 - 25	90 - 70	0 - 120	240 - 190
Medium	35-55	150-160	25 - 50	70 - 40	120 - 250	190 - 110
High	55-75	120-150	50 - 90	40 - 10	250 - 370	110 - 30
Very High	>75	0-110	> 90	10	> 370	30 - 0

[1] Specific recommendations will vary depending on the site, soil type, cultivar, management practices and anticipated end-use of the crop.

[2] Recommendations for phosphorus fertilizer rates are based on band application. Recommended rates should be doubled if phosphorus fertilizers are broadcast.