Growing Irrigated Potatoes

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Production Considerations

Production of irrigated potatoes requires specialized equipment and a substantial capital investment. Before investing in this enterprise, the following questions must be considered:

- Is your soil type suitable for irrigation?
- Is there an adequate supply of good quality water for irrigation?
- Can a water permit be obtained for the potential irrigable land?
- What potato production and irrigation machinery will have to be purchased?
- Do you have potato production experience? Irrigation experience? If not, do you have potato production or irrigation consulting services available or a business partner with experience?
- Do you know how to market your potatoes (which can include forward contracts, an adequate sales outlet, trucking and transportation, storage, and a potato broker)?
- Have you determined the profitability of the other crops in your irrigated cropping rotation?

Before going into irrigated potato production, you should not only be knowledgeable about the cultural aspects of potato production, but equally knowledgeable about the economic aspects, which include fixed investments, labor and operating capital requirements, price risk, potential annual costs and returns, market grading criteria, storage requirements, delivery expectations and marketing alternatives.

Planting Season

The planting season for potatoes extends from about April 15 to June 15, though planting on light textured soils in southeastern North Dakota may be as early as the first week of April. In general, late varieties used for processing and early maturing varieties for the fresh market should be planted first. Early maturing table varieties destined for storage may be planted in late May or early June.

Varieties

Potato yield response to irrigation will vary depending on whether short season or long season varieties are wanted. In general, the full season varieties will show the greatest response to irrigation. Most varieties that have performed well under dryland conditions also perform well under irrigation. Market demand will generally dictate the selection of a variety or varieties to grow.

There are three types of potatoes grown under irrigation: smooth red skinned varieties (used primarily for the fresh market), smooth white skinned varieties (used in processing; chips and dehydrated products), and russet skinned varieties (used for the fresh market, french fries and dehydrated products). Within each of these types there are early and late maturing varieties.

A desirable characteristic for potatoes used in processing is the percentage of total solids (mostly starch). This trait is variety-dependent and typically ranges from 17% to 23% (Table 1). The percentage of total solids is often one to two points lower under irrigation than under dryland conditions, and may be further reduced by excess nitrogen. The most important varieties for production of french fries are Russet Burbank, which has good yields, high solids, and stores well, and Shepody, which can be harvested earlier with acceptable yield and solids content. Another important processing trait is the percentage of reducing sugars that influence browning during the fry process. NorValley and Snowden are somewhat resistant to the increase in reducing sugars that comes with storage at colder temperatures.

With a high percentage of total solids, good storage characteristics, and appropriate shape, the Russet Burbank variety is the most popular variety grown under irrigation. Currently, it is the industry standard for french fry potatoes. However, other varieties were higher yielding on irrigated potato trials.
Yield Potential

The major advantages of irrigated potato production are higher yields, earlier production and drought protection. Yields of potatoes grown under irrigation in North Dakota have averaged about double that of dryland potatoes.

Irrigated potato variety trials have been conducted on light textured soils (sands and loamy sands) in various areas of North Dakota since 1941. The first trials were begun at the Williston Research Center. From 1975 through 1986, the trials were conducted at the Karlsruhe irrigation site where the 12 year average for all varieties was 294 hundredweight/acre (cwt/ac). Irrigated variety trials have been conducted at the Oakes Research Test Area since 1987 and at the Carrington Research Extension Center since 1989.

Yield results from several common varieties grown at the Oakes Field Trials Site for the 1994, 1995 and 1996 growing seasons are shown in Table 1.

Marketing

It is important to establish a marketing plan before planting potatoes. This may mean contract growing for a processor, an arrangement to sell through a marketing association or broker, or gambling on the open market at the end of the growing season.

The major markets for potatoes are the process potato market, the fresh market and for seed. Seed production is the most technically demanding because of the need to meet rigid disease free standards for certification.

In recent years, the main demand for irrigated potatoes has been for french fries, where processors prefer the Russet Burbank variety. Proper irrigation management can produce a uniform potato shape which is long and consistent in size. Also, the total solids or potato density can be maintained such that high quality french fries can be produced with minimum waste.

A large portion of the potatoes used for processing are grown under contract, which reduces the risk involved in marketing but also limits the possible profit. Without a contract, there is a risk of not finding a market after incurring costs of around $1100/acre. From 1992 to 1997, North Dakota potato prices paid to producers fluctuated from a low of $2.30/cwt in June of 1992 to a high of $7.75/cwt in April and May of 1994. Price fluctuations of this magnitude emphasize the need for managing price risk through some type of forward contract before incurring the large capital investment required for irrigated potato production.

Production and Cultivation Practices

Seed bed preparation before planting will be determined by the previous crop. The soil should be loose at planting with a minimum of preplant tillage.

Seeding Rate and Depth

The amount of seed needed for planting depends on variety, distance between rows, the spacing within rows and the size of the seed pieces (Table 2). Seed pieces should be cut from tubers no larger than 10 ounces for round varieties and 12 ounces for Russet Burbank. Seed pieces cut from smaller tubers are more uniform in size, give better plant stands and usually more tubers per hill.

A healthy 1.5 to 2 ounce seed piece is considered best to establish a vigorous plant. Plants from seed pieces smaller than 1.5 ounces are generally slower to emerge and have less vigor. Small seed pieces are also more likely to decay before the plant becomes established. Seed pieces cut larger than 2 ounces result in higher seed costs with little potential benefit.
Irrigated potatoes can be spaced, within the row, closer than under dryland conditions. Seed spacing is based on varietal characteristics such as tuber-set, resistance to hollow heart, and resistance to the development of misshapen tubers. Wider spacing (10 to 12 inches) is recommended for varieties with heavy tuber-set, smooth tubers, and resistance to development of hollow heart and misshapen tubers. Closer spacing (8 to 10 inches) is recommended for varieties with poor tuber-set to reduce the number of oversized tubers. Hollow heart is caused by excess moisture and conditions that cause rapid tuber growth. Since a potato grows from the inside out, a hollow center can result from this rapid growth, thus the name hollow heart. Close spacing is an effective way to reduce hollow heart.

Generally the center of the seed piece should be planted 2 to 4 inches below field level and covered with 2 to 3 inches of soil. Shallow covering usually results in quicker emergence, less seed decay, less blackleg and less rhizoctonia attacking the sprouts. However, the best seed depth will vary somewhat with soil moisture and temperature. Moist soil with temperatures averaging from 50 to 60 °F favor wound healing in the soil with minimum seed decay. Very deep planting may result in poor wound healing and lead to seed decay, particularly if heavy rains follow planting.

**Table 2.** Quantity of seed potatoes needed to plant an acre of potatoes with different seed piece sizes and spacing (cwt).

<table>
<thead>
<tr>
<th>Distance between rows (inches)</th>
<th>Distance between seed pieces (inches)</th>
<th>1/2 Average Seed Size</th>
<th>1/4 Average Seed Size</th>
<th>2 Average Seed Size</th>
<th>2 1/2 Average Seed Size</th>
</tr>
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<tr>
<td></td>
<td></td>
<td>1/2 ounces (cwt)</td>
<td>1/4 ounces (cwt)</td>
<td>2 ounces (cwt)</td>
<td>2 1/2 ounces (cwt)</td>
</tr>
<tr>
<td>36</td>
<td>8</td>
<td>20.4</td>
<td>23.8</td>
<td>27.2</td>
<td>30.6</td>
</tr>
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</tr>
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<td>8</td>
<td>19.3</td>
<td>22.6</td>
<td>25.8</td>
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<td>12.3</td>
<td>14.3</td>
<td>16.3</td>
<td>18.4</td>
</tr>
</tbody>
</table>

**Growth Stages**

The growth, development and **water requirements** of the potato plant can be divided into the following four stages:

**VEGETATIVE.** After planting, this stage of growth begins when the eyes break dormancy and produce sprouts. This stage has a duration of 15 to 30 days and ends with tuber initiation. Stored soil moisture and spring rains are usually sufficient during this period to provide adequate moisture for proper development. However, soil moisture monitoring should be started soon after emergence. For disease control, irrigation should be avoided between planting and emergence. If the soil is dry prior to planting, irrigate before planting rather than after.

**TUBER INITIATION.** This stage of growth begins when tubers develop at the stolon tips. Approximate duration of this stage is 10 to 14 days. Stored soil and spring moisture supplies are usually adequate during this period however, soil moisture levels should be watched closely because water stress during this period can reduce the number of tubers produced per plant.

**TUBER BULKING.** A constant rate of increase in tuber size and weight occurs during this stage, unless a growth limiting factor is present. This stage can last from 60 to over 90 days, depending on the length of the growing season and presence of pathogens. **Tuber size and quality is closely related to moisture supply in this period.** Research has shown that the total yield of potatoes is most sensitive to water stress during mid-bulking. Mid-bulking occurs three to six weeks after tuber initiation, however, water stress any time during this period will have an effect on the total yield. Tuber growth is retarded by moisture stress and does not resume uniformly when moisture again becomes available. New growth and enlargement will take place at the top end while the other portions of the tuber remain stunted. Thus, especially in some long tuber varieties, constricted areas develop that are related to the stage of tuber growth at the time the moisture stress occurred. Other deficiencies in quality such as growth cracks and knobbiness are also related to moisture stress followed by periods of adequate or surplus moisture.

**MATURATION.** This stage of growth begins with canopy senescence. Older leaves gradually turn brown and die. This condition spreads throughout the vines and leaves eventually resulting in canopy loss. Tuber growth rates are lower than during tuber bulking. Potato plants require less water for tuber bulking during this stage because of reduced transpiration from the dying leaves.
**Weed Control**

Weeds reduce potato yields by competing for water, nutrients and light. Also, certain weed species can cause difficulty in harvesting, release toxins that inhibit crop growth, and harbor insects, diseases or nematodes that may attack potatoes.

An effective weed control program includes environmentally sound cultural, mechanical and chemical weed control methods. Crop rotations, cultivation and the use of different herbicides help avoid the buildup of resistant weed species. Certain herbicide residues from previous years can damage potatoes. Use a planned weed control program and avoid herbicides that will injure or reduce growth of subsequent crops. Always read the pesticide label for information on crop rotations and intervals.

Tillage and herbicides are the two primary means of controlling weeds in potatoes. Cultivators, harrows and rotary hoes are commonly used. The first tillage operation after planting is usually a “blind” cultivation or harrowing before the crop emerges. The number of tillage operations will vary, but three cultivations and two harrowing operations are common.

After emergence, inter-row cultivation is used to control weeds and to form a ridge or hill over the seed-piece and developing tubers. Besides controlling weeds, the ridge or hill helps protect tubers from sunburn (tuber greening), late season frosts, excessive rainfall or irrigation, and reduces the amount of soil to be moved at harvest. One danger of excessive cultivation and deep cultivation of potatoes is root pruning. Potatoes are a shallow rooted crop, with roots growing laterally 10 to 18 inches and downward to a maximum depth of 3 feet. Root pruning may be a problem with late cultivations, reducing the overall growth potential of the potato plant.

Herbicides labeled for injection into irrigation systems and recommendations for use in the control of weeds in potatoes can be found in NDSU Extension Circular W-253 (Revised), the current years Agricultural Weed Control Guide, and in the current year’s NDSU Crop Production Guide.

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**Fertilization**

A potato crop makes a large demand on the soil for nutrients. The amount a 300 cwt/ac crop of potatoes will utilize depends on potato variety, climate, soils, and irrigation system management. The average nutrient content is:

- Nitrogen 200 lbs.
- Phosphorus (P₂O₅) 60 lbs.
- Potassium (K₂O) 300 lbs.

One-third to one-half of these nutrients are found in the vines and returned to the soil. The remainder is removed with the harvested tubers and must be replaced. The partitioning of nitrogen in a potato plant as it occurs during the growing season is shown in Figure 1. Phosphorus, potassium and other nutrients are seldom deficient in North Dakota soils for potatoes unless the soil is very sandy or the pH tests above 8.0. Land that has been leveled can be deficient in zinc. Soils with a DTPA extract zinc level below 0.5 parts per million (ppm) are more likely to show a response to zinc fertilization.

Mechanical application of sulfur may not be needed when irrigating with water containing high sulfate (30 ppm or greater) concentrations. Response to sulfur is likely only when soil sulfur levels are low and sulfur contained in irrigation water is not adequate.

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**Figure 1. Uptake of nitrogen for Russet Burbank potatoes using an emergence date of June 1.** (Adapted from Sultanpour, American Potato Journal, Figure 7, Vol. 46: 111-119, 1969.)
Soil Testing

The best way to determine the amount of fertilizer to apply is by a soil test. Fields should be tested every year for nitrate-nitrogen and every two to four years for phosphorus and potassium. Recommendations for nitrogen, phosphorus and potassium based on soil test results are shown in Table 3.

With a good crop rotation, a certain amount of residual nitrogen will be carried over for use by potatoes. Potatoes following any legume such as soybeans, alfalfa, dry beans, or clover will benefit. Also, if sugarbeet leaves are green at harvest, some N would also be expected to be released the following year. Potatoes following corn or small grains may not inherit much residual nitrogen. Soil sampling before planting will indicate how much residual nitrogen is left in the soil but may not reflect mineralization of residues during the year. Previous crop nitrogen credits for different crops should be subtracted from nitrogen required. Nitrogen credits are published in the annual NDSU Crop Production Guide and other Extension Service publications.

Fertilizer Application

Fertilizer applied at planting should not come in direct contact with the seed pieces. The recommended method is to place fertilizer in two bands, each band 2 inches to the side and 2 inches below the seed pieces. Broadcasting is also acceptable. Application of all the required nitrogen in a single preplant operation is not a recommended practice. Fertilizing to achieve maximum utilization of nitrogen in potatoes on irrigated sandy ground requires split applications. A rule of thumb on medium to heavy soils would be one-half the needed nitrogen applied preplant and the remaining nitrogen needs applied as urea or 28% liquid solution at hilling. On sandy soils consider applying one-third to one-half at planting followed by one-fourth to one-third at emergence and the remainder at hilling. Additional N should be applied using chemigation as determined by petiole sampling.

Additional nitrogen becomes available to the plants through soil mineralization during the growing season. This occurs at about 15 lbs/ac per warm season month, but varies due to soil organic matter level and previous crop residues. Based on plant analysis, additional nitrogen may be applied through the irrigation system. Studies on irrigated potatoes at the Oakes research site show little to no advantage to applying more than 200 lbs/ac of total nitrogen to reach optimum yields. The quality of the potato for storage also declines if excessive nitrogen is used.

All fertilizer products can be used in potato production. Dry product blends that match soil test needs and are broadcast applied prior to seedbed preparation offer management and application convenience. Also, during the hilling operation, the fertilizer is moved to the row with the soil, which concentrates nutrients in the active root growth zone. Equal management convenience can be obtained with a variety of fertilizer products that are sidedress applied in bands that the root system intercepts early in the vegetative growth stage.

Table 3. Nitrogen, phosphate and potash recommendations for potatoes with yield goals.

<table>
<thead>
<tr>
<th>Soil N Plus Fertilizer Method</th>
<th>Soil Phosphorus Test (ppm)</th>
<th>Soil Potassium Test (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yield Goal cwt/ac</td>
<td>Bray-1 Olsen</td>
<td>VL²</td>
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<tr>
<td>-------------------</td>
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</tr>
<tr>
<td>200 lbs/ac</td>
<td>0-5</td>
<td>6-10</td>
</tr>
<tr>
<td>300 lbs/ac</td>
<td>0-3</td>
<td>4-7</td>
</tr>
<tr>
<td>400 lbs/ac</td>
<td>135</td>
<td>95</td>
</tr>
<tr>
<td>500 lbs/ac</td>
<td>180</td>
<td>125</td>
</tr>
<tr>
<td></td>
<td>225</td>
<td>155</td>
</tr>
</tbody>
</table>

1 ppm - parts per million of phosphorus or potassium in the soil test
2 VL - Very Low, L - Low, M - Medium, H - High, VH - Very High.

Subtract the amount of nitrate-nitrogen in the top 2 feet of soil from the N figures to determine the amount of nitrogen to apply.
Chemigation

Applying fertilizer through the irrigation system is called chemigation. Required equipment is outlined by state law and administrative rule. Backflow protection equipment must be installed at all water pumps. Chemigation is a recommended Best Management Practice (BMP) when used with center pivot or lateral move irrigation systems, however, it is not recommended for volume gun (“big gun”) irrigation systems. Because volume guns throw the water high into the air, the uniformity is affected by the wind causing poor chemical application and drift.

Injection pumps which use either a piston or a diaphragm are available. The piston pumps have a larger capacity and are generally used for injecting liquid fertilizer. They are available with either a single or double piston and range in capacity from less than 1 to over 300 gallons per hour (gph). The most common have a maximum capacity of 18 gph using a single piston and 36 gph with a double piston. Diaphragm pumps are best suited to injecting smaller amounts of chemicals. They can inject chemicals with more precision than piston pumps and are commonly used for pesticide injection.

Liquid urea-ammonium nitrate (28-0-0) is the preferred nitrogen source for chemigation. From 10 to 30 lbs-N/acre are usually applied during each chemigation event. To accurately determine the amount of nitrogen fertilizer to apply, the chemigation injection pump needs to be calibrated. Chemigation calibration worksheets are available from county Extension Service offices. The injection pump should be checked before each chemigation event to ensure it is injecting the desired amount of fertilizer.

Anhydrous ammonia should not be injected into irrigation systems. Irrigation water with high bicarbonates (HCO₃⁻) will generally cause an ammonium carbonate (NH₄CO₃) precipitate which will plug sprinkler nozzles. Almost all groundwater in North Dakota has high bicarbonates.

Petiole Sampling for Nitrogen Management

Petiole sampling will help determine the nitrogen status of the potato plant during late vegetative growth and tuber bulking. It can be an effective tool for both high yield production and groundwater nitrate contamination protection. The petiole is that part of the potato plant connecting the leaf blade with the stem (Figure 2).

Nitrogen demand is high during vegetative growth (the three to four weeks after seeding). Uptake is rapid and nitrogen stored in vegetative growth later translates to the tubers. However, lysimeter studies at the Oakes research site have shown that from April to early May, 43% of yearly drainage and 37% of annual nitrate loss takes place. Hence, preseason nitrogen fertilization that exceeds growth needs during this period increases the risk of drainage loss. Petiole analysis can help manage crop nitrogen needs under high leaching potential, irrigated potato production.

Figure 2. Petiole sampling procedure for potatoes.
The 4th or 5th petiole from the top of the plant is used for tissue analysis of nitrate nitrogen.
Petiole samples should be taken several times during the growing season, ideally once per week to help establish petiole nitrate trends. Soil samples to a depth of 18 inches should be taken in conjunction with the petiole samples and analyzed for soil nitrate levels.

Analysis of petiole nitrate during early vegetative growth is problematic because of early-season fluctuations, but should be in the range of 12,000 to 22,000 ppm at the time of tuber initiation (Figure 3). The petiole nitrate levels should be allowed to drop slowly through the season with a measured range from 11,000 to 15,000 ppm at mid-season and 6,000 to 8,000 late in the season. This provides for rapid, uniform tuber growth and still allows proper tuber maturation prior to harvest.

If petiole nitrate level indicates deficiency, supplemental nitrogen can be applied in early season by side-dressing or through the irrigation pivot at any time during early to mid tuber bulking. Insufficient nitrogen supply can cause premature senescence and susceptibility to related diseases, reducing yield potential. Large fluctuations in nitrate supply can lead to quality problems (knobs, sugar ends, etc.) and should be avoided. Excess nitrogen fertilizer can reduce yield and specific gravity, increase reducing sugars in the tuber (poor fry quality) and delay maturity, which can cause excess skinning at harvest and lead to poor storability.

Nutrient concentrations in recently matured whole leaves (fourth leaf from the top) can also be used to diagnose nutrient disorders (Table 4).

**Pest Control**

Irrigation not only improves the yield and growth potential of potatoes but also increases the number of pests that feed on them. The timely application of water during the growing season provides an almost ideal environment for weeds, insects and disease organisms, so efforts to control these pests may be greater than under dryland conditions.

**Insects**

The insects affecting potatoes in North Dakota are primarily aphids, the Colorado potato beetle, the potato flea beetle, wireworms and leafhoppers. The application of a systemic insecticide at planting will usually control these insects through the middle of July. If insects become a problem after the middle of July it may be necessary to apply foliar sprays. Insecticides can be applied by aerial application or, if labeled, can be applied through the irrigation system.

The Colorado potato beetle has developed a high degree of resistance to the synthetic pyrethroid insecticides, so they may not provide reliable control. In situations where poor control has occurred with this class of insecticides, growers are advised to switch to another class of insecticide such as an organophosphate or carbamate compound. More information on insect control can be found in NDSU Extension Circular, E-881, Potato Insect Control, and the current year's NDSU Crop Production Guide.

**Figure 3.** Recommended petiole nitrate for irrigated potatoes in North Dakota.

![Graph showing petiole nitrate levels](image)

**Table 4.** Nutrient sufficiency levels in recently matured leaves taken 45-55 days after emergence.

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>P</th>
<th>K</th>
<th>Ca</th>
<th>Mg</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percent</td>
<td>5.0</td>
<td>0.3</td>
<td>4.5</td>
<td>0.6</td>
<td>0.3</td>
<td>0.2</td>
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<tr>
<td>Parts PPM</td>
<td>51</td>
<td>25</td>
<td>6</td>
<td>30</td>
<td>21</td>
<td>1.0</td>
</tr>
</tbody>
</table>

- **N** - Nitrogen
- **P** - Phosphorus
- **K** - Potassium
- **Ca** - Calcium
- **Mg** - Magnesium
- **S** - Sulfur
- **Fe** - Iron
- **Zn** - Zinc
- **Cu** - Copper
- **Mn** - Manganese
- **B** - Boron
- **Mo** - Molybdenum
Disease

High quality, healthy seed is essential to production of a good potato crop. Use only certified seed. Sanitize knives between seed lots and prior to cutting. Plant seed immediately after cutting. If possible, avoid irrigation to obtain crop emergence. Early irrigation can lead to early infection from Verticillium and to problems with soft rot and blackleg.

Potatoes should not be grown more often than every three years on the same piece of land. This reduces carryover of diseases such as early blight, silver scurf, late blight, and Verticillium wilt. Potatoes should be monitored beginning in late June for both early blight and late blight. Early blight is common on irrigated potatoes. Fungicide applications should begin when early blight is beginning to show up on the lower leaves of the plants.

Late blight can cause the greatest loss. This disease has been common since 1992, and the new genotypes (A2 mating types) of the fungus are more likely to cause problems in years with marginal conditions than the old genotypes. Late blight is favored by extended periods of cool, cloudy, foggy, and wet weather. It is also favored by the nearly continuous wet conditions near the pivot of center pivot irrigation systems. It can spread rapidly and is very destructive. The new genotypes actively attack stems as well as foliage and more actively attack the tubers. Information on the current status of late blight under non-irrigated conditions is available on the Blight Hot Line, 1-800-482-7286. An application of fungicide should be made before the rows close to provide protection within the canopy, with regular applications thereafter. Once conditions favor late blight, fungicides should be applied as recommended by the Hot Line.

Foliar fungicides can be used to control early and late blight by preventing entry of the fungus into the plant. To have maximum effectiveness, fungicides must be on the foliage before the fungus spores contact the leaves. Labeled fungicides can be applied through the irrigation system, but coverage of foliage may be less complete than with ground application. Information about fungicides can be found in the current year’s NDSU Crop Production Guide or the current year’s Field Crop Fungicide Guide, PP-622. Fungicide applications should continue after first vine kill to reduce tuber infection. Vines should be dead before harvest to reduce tuber infection.

Soil inoculum of verticillium wilt can reach high levels in a single season if the highly susceptible variety Kennebec is grown. This inoculum is stable for several years. Russet Burbank is susceptible.

Two applications of Ridomil (see label) will help protect against Pythium leak and Phytophthora erythroseptica pink rot. They will not protect against tuber infection from the A2 mating type of the late blight fungus.

Avoid short rotations of potatoes and dry beans. Pythium, which causes leak in potatoes, causes a root rot in dry beans. Pythium is favored by wet, hot soil conditions, so it is more likely to be a problem under irrigation. Potatoes can be infected with white mold. However, this disease is usually not a problem except when potatoes are rotated with dry beans under irrigation or seeded on white mold-infected sunflower ground.

Irrigation

Irrigation Management

The potato is sensitive to moisture stress over much of the growing season. High yields and high quality are achieved by maintaining relatively high soil moisture levels. The average seasonal water use for potatoes is near 18 inches, which is provided by stored soil moisture, rain and irrigation. The average daily water use, cumulative water use and rooting depth are illustrated in Figure 4. Water use rates begin at about 0.02 inches per day when the crop emerges and increases to over 0.25 inches per day when the potato canopy completely shades the ground. As the potatoes achieve full tuberization, water use will decrease. The frequency and amount of irrigation will depend on the water holding capacity of the soil, the crop growth stage, and the prevailing weather conditions.

Water Holding Capacities of Soil

The water holding capacity of the soil has a great influence over when and how often irrigation is required. Different textures of soil have different available soil water holding capacities. The variation in water holding capacities of general soil textures is shown in Table 5. Note that the more water a soil has available for the plant the less frequent the irrigations should be. For example, if the potatoes are using 0.25 inches of water per day, you want to irrigate when the root zone moisture depletion reaches 40%. For a sandy loam soil (using an 18 inch
Figure 4. Seasonal evapotranspiration and irrigation management criteria for potatoes. (Adapted from Stegman, NDSU Research Reports)

Effective Rooting Depth

Potatoes are a shallow rooted crop. Typically, roots grow laterally 10 to 18 inches and downward to a depth of about 3 feet (Figure 5). Root extension to this depth is usually completed within 30 days after plant emergence. Root distribution is heavily concentrated near the soil surface. About 90 percent of the roots will be found in the top 2 feet. Irrigation timing and amount should be based on the soil moisture depletion in the top 12-18 inches of coarse textured soil profiles and in the top 18 to 24 inches of finer textured soil profiles.

Water Management

During the 1998 growing season there were approximately 130,000 acres of potatoes in North Dakota. Of these, around 35,000 acres were irrigated. Center pivot sprinkler systems are used on over 99% of the irrigated potato acres in North Dakota.

Irrigation as practiced in North Dakota is called “supplemental” irrigation because the water applied by irrigation supplements the water received from rainfall.

The object of irrigation water management is to balance the applied amount with the amount received from rain to maintain an optimal growing environment for the potatoes.

Managing any irrigation system for the production of crops can be divided into three basic categories: mechanical management, irrigation system management associated with cultural practices, and irrigation scheduling of water.
Mechanical Equipment

Center pivots are machines and thus require routine maintenance to operate properly. Checking the operability of an irrigation system before the irrigation season begins is just as important as properly operating the system during the season. Fixing small problems is less expensive than repairing a major breakdown, especially with irrigated potatoes. Any downtime of the center pivot during tuber bulking will affect both yield and quality. Following are some of the most common problems associated with center pivot downtime during the growing season.

During the fall, winter and spring, when the irrigation system is not being used, rodents can damage electrical wiring in control panels and motors. During the fall, they will make a nest in the electrical control panels if they can gain entrance. During the winter they will chew on electrical wiring which can cause shorts and failure the following season. This can be prevented by plugging all holes and maintaining a tight door seal on all the electrical control panel doors and covers.

Rodents also do damage to electrical motors if they can get access to the windings. Damage can be prevented by checking all motor openings to see if they are properly screened to keep rodents out. If a screen is damaged or missing, it should be replaced with 1/4-inch mesh screen. This size screen can then be left in place during operation without plugging with dust and debris.

Before the irrigation season begins, the gearboxes on all the towers should be checked for moisture accumulation and that each contains the correct amount of proper weight oil. Lack of oil or water in the oil are major causes of tower drive malfunction during the season. Remove the gear box drain plug just long enough to drain the condensed water then fill with oil.

Before the season begins and during the season if necessary, remove and clean the sand trap on the last tower. Here is where sand, scale and other debris collects. The amount and type of debris in the sand trap can tell a lot about the operation of the pivot.

Application Uniformity and Rate

The purpose of sprinkler irrigation is to make sure every square foot of ground receives the same amount of water and at the same rate. The most important irrigation management requirement is that the sprinkler package on the center pivot apply water uniformly along the entire length of the center pivot.

Poor distribution of water and, if chemigating, poor distribution of nitrogen or pesticides can have a major impact on yields. For potatoes, which are very responsive to water and nitrogen, the uniformity of the applied water can have a large impact on production. Some parts of the field will receive too much water and/or nitrogen and some parts will receive too little. The only way to check the uniformity is by performing a can test.

A can test involves setting out a line of uniformly spaced cans under the full length of the center pivot. After the pivot passes over the cans, measure the amount caught in each can. Record the distance from the pivot point and amount. Total all the caught amounts and divide by the number of cans to determine the average
amount. Then compare the caught amounts to the average to determine the areas where the pivot is over or under applying water.

Along with the can test, the application rate of the sprinklers should be checked. The application rate is the amount of water applied to a particular point in the field as the center pivot passes over it. Too high an application rate can lead to runoff and washing of soil. For potatoes, this can mean washing off the tops of the hills causing green top or water running down the furrows and keeping the low spots wet. A continuously wet low spot can hinder the movement of a tower that travels through it by creating deep wheel tracks or cause the tower wheels to bog down. Wet spots are also ideal areas for the development and growth of fungus such as early and late blight.

**Tips for Checking Center Pivot Sprinklers:**
While the system is operating, walk down the entire length looking closely at the operation of each sprinkler. Frequently, sprinkler problems can be spotted and corrected. The most common problems are plugging, not rotating properly, and broken parts. Generally these problems are quite noticeable.

Check the uniformity of the pivot by placing at least one rain gage (two would be better) under each of the last five spans of a standard quarter section pivot. The rain gages should all be exactly alike. Write down the amount in each rain gage after the pivot has passed over and note the amount of variation from the average.

If the tops of hills are being washed off or water is running down the furrow into low spots, reduce the amount of water applied by increasing the speed of the pivot. This may help, but pay more attention to the water needs of the potatoes. If increasing the speed of the center pivot doesn’t help you may have to change or alter the configuration of the sprinkler package.

**Endguns**
North Dakota state law prohibits spraying water onto a maintained road. If an endgun is spraying a road, its on-off switches should be adjusted at the pivot point.

**Cultural Management**

**Irrigating Before Planting**
Irrigated potatoes are often planted on sandy soils. It is not uncommon to have a dry spring. If the soil is dry at planting time, it is better to irrigate before planting than after. Planting into soil with moisture will ensure better germination than planting into dry soil and irrigating afterward.

**Disease Control**
Many of the diseases (early blight, late blight, soft rot, etc.) that affect potatoes are caused by fungi. Water and heat provide the optimum growing conditions for fungi. Center pivot management can either hinder or help the conditions which favor fungal growth.

Continuous wet spots in the field can be breeding grounds for fungi. The pivot point of a center pivot is always wet due to the slow speed of the pivot. This can be controlled by plugging the sprinklers on the first span closest to the pivot point. The span to the first tower on a pivot usually waters about 2 acres, so even if all the sprinklers on the first span were plugged, only 2 acres would be lost. Usually, plugging the first three sprinklers will be sufficient.

Weeds that are members of the nightshade family can be carriers for the blight fungus, so kill all weeds around the pivot point and wells or pumping stations within the field.

**Irrigation Scheduling**
Irrigation scheduling is the practice of using some method to decide when to start an irrigation system and how much water to apply. No matter what method is used, they all start with knowing when and how much rain has been received on the field and then using some mechanism to decide when to irrigate.

Growing season water use for potatoes is approximately 18 inches (rainfall plus irrigation) in North Dakota with an average peak daily water use between 0.25 and 0.3 inches per day during tuberization. All irrigation scheduling methods can be classified as 1) measuring and tracking the soil moisture levels in the root zone, 2) keeping track of the amount of crop water use each day and 3) combining soil moisture measurement with crop water use.

**Rainfall**
Knowing how much rain has been received and on what day is very important for irrigation water management. A rainfall record book should be kept for each potato field. To accurately measure rainfall received on a particular field, install two good quality rain gages at opposite ends of the field in such a way that they don’t collect irrigation water.

**Soil Moisture**
Soil moisture levels in the root zone of potatoes can be measured using a variety of instruments or by the
“feel” method. The feel method of soil moisture determination is used on over 80% of the irrigated acres in the US.

The soils under a center pivot are usually not uniform. Finer textured (heavier) soils hold more water and won’t reach critical soil moisture deficient levels (when yield loss starts) until after the potatoes on coarse textured soil have already started to stress. Potatoes will use the same amount of water regardless of soil type (if moisture is available), but coarse textured soils hold less water. Therefore, the percent of soil moisture deficiency under an irrigation system will vary with soil type.

Don’t just check soil moisture levels where it is convenient and near the road; use the coarsest soils in the field for scheduling purposes.

The soils that have the lowest water holding capacity will dictate the frequency and amount of irrigation. Potatoes have an effective root depth of 2 feet, but the soil approximately 10 inches below the top of the hill will generally dry out soonest because that is where most of the adventitious roots are located. Using a soil probe to obtain samples from this depth in several locations in the field will provide an accurate estimate of the soil moisture status for the potatoes.

Potatoes thrive best when the soil moisture level in the root zone is maintained between 60% and 80% of available water capacity, which is the same as 20% to 40% depletion of available water. Irrigation is initiated when soil moisture levels in the coarsest soils in the field reach 60% of available water.

Irrigated potatoes are commonly grown on sandy soils. These soils have a water holding capacity around 1 inch per foot of soil depth. Because of the low water holding capacity, irrigators generally put on small amounts of water (0.5 to 0.8 inches) every two to three days, depending on rainfall amounts.

**Potato Water Use Estimates**

Daily water use estimates for potatoes can be obtained by using the charts in NDSU Extension Service Circular, AE-792, Irrigation Scheduling by the Checkbook Method, and electronically by accessing the NDSU Extension Service computer system. During the growing season, the electronic estimates are available on the World Wide Web or through the NDSU Extension electronic bulletin board (ExtNet).

**Checkbook Method.** The checkbook method of irrigation scheduling (AE-792) combines soil moisture measurement with crop water use estimates. The soil moisture balance in the root zone is treated as a bank account. Water added to the soil in the form of rain or irrigation is considered a deposit, and water removed by potatoes or drainage below the root zone are considered withdrawals. With this method, the irrigator can track the change in soil moisture in the root zone throughout the season and do a better job of managing irrigation water.

**ExtNet Crop Water Use Reports.** ExtNet is the computer network that connects the NDSU campus with all the county extension offices. Access to ExtNet is available to anyone with a computer with a modem for a $30 annual fee. The application forms are available from NDSU Agricultural Communications Computer Services. Two crop water use reports are provided under the WEATHER section of ExtNet.

One report is a summary report of the potato water use for the previous seven days. This report (called Weekly) is only available from June 15 to September 30 each growing season. The other report (Daily) is available year round and can be used to obtain potato crop water use estimates from previous years. These reports are explained in more detail in the bulletin WEATHER, Software Users Guide 11, from NDSU.

**Crop Water Use Maps.** Color coded crop water use maps and numerical tables for North Dakota are available on the Internet via the World Wide Web (WWW). The maps and tables are updated daily from June 15 to September 30 each growing season. During the rest of the year, example maps and the table of values for the previous growing season are shown. The maps are shown after an emergence date for a particular crop is selected. For potatoes, the six selectable emergence dates are seven days apart and start on the first of May. They were created to provide accurate estimates of crop water use for the eight major irrigated crops in North Dakota. They are available at this address:

http://www.ext.nodak.edu/weather/ndawn

The maps are created using daily weather data collected by the North Dakota Agricultural Weather Network (NDAWN). Each weather station on the network is automated and the weather data are retrieved every day. The crop water use estimates are calculated using the weather data from each automated weather station and the numbers are shown on the maps. The crop water use estimates for the eight crops use a reference ET amount (inches of water use per day) calculated with the Jensen-Haise equation. The reference ET amount is adjusted for each crop to produce the estimated daily crop water use amount.
Harvest Considerations

Maturity and Vine Killing

Potatoes are considered mature when they have reached a good marketable size, separate easily from the stolons, and can be harvested with a minimum amount of tuber skinning. Tubers generally do not mature until after the vines die. However, with the use of fungicides and insecticides, plants usually remain green until frost. It is usually necessary to kill and defoliate the plants by either applying vine desiccants or by mechanical means in order to harvest early and extend the harvest season. Early termination of the plants is also used to control tuber size or to supply early markets. Maturity is hastened by spraying plants 10 days to three weeks before harvest with a chemical desiccant. The desiccants currently labeled for use on potatoes can be found in NDSU Extension Circular W-253 (revised), the current year's Agricultural Weed Control Guide.

Irrigation for Bruise Control

Bruising of harvested potatoes is becoming an important concern to the fresh pack and processing companies. Descriptive terms such as blackspot, shatter, cracking and pressure bruising are all used to identify potato tuber injury. Although most bruising is caused by mechanical handling during harvest and transportation, research has shown that irrigation can be used to reduce bruising during the harvesting process. On sandy soils, a soil moisture content between 60% and 80% of field capacity (40% to 20% depletion) provides conditions for a desirable soil load into the harvester with optimum separation of potatoes and soil and minimum tuber damage. If the soil is dry before harvest, a final irrigation should be applied at least one week prior to harvest to raise the soil moisture content and also raise the tuber hydration level. Air temperature also has a significant effect on bruising. Harvesting when the tuber temperature is less than 45 degrees Fahrenheit will increase shatter and cracking of the tubers.

Groundwater Protection

A large portion of the irrigated potato acreage is on sandy soils which lie over relatively shallow aquifers (10 to 50 feet). Sandy soils overlying shallow aquifers planted to a shallow rooted, nitrogen loving crop like potatoes can pose a groundwater contamination risk. The key to substantially minimizing the risk to surficial aquifers is controlled management of inputs and good crop rotation.

Results from many studies indicate that groundwater contamination occurs when nitrogen fertilizer, pesticides, and water are not well managed. Excessive application and poor timing are regarded as the main causes. This type of management is not economical, nor does it protect vulnerable water resources. Irrigated agriculture offers significant opportunity for controlled application of inputs.

The need to follow practices that utilize water and nitrogen efficiently is particularly important for the safety of drinking water supplies. Many rural water systems have their wells in the same aquifers where potatoes are grown. Many people in these areas are very concerned about their water supply and view irrigated potato production with apprehension. Producers can maintain yields and protect surficial aquifers by matching pesticides, nitrogen and water to potato crop needs at different growth stages.
Economic Analysis

An analysis of the economics of growing irrigated potatoes must be related to the time frame of one's planning horizon. If the irrigation system is already in place, then the pertinent question is, What crop do I raise this year? This is an annual decision that must be repeated every year. The decision criteria is to determine which crop will result in the greatest return over variable costs. It does not matter at that point what the total cost of the land, machinery or irrigation system is. The main concern is to raise a crop that fits into the crop rotation and contributes the most income to pay for these fixed costs. Obviously, the operator would choose a crop that results in the most money left over after paying for variable costs.

However, if the decision time is prior to making the investment in an irrigation system, then the pertinent question becomes whether or not to invest in an irrigation system to produce irrigated crops rather than dryland crops. At this point the irrigation system can still be considered a variable cost because the operator has not yet committed to the investment. In this decision the operator is still looking to maximize return over variable costs; however, the ownership costs of the irrigation system should be included in the variable costs.

Enterprise Budgeting

Both situations require the information contained in enterprise budgets to make an informed decision. To analyze this investment, it is necessary to consider a complete rotation, since few crops will be successful in a monoculture over several years. Table 6 lists estimated costs and returns for several crops grown under irrigation. The prices of both inputs and products vary over time. For long run planning it is necessary to use average prices and yields over the length of the planning horizon.

Assuming a three-year rotation with the crops shown in Table 6, there are extreme differences in return over variable cost and return to labor and management for each of the three crops. It is obvious that of these crops, a producer would want to include potatoes as often as possible in the rotation as long as the yield could be maintained. In contrast, the corn budget projects a loss of $63.35 per acre before putting a value on labor and management. The logical question then becomes, Should corn be grown at all? The assumption is that corn, or something like it, is needed in the rotation to ensure that disease pressure does not build to the point that the other more profitable crops can not be produced.

In a long run analysis, the average return to labor and management of all the crops in the rotation must be positive. A rational decision-maker would want this value to be equal to or greater than the fair market value of the labor and management effort contributed by the owner-operator. Individual crops in the rotation may not measure up to this goal, but as long as the return over variable costs is positive for each crop, then they are all helping to pay for the fixed costs. These budgets assume that all labor and management is provided by the owner-operator(s). Any labor that is hired should be included in the variable or direct cost section of the budget.

Fixed Costs

Fixed costs are the expenses for each crop that will be incurred regardless of production. They include overhead and machinery ownership costs, which vary depending on the investment value of the machinery needed for each crop. Other fixed costs include the ownership costs of the irrigation development and the land itself. These costs would be constant for all potential crops to be grown. Irrigation ownership costs were calculated using a center pivot on a quarter section of land (160 acres) and irrigating 130 acres of that quarter. All the purchased equipment and installation are new and required the following investment:

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Center Pivot</td>
<td>$39,000</td>
</tr>
<tr>
<td>Pump, Motor, Electrical</td>
<td>$16,000</td>
</tr>
<tr>
<td>Well (at pivot point)</td>
<td>$10,500</td>
</tr>
<tr>
<td>Pipe, valves, etc.</td>
<td>$4,500</td>
</tr>
<tr>
<td>Land Preparation</td>
<td>$4,000</td>
</tr>
<tr>
<td><strong>Total Investment</strong></td>
<td><strong>$74,000</strong></td>
</tr>
</tbody>
</table>

Renting Irrigated Land

Cash renting irrigated land involves determining a value for the landowner's contribution. The landowner is contributing the land and the irrigation system in a typical arrangement. A minimum rent that will cover the landowner's contribution is the sum of the ownership costs of the irrigation system and the land costs. Since land does not depreciate, the applicable costs are the land taxes and the dryland rental market rate. In this example, the value of this contribution is $78 per acre. Competition for irrigated land will push rents above this minimum depending on the profitability of the crops to be raised.
Table 6. Economic cost budgets (1998) for a possible growing rotation involving potatoes on a per acre basis (Center pivot covering 130 acres of irrigated land).

<table>
<thead>
<tr>
<th></th>
<th>Potatoes</th>
<th>Corn</th>
<th>Drybeans</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marketable Yield</td>
<td>325 cwt</td>
<td>120 bu</td>
<td>2000 lbs.</td>
</tr>
<tr>
<td>Expected Price</td>
<td>$4.15</td>
<td>$2.25</td>
<td>$0.18</td>
</tr>
<tr>
<td>MARKET INCOME</td>
<td>$1,348.75</td>
<td>$270.00</td>
<td>$360.00</td>
</tr>
<tr>
<td>DIRECT (VARIABLE) COSTS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Seed</td>
<td>220.00</td>
<td>29.12</td>
<td>28.00</td>
</tr>
<tr>
<td>- Herbicides</td>
<td>48.88</td>
<td>23.45</td>
<td>16.04</td>
</tr>
<tr>
<td>- Fungicides</td>
<td>124.90</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>- Insecticides</td>
<td>31.50</td>
<td>14.96</td>
<td>0.00</td>
</tr>
<tr>
<td>- Fertilizer</td>
<td>38.14</td>
<td>33.38</td>
<td>15.08</td>
</tr>
<tr>
<td>- Crop Insurance</td>
<td>27.42</td>
<td>11.20</td>
<td>13.05</td>
</tr>
<tr>
<td>- Fuel &amp; Lubrication</td>
<td>13.79</td>
<td>11.29</td>
<td>9.12</td>
</tr>
<tr>
<td>- Repairs</td>
<td>34.43</td>
<td>13.70</td>
<td>12.74</td>
</tr>
<tr>
<td>- Irrigation Power</td>
<td>31.06</td>
<td>31.06</td>
<td>31.06</td>
</tr>
<tr>
<td>- Irrigation Repairs</td>
<td>9.97</td>
<td>9.97</td>
<td>9.97</td>
</tr>
<tr>
<td>- Drying</td>
<td>0.00</td>
<td>14.40</td>
<td>0.00</td>
</tr>
<tr>
<td>- Custom Hauling</td>
<td>97.50</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>- Miscellaneous</td>
<td>17.75</td>
<td>1.05</td>
<td>1.00</td>
</tr>
<tr>
<td>- Operating Interest</td>
<td>34.77</td>
<td>9.68</td>
<td>6.80</td>
</tr>
<tr>
<td>SUM OF LISTED DIRECT COSTS</td>
<td>$730.11</td>
<td>$203.26</td>
<td>$142.86</td>
</tr>
<tr>
<td>RETURN OVER VARIABLE COSTS</td>
<td>$618.64</td>
<td>$66.74</td>
<td>$217.14</td>
</tr>
<tr>
<td>INDIRECT (FIXED) COSTS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Machinery Depreciation</td>
<td>54.54</td>
<td>26.58</td>
<td>21.08</td>
</tr>
<tr>
<td>- Machinery Investment</td>
<td>31.61</td>
<td>16.39</td>
<td>12.58</td>
</tr>
<tr>
<td>- Irrigation Depreciation</td>
<td>31.49</td>
<td>31.49</td>
<td>31.49</td>
</tr>
<tr>
<td>- Irrigation Investment</td>
<td>16.30</td>
<td>16.30</td>
<td>16.30</td>
</tr>
<tr>
<td>- Land Taxes</td>
<td>3.97</td>
<td>3.97</td>
<td>3.97</td>
</tr>
<tr>
<td>- Land Investment</td>
<td>26.25</td>
<td>26.25</td>
<td>26.25</td>
</tr>
<tr>
<td>SUM OF LISTED INDIRECT COSTS</td>
<td>$178.14</td>
<td>$130.09</td>
<td>$119.14</td>
</tr>
<tr>
<td>SUM OF ALL LISTED COSTS</td>
<td>$908.25</td>
<td>$333.35</td>
<td>$262.00</td>
</tr>
<tr>
<td>RETURN TO LABOR &amp; MANAGEMENT</td>
<td>$440.50</td>
<td>($63.35)</td>
<td>$98.00</td>
</tr>
</tbody>
</table>

3 year Average - $158.38

For more detailed information on crop budgets, consult the Farm Management Planning Guide - Irrigated Crop Budgets (Central or Western, North Dakota) available from the NDSU Agricultural Economics Department, Fargo, ND.

Additional Sources of Information

- **Seed Potatoes**, Red River Valley Potato Growers Association, PO Box 301, East Grand Forks, MN, 56721.
- **Irrigation Handbook**, Extension Agricultural and Biosystems Engineering Dept., NDSU.
- **Potato Insect Control**, NDSU Extension Bulletin Number E-881.
- **Disease Control Guidelines for Seed Potato Selection, Handling and Planting**, NDSU Extension Bulletin Number PP-877.
- NDSU Extension Circular W-253.
- **Agricultural Weed Control Guide**, NDSU Extension Circular PP-903.
- **Production Guides and Handbooks**, Potato Processing Companies
- **Irrigation Scheduling by the Checkbook Method**, NDSU Extension Bulletin, AE-792
- **Estimated Irrigated Crop Budgets (Central or Western) North Dakota**, Section IV of the Farm Management Planning Guide, NDSU Agricultural Economics.