Chapter 5
Field Selection, Crop Rotations, and Soil Management

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Introduction

In developing a sustainable, efficient potato cropping system, several key decisions need to be made before planting, including: (1) selecting a suitable field for production, (2) developing an appropriate tillage and residue management program to optimize soil health, and (3) choosing a compatible sequence of crops for the rotation

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that favors the production of a healthy, productive potato crop. Since each field has its own unique set of characteristics, growers need to adapt management plans on a field-by-field basis to maximize production efficiency. The key factors that need to be considered in developing sustainable field management plans that promote soil and plant health include: soil physical and chemical characteristics, topography, crop rotation history, previous pest problems, tillage management practices, and production costs.

Field Selection

The suitability of a field for potato production depends on a wide range of characteristics, including soil physical and chemical properties, topography, cropping history, and previous pest problems, all of which influence soil health. Ideally, potato fields should have low to moderate slopes and soils that are deep, well drained, and friable with good water-holding capacity and low soluble salt and sodium concentrations.

Soil Health

Some of the key factors influencing soil health include the accumulation of adequate levels of soil organic matter for promoting good soil tilth, good soil structure and minimal soil compaction to provide adequate aeration and drainage for root growth, and optimal soil chemical characteristics that enhance nutrient availability and uptake.

Soil Texture and Organic Matter

Some of the key soil physical properties influencing potato growth and development include texture, which is related to the proportions of sand, silt, and clay; structure, which is influenced by the arrangement of individual soil particles into definable aggregates; and bulk density, which is soil mass per unit volume (g/cm^3).

Potatoes grow effectively in soils with textures ranging from sands to clay loams, although yield potentials can vary appreciably across textural classes. Soils with relatively fine textures, such as clay loams and silty clay loams, generally have much lower water infiltration rates than coarse-textured soils and, therefore, are more prone to runoff and unequal soil water distribution. This can be a substantial problem in fields with slopes greater than 5%.

Runoff problems can result in excessively dry soils on upper slopes and ridges and waterlogged soils in low areas, unless addressed through specialized tillage operations, such as basin tillage. Excess water can erode soil and leach soluble nutrients out of the root zone. Waterlogged conditions can also reduce soil aeration, which contributes to reduced root physiological activity and increased disease susceptibility and tuber disorders.

The relatively low infiltration rates characteristic of fine-textured soils make them more suitable for set-move sprinkler irrigation systems, such as wheel lines and hand lines, or solid-set systems. Surface irrigation is also more effective on fine-textured soils.

Sandy soils, on the other hand, typically have high infiltration rates and low water-holding capacities, which are more suitable for center-pivot and linear-move irrigation systems. In addition, sandy soils are generally more susceptible to nutrient leaching than fine-textured soils because of their lower water-holding capacity.

Soil water-holding capacity, permeability, and tilth tend to improve as soil organic matter content increases. However, many soils in potato-producing areas have an organic matter content less than 1%. As a result, growers must make consistent efforts to increase soil organic matter levels by returning crop residues to the soil and minimizing residue burning and unnecessary tillage operations.

Soil Compaction

Compaction can result from any process that breaks down soil structure and increases bulk density, which reduces the amount of pore space available to hold water and air. Compacted soil layers typically result from excessive wheel traffic or heavy axle loads, particularly when equipment is operated on wet soils. Natural hardpans also occur and can have similar effects on soil water movement and crop growth. These zones of high soil bulk density can decrease soil water-holding capacity, infiltration, and drainage, which can result in excessively wet and dry areas in the field and increased runoff and erosion.

Soil compaction can substantially reduce potato production efficiency. Compacted soils and hardpans interfere with potato root and tuber growth because of increased mechanical resistance of the soil. Compaction also increases the amount of energy required for plant emergence and root extension and reduces the plant's ability to absorb water and nutrients.

Another effect of compacted soil is that potato plants are typically less vigorous and more susceptible to stress-induced tuber defects than those grown in non-compacted soils. Limitations on root growth, coupled with uneven soil water distribution in the field, can also hasten the onset of early dying and increase the incidence of several other potato diseases, including Rhizoctonia, pink eye, and pink rot.

Generally, clay soils compact more readily than sandy soils, although hardpans in sands can also severely limit potato root penetration. Compaction of clay and loam soils can lead to clod problems at harvest, which can increase labor requirements, interfere with harvester operations, and increase tuber bruise damage. In addition, wet soils are more susceptible to compaction than dry soils; so if possible, fields should be allowed to dry to moderate soil moisture levels before conducting tillage operations.

Compaction can occur at different depths in the soil profile. Compacted layers in the upper part of the root zone can be loosened by tillage operations, such as ripping or chisel plowing, as well as by root penetration by deep-rooted crops, such as alfalfa. Loosening deeper compacted layers is more difficult, but the effects on potato growth and yield are usually less severe.

Growers can use the following management practices to help minimize or reduce soil compaction in potato rotations:

- Avoid field operations, such as tillage, planting, and harvesting, when soils are too wet. Also, consider performing primary tillage operations directly after harvest in areas where soil moisture is typically drier in the fall than in the spring.
- Chisel or rip when soils are relatively dry at a depth that will adequately disrupt the compacted layers. Vary the depth of tillage operations from year to year to avoid developing tillage pans.
- Reduce axle loads by using lighter field equipment or equipment with axle loads distributed over several axles rather than one or two.
- Minimize repeated passes across the same wheel tracks, and avoid unnecessary field operations.
- Use deep-rooted rotation crops, such as alfalfa, small grains, and corn that help break up hardpans and improve soil structure. These crops also return relatively large amounts of crop residue to the soil.
- Increase the number of years between potatoes and other row crops, such as sugar beets, onions, and beans in the rotation. Row crops return little crop residue to the soil, and the heavy equipment traffic associated with their production can increase soil compaction.
- Incorporate green manure crops, cover crops, manure, composts, and other crop residues to help increase soil organic matter and improve soil structure and drainage.

Topography

The development of center-pivot and linear-move irrigation systems, together with basin tillage, has greatly expanded the range of topographic conditions under which potatoes are grown. Selection of an appropriate field site should take into account the availability of field equipment necessary to manage the field and the potential for soil erosion and nutrient and pesticide leaching and runoff. Strongly sloping ground increases the potential for soil erosion and uneven water distribution. It also presents severe limitations to planting, cultivating, and harvesting operations (Fig. 5.1).

Slopes greater than 5% substantially increase runoff and erosion potential unless growers use some form of basin tillage, such as dammer diking (Fig. 5.2), to intercept and hold water in place. Even with basin tillage, however, runoff can be significant in wheel tracks. Slopes greater than 10% create problems with slippage and alignment of planting, cultivation, and harvesting equipment.

Fig. 5.1 Steep slopes can present challenges for planting, cultivating, and harvesting operations. (Photo credit: Potato Grower Magazine/Harris Publishing)

Fig. 5.2 Dammer diking equipment form small catchment basins in furrows that help reduce runoff and improve soil water uniformity on sloping ground. (Photo credit: Potato Grower Magazine/Harris Publishing)

Misalignment and unequal spacing of rows can cause plant damage during cultivation and harvesting operations and can also create a hazard for equipment operators. The lower areas of the field also tend to accumulate excess moisture, resulting in a greater risk of diseases, while the ridges tend to be too dry, resulting in reduced yield and quality.

Soil Chemical Characteristics

The primary soil chemical characteristics that affect potato production are pH, cation exchange capacity (CEC), soil salinity, and sodicity.

Soil pH

Potatoes grow well under a fairly wide range of soil pH levels, although soils with near neutral pH (6.5–7.5) generally provide maximum nutrient availability. However, potatoes frequently are grown on high pH soils (greater than 7.5).

At high soil pH levels, the availability of phosphorus, iron, zinc, and manganese typically are reduced, which creates a need for growers to modify fertilizer management practices that improve nutrient uptake efficiency. Under acidic soil conditions (pH less than 6.0) nutrient availability is also reduced, and soils frequently need lime applications to raise soil pH to the optimal range for nutrient uptake.

Cation Exchange Capacity

Cation exchange capacity (CEC) is an important soil property that strongly influences the availability of positively charged ions (cations), such as potassium, ammonium, calcium, magnesium, iron, zinc, and manganese. Since clays contain the vast majority of cation exchange sites in soils, CECs are proportional to clay content. Although CEC is usually not a limitation to potato production, soils with low CECs, such as sands, usually have a greater need for in-season nutrient applications than those with high CECs.

Soil Salinity

Saline soils, which have relatively high soluble salt concentrations, can reduce potato growth and yield by decreasing the plant's ability to absorb water from the soil. Salinity can also interfere with plant physiological processes involved in dry matter production and distribution within the plant. This condition may cause reduced vine and tuber growth. Saline soils can be reclaimed if infiltration and drainage characteristics are adequate and sufficient amounts of low-salt water are available to leach salts out of the root zone.

For long-term irrigation management considerations, growers should adjust water application amounts to maintain adequate leaching of salts out of the root zone. The amount of leaching required, known as the leaching requirement (LR), is the amount of drainage water (DW) that must be produced, expressed as a fraction of the amount of water applied to the soil (IW).

The LR depends primarily on the ratio of the salinity (electrical conductivity [EC]) of the irrigation water (EC_{iw}) to the acceptable level of salinity in the soil solution as measured in the DW (EC_{dw}). The LR can be determined using the following relationship: LR = ECiw/ECdw.

Recommended long-term LRs for potatoes grown on saline soils are usually about 6–8%. For potatoes, the EC of a saturation extract of the soil should not exceed 1.7 dS/m to avoid yield loss, while the EC of the irrigation water should not exceed 1.1 dS/m. The amount of water that will be needed to leach salts out of the soil will depend on the depth, texture, and permeability of the soil and the proportion of the initial salinity that growers must remove.

Sodicity

Sodic soils have high sodium concentrations adsorbed on clay particles that disrupt soil structure, which results in a substantial reduction in soil permeability. Low soil permeability associated with sodicity interferes with soil water availability and root growth. High soil sodium concentrations can also become toxic to plants by disrupting physiological processes and damaging tissue. The combined effects of sodicity on soil physical conditions and plant physiological processes can cause severe stunting and even death of potato plants.

The sodium adsorption ratio (SAR) provides a good indication of the sodicity hazard in irrigation waters. The SAR, which is a standard test conducted by commercial laboratories, represents the ratio of the sodium concentration in the irrigation water to the concentrations of calcium and magnesium. If the SAR is below 6, there should be no significant reduction in soil permeability. When the SAR increases to between 6 and 9, there is an increasing hazard to soil permeability. Severe permeability problems are likely when the SAR exceeds 9.

To reclaim sodic soils, sodium has to be displaced from the cation exchange sites by calcium. Growers can accomplish this by adding a soluble source of calcium, such as gypsum, or adding acidifying agents, such as sulfuric acid or elemental sulfur, to dissolve existing $CaCO_3$ (lime) in the soil. Reclamation of sodic soils typically requires large amounts of amendments, often in the range of several tons per acre or more.

Once the sodium has been displaced, it needs to be leached out of the root zone by application of adequate amounts of low-sodium water. As with salt removal, the amount of water required to leach sodium out of the soil profile will depend on the concentration of sodium in the soil, as well as the depth, texture, and permeability of the soil.

Field History

In addition to soil characteristics and topography, growers should consider the history of the field when selecting appropriate sites for growing potatoes. In particular, growers need to know the cropping history of the field, previous pest populations, and pesticide use practices.

Growers are advised to not have potatoes follow potatoes too closely in the rotation. Longer rotation intervals help avoid buildup of soilborne potato diseases, such as Verticillium wilt and Rhizoctonia. Growers should also avoid planting potatoes after crops such as sugar beets and onions, which are intensively managed with heavy equipment, because of the negative effects of soil compaction on potato yield and quality. When following alfalfa, canola (Fig. 5.3), or other forage legumes, growers should take care to manage nitrogen fertilization because of the large amounts of nitrogen mineralized from plant residues.

In evaluating the pest history of a field, growers need to gather accurate information on the presence of nematodes, wireworms, and problem weeds. If field records or other information on nematode populations are not available, growers would be wise to take field samples using appropriate procedures and submit them to public or commercial laboratories for a quantitative analysis of pest levels in the soil.

The potential for herbicide carryover should always be carefully considered when determining whether or not to plant potatoes in a particular field. Many

Fig. 5.3 Rotation crops, such as canola, help break pest cycles and improve soil physical conditions. (Photo credit: Potato Grower Magazine/Harris Publishing)

herbicides used to control weeds in common rotation crops can cause injury to potatoes if applied within 12 months prior to potato planting.

To facilitate field management in the future, detailed information on pesticide applications, including materials applied, plant-back restrictions, application rates, and timings should be maintained along with pest levels, field cropping histories, and important climatic information, such as soil temperature and irrigation and precipitation amounts and timings.

Crop Rotations

When considering crop rotation options, short-term economic returns must be balanced against the potential long-term benefits to the entire agricultural enterprise. Crop management systems should promote and maintain sustainable, economically efficient production throughout the rotation. When planning crop rotations, potato growers should also consider the potential for improving soil conditions and minimizing pest levels in addition to evaluating production costs and potential economic returns.

A primary benefit of a well-designed crop rotation is improved soil health. The addition of large amounts of crop residue to the soil over time can improve soil tilth, nutrient availability, and aeration, as well as increase soil water-holding capacity, infiltration, and drainage. These improved soil conditions can increase potato yield and quality while reducing water runoff and erosion.

The potential effects of previous crops on weed, insect, disease, and nematode populations are other key considerations in planning a rotation. For example, the inclusion of non-host crops in a rotation can reduce populations of pests that attack potatoes, particularly when the number of years between potato crops is increased.

A well-known example of this response is Verticillium wilt, which is greatly affected by rotation length. Rotation lengths of at least 4–5 years are typically required to adequately reduce soil inoculum levels of this disease and build up populations of beneficial soil organisms. Increasing the length of the rotation also helps reduce the severity of Rhizoctonia, black dot, common scab, and silver scurf. In addition, the use of non-host crops and longer rotations are primary management tools for reducing nematode populations in soil.

Opportunities to control weeds are also affected by the cropping sequence. For example, nightshade is more easily controlled in a wheat-sugar beet-barley-potato cropping sequence than in a wheat-potato-wheat-potato sequence. Most perennial weeds should be controlled by using a combination of herbicides and tillage during the years prior to potato production. In some cases, it may be advisable to delay potato production for a year or two to implement appropriate weed control strategies.

Any rotation that introduces new classes of herbicides and unique weed control practices has the potential to reduce weed problems in potatoes. However, care should always be taken to follow herbicide label restrictions on plant-back intervals to avoid herbicide carryover damage.

Cover Crops and Green Manures

The terms cover crop and green manure are often use interchangeably and refer to crops planted specifically with the intended purpose of managing soil quality, reducing erosion, improving fertility, and/or reducing pests. The inclusion of various cover crops and green manures in the potato cropping rotation has been shown to have beneficial effects on pest suppression as well as tuber yield and quality. These crops may be grown to maturity and harvested, or flailed and incorporated into soil to maximize the addition of organic matter. In some production systems, cover crops are grown over an entire season; in others they are planted in the spring prior to a cash crop or after harvest of cereals or other crops in late summer. The management of green manures and cover crops are covered in detail in Chap. 6.

Crop Sequences in Potato Cropping Systems

Crop sequences that include potato vary widely from region to region and farm to farm depending on local marketing options, climate, and other factors. Rotations can be as short as 2–3 years (ex., wheat-potato and wheat-wheat-potato), to well over 5 years in regions with high pest pressure. Almost all rotations include high-residue crops, such as small grains and corn, but may also include crops such as beans, peas, sugar beets, or alfalfa.

A 2-year wheat-potato rotation is far too short to provide adequate suppression of common soilborne diseases and nematodes. Consequently, growers typically treat these fields with fumigants, such as metam sodium, metam potassium, 1,3-dichloropropene, or chloropicrin in the fall before planting potatoes in an effort to reduce the effects of early dying and other diseases.

Short rotations can have significant impacts on potato crop quality and yield. Research conducted in eastern Idaho showed that average yields for 3-year wheat-wheat-potato rotations were usually about 3000–4000 lb./ac higher than those for 2-year wheat-potato rotations. A 4-year rotation of potatoes, sugar beets, and 2 years of grain usually performs better with a year of grain between the sugar beets and potatoes because of reduced soil compaction and disease problems.

When alfalfa is included in the potato rotation for 2–4 years, it often is followed directly by potatoes. However, a grain crop is frequently grown between alfalfa and potatoes to moderate the effects of high nitrogen release from alfalfa residue on the subsequent potato crop and to reduce plant residue management problems.

About 50% of the nitrogen mineralized from an alfalfa crop is released during the first year after incorporation. An additional 25% of the nitrogen is released during the second year.

Preplant Tillage Management

The selection of preplant tillage operations will depend, to a large extent, on soil type and structure, soil erosion susceptibility, and energy costs, as well as on the residue management requirements of the previous crop. The tillage system should be designed to effectively incorporate crop residues, break up compacted soil layers, improve water infiltration, and prepare the soil for planting, while minimizing the potential for soil erosion. A properly designed tillage system can also help improve the control of annual and perennial weeds and volunteer potatoes. See Chap. 12.

Fall Tillage

For years, potato growers have used moldboard plowing as a primary tillage method before potatoes (Fig. 5.4), particularly on relatively flat ground where water and wind erosion are not significant problems. Plow depth is an important consideration. It varies somewhat with soil type and the amount and type of crop residue, but usually is about 8–12 in. Growers should avoid plowing wet fields in order not to develop compacted layers at the bottom of the plow shear.

Fall plowing is usually preferred over spring plowing because potato producers can till ground over a longer period, and it also allows more time for crop residues to decompose. Fall plowing, however, can increase susceptibility to wind erosion because of the lack of crop residue on the soil surface.

Fig. 5.4 Moldboard plowing is often used as a primary tillage method before potatoes. (Photo credit: Potato Grower Magazine/Harris Publishing)

Growers who plow potato ground in the fall often leave fields with a rough surface over winter. Fields that have only been plowed in the fall are usually disked and roller-packed or harrowed in the spring after application of broadcast fertilizer. Some growers prefer to cultivate in the fall, especially after broadcasting fertilizer or prior to fall bedding. Producers typically use disks and/or roller packers, as well as bedding equipment for these secondary tillage operations.

Potato growers commonly use chisel plows, with chisel points or sweeps, in the fall to break up hardpans and compacted soils and improve water infiltration during the fall and winter months. For grain fields, growers typically irrigate, chop the crop residue with a straw beater, and then chisel plow the ground in the late summer after harvest. The grain stubble is then either disked or left standing over winter to improve soil moisture distribution and reduce erosion.

Although growers use several types of chisel implements under a range of field conditions, they often use sweeps in fields where hardpans are a problem. Growers prefer using chisel points on sloping ground that is prone to erosion.

Growers can disrupt compacted soil layers by sub-soiling below the plow layer with deep rippers or chisel plows when soils are relatively dry. Sub-soiling when soils are too wet will usually not adequately fracture the compacted layer and may, in some cases, make the compaction problem worse. For chiseling to be effective, tillage depth must exceed compaction depth so that hardpans are adequately disrupted. Ideally, growers need to set shanks at an operating depth that will lift and shatter the compacted soil layer without exceeding the sheer stress value of the soil. Growers should set shank spacing so that the entire surface layer of soil is disrupted by the tillage operation. An integrated approach to reducing compaction should also include increasing soil organic matter levels through the use of soil-building crop rotations and appropriate residue management practices.

After a grain crop, some growers will disk the field twice in the fall at opposite angles. They will then establish beds and fertilize during the marking operation. Fall bedding (Fig. 5.5) has increased in popularity in recent years. Growers usually irrigate potato fields, fertilize, and then chisel or use a moldboard plow before forming beds in the fall. Fall bedding allows more time for soil preparation work to be done when conditions are usually good and a grower has more time. Fall soil preparation also provides added time in the spring for growers to focus on seed preparation, pest management, and planting operations.

Some fall field preparation, such as minimum or conservation tillage, may need to be performed on sandy soils to help reduce wind erosion. This may involve leaving previous crop residues partially incorporated on the surface of the soil to help hold the surface soil in place. This approach can be effective in reducing soil erosion, but can also make it more difficult to incorporate preplant, broadcast-applied fertilizer and herbicides.

Spring Tillage

During spring tillage operations, growers apply broadcast fertilizer over the field, then disk and harrow, and mark the rows with shanks mounted on a tool bar or other implement.

Fig. 5.5 Beds can be fertilized and formed in the fall to allow more time for other operations in the spring. (Photo credit: Potato Grower Magazine/Harris Publishing)

Pre-plant bedding or “marking out” is typically performed in the spring prior to planting, particularly to facilitate accurate rowing spacing with large, multi-row planters. Global Positioning System (GPS) guided tractor steering systems have greatly improved row position accuracy and essentially eliminated errors during the row marking operation. This, in turn, helps prevent plant root and tuber damage during subsequent hilling and harvesting operations.

When planting, it is important to avoid leaving excessive crop residues on the surface that can be incorporated into the seed row. Large amounts of undecomposed crop residues, particularly from green manure and animal manures, can favor the development of tuber diseases, such as common scab, Pythium seed piece decay, and bacterial soft rot.

Dammer diking, or reservoir tillage, is a tillage operation growers perform after planting at final cultivation that forms small catchment basins in the furrows (Fig. 5.2). These basins are designed to increase water infiltration and reduce water runoff, which generally improves soil water uniformity across sloping ground. The basins also help to reduce soil erosion and surface movement of fertilizers and pesticides. When used properly, basin tillage significantly improves water use efficiency on sloping ground.

Fumigation

For many producers, fumigation is an important step in the ground preparation process prior to planting potatoes. Estimates of the proportion of potato acreage that is fumigated run from around 50% in Idaho, to over 80% in the Columbia Basin. Growers in other production regions in the Midwest and Eastern U.S. also fumigate prior to potatoes, with the proportion of treated acres depending on factors such as cropping history, length of rotation, yield potential, and variety choices.

Economics is a major factor in the decision on whether or not to fumigate, as it can be one of the single most expensive crop production inputs. That cost has to be balanced against the economic benefits gained from increased tuber yield and quality. For example, fumigation is estimated to increase yields by an average of 8–10% in some production regions. Slightly stronger yield responses are expected in long-season production areas due to increased pest pressure. Even bigger impacts on tuber quality attributes, such as size and the incidence of external and internal defects, have been reported in some studies. In some situations, fumigation is one of the few effective tools to reduce losses, or outright rejection, of the crop due to damage from pests, such as root knot nematode and wireworm.

The decision on whether or not to fumigate should be made on a field-by-field and year-to-year basis. The key information needed to make these decisions are field histories of pest damage and results of soil sampling to determine populations of damaging nematode species and soilborne pathogens, such as Verticillium. Since many of the pests that damage potatoes are not uniformly distributed throughout a given field, it is important that the sampling process is extensive and takes into account differences in soil type and crop rotation. See Chap. 10 for more specific recommendations on soil sampling procedures.

Fumigation is generally done in the fall prior to potatoes, and requires extensive ground preparation for optimum results. Because these products move laterally and upward through the soil from the point of application, anything that impedes that movement, or allows rapid loss of the product from the soil, reduces efficacy. It is important that clods and compaction layers are broken up and crop residues are finely chopped and incorporated. Failure to do this may allow disease organisms to survive in clods and large pieces of plant debris where the fumigant cannot penetrate. Plant debris that is not well incorporated also allows the fumigant to escape from the soil before pests are exposed to an adequate concentration for the duration needed to achieve control. More specific recommendations on soil preparation, soil moisture, and application procedures of fumigants are given in Chap. 10.

It is important to understand that fumigation is not a cure-all, and it cannot take the place of a good crop rotation plan. Fumigants reduce populations of both soilborne pests and beneficial microorganisms. As a result, populations of pests can rebound to damaging levels after only one planting of a susceptible crop, resulting in the need to fumigate again the next time potatoes are grown in that field. The suppression of beneficial soil microorganisms resulting from fumigation can alter the response to fertilizers and result in higher levels of herbicide residues. These effects occur because fumigation suppresses the populations of soil microorganisms responsible for nutrient cycling and herbicide breakdown.