CROPPING SEQUENCE AND ROTATION: IMPACT ON POTATO PRODUCTION AND SOIL CONDITION

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ABSTRACT

Cropping sequence and length of rotation play an important role in potato production. Too often, growers are forced to base their cropping system decisions on short-term economic survival. Our market-based economy rewards economic efficiency and has helped push the trend to larger farms with lower production costs. Improving economic efficiency, with large, specialized potato equipment, means farming more potato acres. If the farm size can't be increased, then the rotation must be shortened to get more potato acres. But shorter rotations can drive up input costs and reduce yield and tuber quality and, what appeared to be a good economic decision, often turns out to be a cropping system that is not sustainable. It is a mistake to assume that yield, tuber quality, and input costs will remain static as rotations are shortened. Many factors need to be included in the cost of production estimates that all farms should be calculating as they consider length of rotation and cropping sequences. These factors include yield and tuber quality loss due to increased pest damage and decreased soil health, as well as increased operating costs in response to these negative impacts. It is also important to consider the risk of development of pesticide resistance in poorly designed cropping systems. Risk of developing pesticide resistance is much greater as the years between potato crops decreases and if pesticides of the same mode of action are used in the potato and the rotational crops. Truly sustainable cropping systems must balance agronomics and economics over both the short and the long term.

PESTICIDE RESISTANCE

Pesticide resistance is defined as the ability of a pest population to survive a pesticide treatment to which the original population was susceptible. Weeds, disease pathogens, and insects are all pests capable of developing resistance. Pesticide-resistant organisms may occur naturally within a population in very low numbers. However, repeated use of pesticides with the same mode of action (MOA) (the sequence of events in which a pesticide kills a pest organism) allows the initially small percentage of resistant organisms in the population to survive and reproduce while susceptible organisms are killed. As a result, the percentage of the pest population that is resistant to the MOA being used repeatedly becomes so large that the MOA is no longer effective on that pest population (Figure 1).

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There are several mechanisms by which a pest organism may be pesticide resistant. (1) The site within the organism where the pesticide acts (site of action) may be altered so that the pesticide can no longer interfere with the organism. (2) A resistant organism may metabolize or detoxify the pesticide more quickly than a susceptible organism; and (3) A resistant organism may be able to sequester the pesticide away from the site of action or block uptake or translocation so the pesticide never arrives at the site of action. Pest populations may develop multiple-resistance or cross-resistance. Multiple-resistance occurs when a population is resistant to pesticides with different MOAs. Populations with cross-resistance are resistant to different pesticides that all have the same MOA.

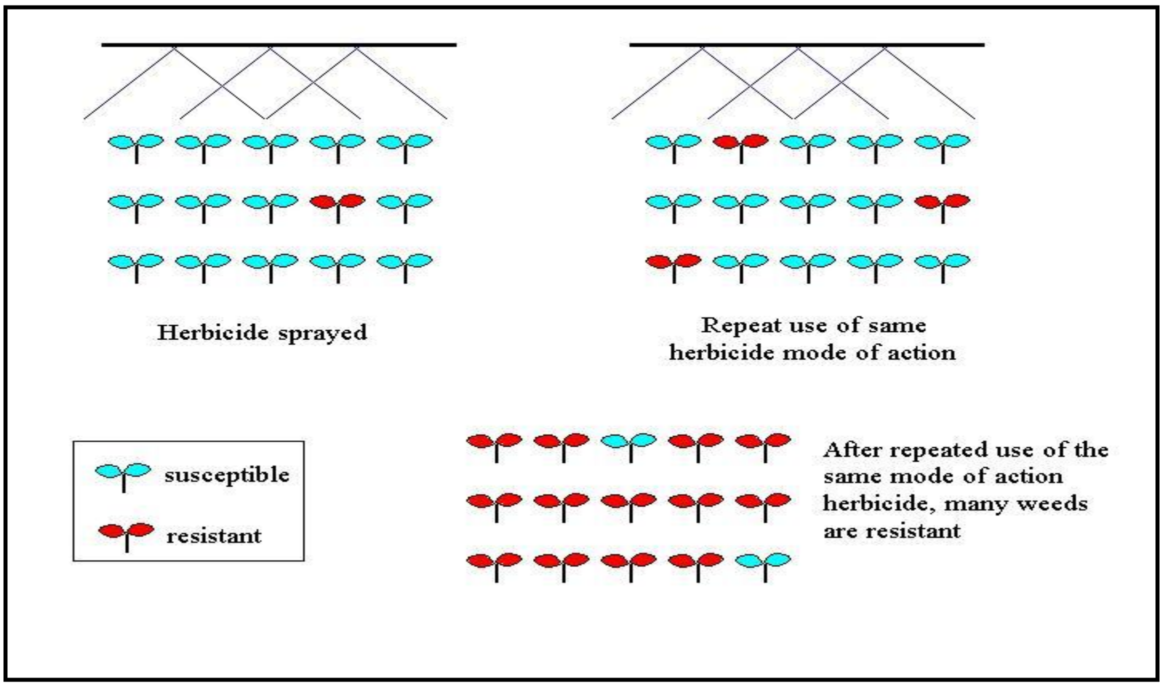

Figure 1. Resistant weed selection from repeated use of herbicides of the same mode of action. A similar effect occurs with disease pathogens, insects, and nematodes.

Development of pesticide resistance can be prevented or delayed by use of several good management strategies. One such strategy is alternating pesticides with different MOAs, both within and across seasons. Increasing the length of rotation also may help prevent the development of pesticide resistance by providing more chances to use MOAs different than what may be absolutely necessary to use in potatoes. Herbicides such as EPTC (Eptam®), metribuzin (Sencor®), pendimethalin (Prowl®), rimsulfuron (Matrix®), or s-metolachlor (Dual Magnum®/Dual II Magnum®) are commonly and effectively used in potato fields in Idaho. Commonly used nematicides include Vapam®, Telone®, Mocap®, Temik®, and Vydate®. Strobilurin fungicides (e.g. Quadris®, Headline®) are commonly and effectively used in potato fields in Idaho for control of early blight. Increasing the frequency of potatoes grown on a particular field increases the likelihood of application of these pesticides and, as a result, increases the risk of development of pesticide resistance. The negative impacts of poor pesticide resistance management strategies can affect not only the fields in question, but resistant populations can spread to neighboring fields and even regions.

It is common knowledge that growing potatoes in the same location year after year is unwise for many reasons. One such reason is the likelihood of building up pest populations for which potatoes are a primary host and/or are more difficult to control in potatoes. Similarly, it is usually unwise to select rotational crops that do not provide at least one year of a break in a pest's life cycle. Rotational crops often provide an opportunity to more effectively and/or inexpensively control certain pests. For example, inserting a grass crop (such as wheat, barley, or corn) between broadleaf crops (such as potatoes, sugar beets, and/or alfalfa) can allow for the use of a phenoxy herbicide, such as 2,4-D or 2,4-DB, which has the advantage of being less costly <u>and</u> having a different mode of action than most herbicides used in broadleaf crops. Other specific cropping sequence issues will be discussed in the sections below.

WEEDS

Ideally, the potato crop will be planted in soil from which the majority of the weed seed bank has been depleted. However, it is very difficult to completely eradicate weed seeds in the soil for a number of factors. Tillage can bring buried seeds to the germination zone near the surface. Depending on the weed species and environmental conditions, weed seeds can remain viable for long periods of time. In addition, new weed seeds are deposited by weeds not controlled in the previous cropping season, and also are transferred into fields by wind, water, birds, animals, humans, and equipment.

Cropping sequence choices may impact weed-related issues in potato production. Broadleaf weed control in grass crops is usually not as difficult as controlling broadleaf weeds in broadleaf crops. Multiple years of grass crops between years of potato production can be a cost effective means of reducing broadleaf weeds commonly found to be a problem in potatoes. As mentioned, the use of different MOAs from year to year is recommended to prevent or delay the development of herbicide-resistant weed populations. Since an increase in length of time before potatoes are again planted in a field usually increases the opportunities to use herbicides with different MOAs than what are used in potatoes, growers should take care to use these opportunites and choose herbicides for their rotational crops that have different MOAs than their potato herbicides. For instance, a herbicide used in potatoes - rimsulfuron (Matrix®) has the same MOA as the following herbicides used in other crops: sugar beet - triflusulfuron (UpBeet®); small grains - imazamethabenz-methyl (Assert®) or thifensulfuron (Harmony GT®); corn – nicosulfuron (Accent®); and alfalfa - imazamox (Raptor®). All inhibit acetolactate synthase. The only way to ensure that herbicides with different modes of action are used through the cropping sequence is to understand the characteristics of each product that is used and know their MOAs.

Tank-mixing herbicides with different MOAs is another way to reduce the risk of developing herbicide-resistant weed populations. Rotating MOAs from season to season and tank-mixing herbicides with different MOAs can be considered a best management practice, even for fields with minor weed pressure. Weed control in fields with minor weed pressure usually can be accomplished with a single application of tank-mixed herbicides with differing MOAs and complementary control spectrum.

In addition to herbicide resistance issues, length of rotation can impact weed control and potato production costs in other ways. Short rotations can increase the occurrence and/or density of weed species that are hard to control in potatoes. Severe weed pressure, especially from weeds that are problematic in potatoes, can increase control costs and the incidence of weed escapes. Potato tuber quality and yield are reduced by weed competition and as a result, net returns are reduced. Fields with severe weed pressure may require an increase in the application rate(s) and/or the number of herbicide applications (i.e. an unplanned, post-emergence rescue treatment may be necessary if early-season weed control is not adequate).

Severe weed pressure also may require the addition of a third herbicide to an early-season, preemergence tank mixture in order to achieve effective control. University of Idaho research comparing the economic return of two- and three-way tank mixtures has shown that, in general, the increased potato tuber quality and yield advantage resulting from more consistent and possibly broader spectrum weed control with three-way tank mixtures than two-way tank mixtures overcomes the cost of adding that third herbicide to the mixture. These tank mixture trials have been conducted for several years at the Aberdeen Research and Extension Center with moderate to severe mixed weed populations of hairy nightshade, redroot pigweed, common lambsquarters, kochia, green foxtail, and tame oat.

Including a green manure within the cropping system can also reduce weed populations and associated costs of control. Fall-planted rye, rapeseed, and Brassica green manure crops have all been shown to reduce weed populations in potato, although yields and economics are not always improved compared to standard weed control practices.

DISEASES

As far as diseases go, crop rotation is all about reducing inoculum. Some pathogens are so common in the soil that it is unlikely that any crop rotation will have a significant effect in reducing disease. Examples include:

*Bacterial soft rot (*Erwinia carotovora)*
*Fusarium dry rot (*Fusarium sambucinum* and *F. coeruleum)*

These diseases are typically managed through means other than crop rotation (good seed handling, seed treatments, fungicides, etc.).

Crop rotations can make it easier to manage some diseases. The pathogens causing the following diseases can survive in the soil, but adequate rotations (three years or more) will significantly reduce the soil as a source of inoculum. Seed-borne inoculum is a much more critical source of inoculum for these diseases in a good crop rotation.

The diseases in this category that are somewhat controlled with adequate rotations include:

*Rhizoctonia canker and black scurf (*Rhizoctonia solani)*
*Silver scurf (*Helminthosporium solani)*

The diseases for which soil-borne inoculum is most critical include (major soil-borne component):

*White mold (*Sclerotinia sclerotiorum)*
*Pink rot (*Phytophthora erythroseptica)*
*Pythium leak (various *Pythium* species)
*Verticillium wilt (*Verticillium dahliae)*
*Powdery scab (*Spongospora subterranea* subsp. *subterranean)*

As the time between susceptible hosts increases, the pathogen population decreases. Even though these pathogens can survive through three year rotations, increasing time between potato crops can lessen the impact of these diseases. Growing potatoes on a one or two year rotation will lead to greater problems with the diseases listed above compared to growing potatoes in a three plus year rotation. Because the organisms causing diseases with a major soil-borne component can live in the soil for several years, normal rotations (3-4 years) will not eliminate the pathogens, but will reduce the disease pressure in the field.

As far as rotation crops as alternative hosts, dry beans and canola are susceptible to white mold. Growing these crops in rotation with potatoes can increase the severity of white mold. The organisms causing pink rot and Pythium leak can infect small grains. Research is currently underway to determine the importance of wheat and barley in the pink rot and Pythium leak disease cycles, and to see if other crops such as corn and sugarbeets are hosts. Verticillium has many alternative plant hosts, such as mint and many weed species. Fortunately, the main crops grown in rotation (small grains, sugarbeets, alfalfa, dry beans, and corn) with potatoes in Idaho are not alternative hosts for Verticillium. The powdery scab organism is not known to infect any of the other major agronomic crops grown in Idaho.

Incorporation of green manure crops has been highly effective in reducing disease pressure without necessarily reducing pathogen population numbers. This holds true even in short (two year) potato rotations. Green manure crops have different modes of action in reducing disease. Some green manure crops release volatile compounds that are similar to chemical fumigants when incorporated into soil. Others may do nothing to reduce pathogen populations, but instead increase soil organic matter, leading to an increase in microbial activity and competition that can suppress disease.

Overall, growing potatoes in a field more frequently than once every three to four years will increase the likelihood of soil-borne diseases. This will, in turn, put more pressure on other disease management practices. Sometimes this added pressure is enough to compromise the efficacy of other management practices and the long-term viability of pesticides due to developed resistance by the disease pathogen. Growers often produce potatoes on less than a three to four year rotation due to short-term economic decisions that are often faulty, but production costs are often lower for longer rotations and the long term cost of shortening rotations is increased disease pressure, higher chemical inputs, as well as increased likelihood of pesticide resistance.

INSECTS

Rotating crops is one of the most effective cultural control practices to reduce potato insect populations. Potato insects that over-winter in soil or on crop residue have increased populations as the frequency of potatoes increases in the rotation. Increasing the frequency of potatoes in the rotation also results in increased incidence of volunteer potatoes in rotational crops, acting as a host and launch site for flying insects, such as Colorado potato beetles. Planting cereal grains after potatoes aids in reducing migrations from overwintering sites to new fields. Colorado potato beetles are weak fliers and have difficulty flying out of foliage that is more than a few inches high.

Furthermore, the collective increase in the frequency of potatoes in rotations results in an increase in the number of acres of potatoes statewide and will impact the populations of insects invading from neighboring fields. There is a direct correlation with infestation incidence and distance of neighboring fields. Planting new potato fields as far from last year's fields as possible (at least 400 yards) will reduce the number of immigrant overwintering Colorado potato beetles into the new field. When good rotation practices are followed, beetles coming into a field will concentrate at the edge. In such a situation, spraying insecticides against this pest only on the infested edge may be adequate.

Cropping sequence also impacts insect pressure. Wireworms are becoming increasingly important in several states, including Idaho, and one of the possible reasons for this is the increased rotation with grasses for the cattle industry. Therefore, avoiding rotations that include clovers and grasses may reduce wireworm populations. However, wireworms in general cannot be controlled with crop rotation itself because of the long life cycle of the most common species. Disturbing soils with cultivation (direct injury and exposure to desiccation or attack by predators), rotating crops, and controlling weeds are the best cultural control techniques available. Because soil dryness can kill many wireworms in an infested field, fallowing a field without irrigation will reduce wireworm numbers, but the control achieved must be weighed against the income lost from missing a crop year. Multiple fall plowing is known to be effective for the destruction of sugarbeet wireworm pupae, the most abundant wireworm in Idaho.

Planting alfalfa may reduce wireworm populations. However, leather jacket damage can be severe in potatoes following alfalfa, especially if the alfalfa is not plowed under until spring. Spider mites can be a problem following corn, bean, alfalfa, and clover seed if volunteer plant populations are high or if downwind from infested fields or along dusty roads.

As mentioned previously, a short rotation may increase the number of volunteer potatoes. Volunteer potatoes have been shown to be sources of both viruses and green peach aphid, which is the most efficient vector of potato viruses. Significant numbers of winged aphids can be produced in volunteer potato after plants have emerged. Aphids moving directly from volunteer potato plants in neighboring fields often transport viruses, since volunteer potato plants often have a high rate of disease infection.

NEMATODES

Nematode infestation on a potato crop results in yield decline and reduction in quality, thereby contributing economic loss to the industry. Among all nematodes, four species cause the majority of damage in Idaho potato fields, namely: root-knot, stubby-root, root-lesion, and potato-rot nematodes. Increased nematode pressure negatively impacts potato production in several ways. Root lesion and root-knot nematodes feed on roots and reduce yield. Root-knot nematodes feeding on tubers reduce quality by introducing physical imperfections at and near the tuber surface. Stubby-root nematodes transmit tobacco rattle virus (TRV) directly to forming potato tubers to cause corky ring spot symptoms. Virus infection blemishes tubers and renders them unmarketable. Damage from potato-rot nematodes is observed as lesions that begin to rot tubers in storage.

Although application of nematicides or biocontrols is often effective in reducing the effects of nematodes, these treatments result in an increased cost of production. There is also concern regarding the frequent use of these chemicals on the activity of beneficial soil microorganisms.

Crop rotation and cropping sequence impacts nematode populations and are important considerations for the management of potato nematodes. Increasing frequency of potatoes in a cropping system results in increased pressure from nematodes. Increasing the time between potato crops, particularly with rotation crops that are poor hosts, results in reduced risk of nematode damage. In general, potato tuber yields are higher in rotational sequences that begin with wheat or barley than in the sequences that begin with potato, sugar beet or onion. However, small grain crops are a host for many nematode species. Infection damage from Columbia root-knot (*M.chitwoodi*) nematode tends to be worse in potatoes following a small grain crop as compared to corn or other poorly susceptible hosts. In contrast, damage from northern root-knot nematode (*M. hapla*) tends to be worse following alfalfa. Resistant alfalfa varieties, such as Archer II, AmeriStand 444NT, AmeriStand 403T, Robust T&N and Roccus reduce populations of root-knot nematodes. Stubby-root nematodes have a wide range of hosts, including cereal crops. Host range studies for potato-rot nematodes have indicated that potatoes and snap beans are good hosts, red clover and corn are intermediate hosts, alfalfa is a poor host, and oat is a non-host.

The use of non-host green manure crops could potentially improve rotations by reducing dependence on nematicides. The oil-seed radish and mustard green manure crops effectively reduce populations of sugarbeet cyst and root-knot nematodes. Experiments conducted at micro plot and field level confirmed that rape seed 'Humus' and oil radish

‘*Raphanus sativus*’ reduced Columbia root-knot nematode population and increased the potato tuber yield and quality under Idaho conditions. Utilization of such resistant cultivars can reduce nematode survival, thereby reducing nematode damage and increasing yield potential. However, good weed control is imperative for these rotational/green manure crops to reduce nematode populations, as weeds are often hosts for nematodes.

In addition to reducing soil densities of nematode population, other benefits of using green manure crops include increased yields of subsequent potato crops, improved soil tilth and water holding capacity, reduced nitrogen leaching into groundwater, weed suppression, reduced soil erosion by wind and water, and potential suppression of other potato pests. To effectively reduce nematode populations, green manure crops require at least eight weeks growth with soil temperatures above 60º F, although new varieties may offer equivalent control with less time required. Nematode control is enhanced with green manure establishment in a fertile, loose soil with adequate moisture and good weed and volunteer potato control. The key to nematode control is to plow down a large quantity of chopped green manure biomass (foliage needs to be green at plowdown). Discing 1 to 2 times, plowing, ripping, and harrowing are recommended.

SOIL

Cropping sequence and rotation impacts soil chemical, physical, and biological properties, such as nutrient cycling, erosion potential, compaction, organic matter, and biological diversity and activity.

Potatoes take up relatively high rates of nutrients and harvested tubers remove some of these nutrients in large quantities. Potassium is the nutrient of greatest removal, with 300-400 lb-K_2O/acre removed for a 500 cwt/acre crop. This nutrient removal can have a depleting effect as the frequency of potato crops increases in the rotation. Removal rates of other crops can also be high. Corn silage and, especially, alfalfa also have high potassium removal rates in comparison to other rotational crops, such as small grains and sugarbeets. Soils contain varying amounts of reserve nutrients found in and among the mineral structures. In some cases, the soil contains thousands of pounds of various nutrients, but these reserves can be depleted over time if the amount removed is not replaced through fertilization and irrigation water. The speed at which the reserve nutrients enter the biologically active pool of nutrients also varies and can be inhibited as the number of high demand crops is increased in the rotation.

Nitrogen is removed at a rate of about 240 lb-N/acre by a 500 cwt/ac potato crop. Phosphorus is removed at about 80 lb-P_2O_5/acre. Calcium, magnesium, sulfur, and chloride are also nutrients with relatively high removal rates with rates ranging between 20 and 50 lb/acre. Micronutrients other than chloride (zinc, iron, manganese, copper, boron, molybdenum, and nickel) are removed at a rate of less than a pound per acre per year (some less than a hundredth of a pound per acre). The levels of any of these nutrients in the soil can also be lowered over time if not replaced. Of course, there is nothing wrong with “mining” the soil if these nutrients exist in great excess of plant need, which is often the case. However, depleting the soil to critical levels can impact plant health over time.

For example, a potato-wheat-wheat-wheat rotation removes approximately 260 lb-P_2O_5/acre and 450 lb-K_2O/acre over the four year cycle. Potato growers commonly apply in excess of the removal rate for the phosphorus and this nutrient is generally not depleted in a potato cropping system. However, the potassium is much more likely to be depleted if the removal rate is not replaced. Other factors, such as mineral fixation, leaching, and decreasing mineral solubility complicate the availability of nutrients, which is one reason why soil testing needs to be the standard for fertilization rather than just basing it on removal rates. Shortening the rotation to a potato-wheat-potato-wheat cycle increases the removal to approximately 280 lb-P_2O_5/acre and 780 lb-K_2O/acre over the four years, most likely requiring an increase in the applied rate of both nutrients.

In addition to nutritional effects, increasing the frequency of potatoes in rotation increases the erosion potential. Potatoes typically are clean-tilled both before and after the season. Most other crops are more conducive to minimum tillage practices that leave a higher percentage of erosion preventing residues on the soil surface. Fall tillage is common prior to potato planting in order to reduce disease inoculum and to hasten straw decomposition. Furthermore, at the end of the season the potato plant leaves little residue on the soil surface and harvesting this tuber crop is the equivalent of a thorough tillage operation. Therefore, it is typical for the soil to be exposed to a high wind and water erosion risk from the fall prior to the spring after potato production. As a result, erosion increases as the frequency of potatoes in the rotation increases. Inclusion of other low-residue crops, such as onions, sugarbeets and beans, has a similar effect on erosion rates, which is compounded if they are root crops for the reasons cited previously.

Erosion results in the loss of valuable topsoil that contains important physical, chemical, and biological properties that are not as prevalent in subsoil materials. Research shows that yield losses occur if the layer of topsoil is less than 12-16 inches. Basin and minimum tillage have been shown to work effectively in potato cropping systems to reduce water erosion. Furthermore, planting a green manure cover crop during the fall before and after potato production greatly reduces erosion and increases the organic matter content of the soil.

In addition to erosion benefits, organic matter is important for many reasons. Organic matter is a source of slow-release nutrients and the site of water and nutrient holding capacity. Organic matter also provides the “glue” that holds soil aggregates together, which is important for good soil structure and facilitation of vigorous root exploration and adequate water, air, and nutrient movement in the soil. The primary component of organic matter is carbon, which is the source of energy for plants and microbes. As organic matter increases, microbial diversity and activity increases. The carbon dioxide released from respiring microbes is slowly released from the soil and captured by the canopy for use in photosynthetic processes. In addition, carbon dioxide is a greenhouse gas and there is a popularly perceived benefit if more carbon is stored in the soil and less is in the atmosphere.

The amount of organic matter being returned to the soil decreases as the number of low residue crops, such as potatoes, increases in the cropping system. High residue crops such as corn and small grains can add significant quantities of organic matter into the soil profile. Harvesting the wheat straw and harvesting corn as silage will reduce the amount of organic matter added to the soil, but these scenarios still result in more organic matter addition as compared to a potato crop.

In addition to residue issues, potatoes typically have high levels of tillage. Tillage warms and dries the soil, resulting in an increase in chemical oxidation and microbial decomposition of organic matter. The net effect of tillage is a significant loss of soil organic matter.

Tillage and organic matter loss also influence compaction. Compaction is a major source of yield reduction in many soils. Harvest and tillage operations in potato production result in destruction of soil aggregates by physical breakage and loss of organic matter binding. Furthermore, field traffic, especially when wet, compacts the soil and results in less pore space for root, water, nutrient, and air movement. As mentioned previously, potatoes and other root crops have relatively more soil disturbance than most other crops. In addition, potatoes often require more trips across the field with heavy equipment. The net effect of potato production is an increased risk of yield loss from compaction. Inclusion of other root crops, such as sugarbeets, into the rotation also increases compaction risk. Other crops, such as alfalfa, can have an ameliorating effect on soil structure.

Finally, soil biology is impacted by both frequency of potatoes in the rotation and the cropping sequence. Increasing the number of potato crops in the rotation favors the selection of potato pathogens, as discussed previously. Also mentioned previously, reducing the amount of residue in the cropping system reduces the food supply for microorganisms. Although microorganisms can be both good and bad for plants, the best scenario is to have large numbers of diverse species of microorganisms. Repeated fumigation and low inputs of residues can decrease the total number microorganisms and the number of species present in the soil. The effects of fumigation on soil microbial populations seem to be most dramatic on soils with low base levels of organic matter. Regardless of the soil type, microbial populations tend to fall dramatically immediately after fumigation, but then rebound with time. The make up of the specific microbial species in the population may change after fumigation. The long term effects of this type of disruption of the soil system are not well understood.

ECONOMICS

University of Idaho research has shown a 40 cwt/ac loss in yield for each year less than four between potato crops. Size and tuber quality have also been shown to decrease as the time between potato crops is reduced. And, as discussed above, increased pest pressure results in potential increases in herbicide, insecticide, fungicide, and fumigant applications. Relative rates of fertilizer may also increase as potato rotations are shortened. Obviously, increased costs with decreased yield and quality result in reduced net revenue for each potato acre and higher costs per hundredweight. The long-term costs of short rotations are more difficult to quantify, but include loss of topsoil from erosion and increased likelihood of pesticide resistance. The cost of pesticide resistance is not only measured in terms of increased pest damage, but also results in an overall increase in pesticide costs as chemical companies have to develop new chemistries, while the cost recovery period for existing products is decreased, resulting in higher prices.

So, what is driving the trend to shorter rotations? There are many factors, but four tend to dominate. First, the potential gross return per acre (Yield x Price) is much higher for a potato crop than for grain or alfalfa, even when potato prices are only average. And, while the chance of a super high potato price is rare, the "jackpot" is significant when it does happen. Second, once a grower invests in specialized potato equipment, no other crop offers the potential of recapturing the investment. Potato equipment is expensive. Third, increasing the frequency of potatoes results in an increased economic efficiency of land (with fixed land payments). And fourth, potato equipment, like most farm equipment, has an economy of size, meaning the cost is less per acre for the larger equipment when used at an economically efficient level. But the economic efficiency exists only when the costs are spread out over an optimum number of acres and the number of acres needed to achieve an economic optimum is greater for the larger-sized equipment. For example, spreading out the cost of a new potato harvester over 500 acres rather than 400 acres results in a decrease in per acre ownership costs. But if the increased use starts to decrease the useful life of the machine, then the cost reduction will be less. The biggest perceived advantage to the grower is spreading the fixed payment on the harvester over more acres.

Long-term profitability is crucial to any sustainable rotation. One of the key management issues is balancing the increased economic efficiency for land and equipment (from shortening the rotation to increase potato acres and reduce machinery ownership costs) against the rising operating costs as potato frequency increases, as shown in Figure 2. Since shorter rotations often reduce yields and require more inputs, determining an accurate cost per hundredweight is essential to any grower struggling with this issue. Each grower has to calculate these costs and balance them with the cost of production and revenue potential for the crops grown in rotation with potatoes.

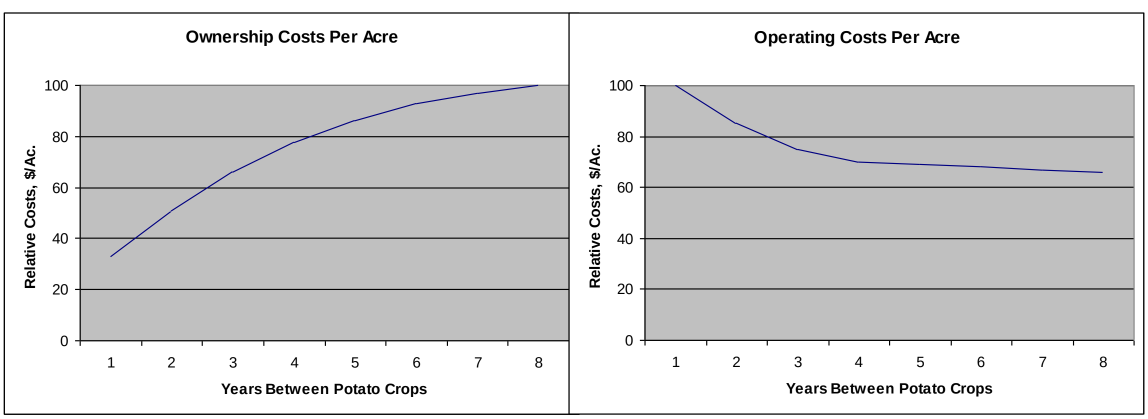

Figure 2. Estimated cost of production for both operating and ownership costs as a function of years between potato crops.

An example of such an exercise is given for a seed potato farm of 1350 acres in a short season climate (Table 1). The scenarios examined include four-, three-, and two-year rotations. The two-year rotation is evaluated both with and without fumigation. These results show that the total cost per acre decreases as the rotation is shortened and potato acres increase, assuming a fixed farm size. The ownership costs per acre are lower because of an increased economic efficiency on machinery. But, the total cost per hundred weight (cwt.) increases as the rotation is shortened. Lower yields on shorter rotations drives up the cost per hundredweight on both operating and ownership costs. Which is the best way to view this from a management perspective? The answer lies in the question "are growers selling potatoes on a per acre or a per cwt basis?," the later being the obvious answer. Of course, this is only one example to illustrate this point. Other factors that need to be examined when evaluating the economics of entire cropping system are:

*What are the costs and returns to the rotational acre (not just the potato crop)?
*Is the land base fixed or flexible?
*How accurate are the yield projections?
*What is the accuracy of the cost estimates?
*What is the frequency of machinery replacement?
*Is the land charge fixed or variable?

Table 1. Cost of production example for a seed potato farm, comparing 2-, 3-, and 4-year rotations on a per acre and a per cwt. basis.

	4-Year	3-Year	2-Year	2-Year with Fumigation
Operating Cost/ac.	$1033	$1024	$1019	$1195
Ownership Cost/ac.	$496	$456	$402	$402
Total Cost/ac.	$1529	$1480	$1421	$1597
Operating Cost/cwt.	$4.13	$4.55	$5.10	$5.20
Ownership Cost/cwt	$1.98	$2.03	$2.01	$1.75
Total Cost/cwt.	$6.12	$6.58	$7.11	$6.94
Yield	250	225	200	230
Potato Acres	350	450	675	675

The land base is fixed at 1350 acres. Projections are based on a 25 cwt./ac. decrease in yield with each year less than four between potato crops (the research based average of 40 cwt./ac. is not used as the yield potential is relatively low for this field). Fumigation partially overcomes this yield loss. Operating costs increase as rotations are shortened based on increased pesticide costs. Some cost savings occur from reduced fertilizer as the yields decline. Ownership costs decrease as rotations are shortened based and potato machinery ownership costs being spread over more acres. In addition, the 2 year scenario has the addition of a second planter and replacement of the 2-row harvester with a 4-row harvester.

The bottom line is determination of the constraining resources and how they interact for an economic optimum for both the long- and short-term viability of the operation and the land.

CONCLUSIONS

Decisions regarding length of rotation and rotational crops in a potato cropping system need to be based on more than potential gross returns. Actual cost of production that accounts for both operational and ownership costs for all aspects of the system need to be considered. Anticipated yield losses, increased chemical control costs, pest control difficulties, and pesticide resistance issues are all important aspects of these decisions. The long-term ramifications of these decisions should also be factored into cropping system decisions, especially with regard to soil condition and pesticide resistance issues. Decreasing the frequency of time between potato crops and careful selection of rotational crops and use of pesticides with different modes of action are best management practices for potato production.

Trade names are provided for clarity and do not constitute an endorsement of the product.