

ROTATIONS

Designing a System that Works for You

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Roadside weeds at Grasslands National Park
Photo credit: Brenda Frick

INTRODUCTION

A rotation is an intentional sequence of different crops grown on a piece of land in successive years. It is a way of providing diversity over time. Many studies show that rotation is the single most effective means of providing higher and more stable yields, soil benefits such as fertility, and improved weed, pest and disease management.

Planning a rotation means managing a great many factors. A rotation must work agronomically and economically. It must meet soil fertility needs, and provide for weed management. It must leave enough time between similar crops so that diseases and insect pests cannot persist from one susceptible crop to another. A sound rotation is the key to managing the cropping system.

“Crop rotation is a critical feature of all organic cropping systems because it provides the principal mechanism for building healthy soils, a major way to control pests, and a variety of other benefits.”

Charles L. Mohler, Senior Research Associate, Cornell University, 2009.

GROW CROPS THAT MAKE SENSE

Developing an optimal rotation plan involves two main sets of decisions, which crops to grow, and in which order to grow them.

Grow crops that work for you

Crop selection is limited by what is regionally adapted. Temperature, moisture, and length of season are the key considerations. Most producers know what works in their region, but with more erratic weather in recent years, it may be hard to determine what will grow best. For less reliable crops, or for crops that are new to the producer, it

might be best to experiment in a smaller field. Even within crops, cultivar performance can vary, so choose carefully.

Specialized equipment is also important, or at least desirable for some crops: vine lifters for lentils, specialized harvesters for potatoes, adjustable height cutting blades for hemp, straw choppers for flax. Be sure that you have, or can access, the proper equipment to effectively manage all crops in your rotation.

Grow what works for your market

For the economic sustainability of the farm, it is important to grow crops that have a market. Most advisors suggest that producers have the market in place before seeding a crop.

Determining cost of production can be difficult, but it is advisable. Each provincial government has guidelines and templates on their websites. Once the cost of production has been established, the sale price can be evaluated. It does the farm little good to sell oats for \$4.00 per bushel if it costs \$6.00 per bushel to bring them to market. But oats may be an ideal crop when buyers are offering \$10 per bushel.

Growing quality is important for successful marketing. Weather may be as big a determinant of this as crop management, but it is still worthwhile to use management practices that improve crop quality. [See **cultural control factsheet.**] This includes steps to retain crop quality in storage. [See **crop quality factsheets.**] Long-term storage can be a benefit in marketing. Organic markets can be volatile, and storage allows a producer to wait for better prices. Markets are largely driven by supply and demand. Prices are often highest when crops are difficult to grow – e.g. during droughts.

If there is no economic market for an agronomically valuable crop, consider other ways of incorporating it

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into the rotation, or other crops that might fill its niche. For instance, if there is no market for fall rye, but it is desirable because it offers good cover in fall and spring and thus is competitive with quack grass, consider using it, perhaps with a legume, as a green manure. Or consider sweetclover, which has a similar life cycle, and would also provide cover in the fall and spring.

Green manures, crops grown to feed the soil, are a critical part of any organic rotation. Including legumes in green manures is especially important, as legumes, can add nitrogen to the soil for following crops to use. Green manures can also add soil organic matter, cycle nutrients and provide opportunities for weed control. When green manures are incorporated into the soil, or mulched over the soil surface, they don't offer an immediate cash return; their value is found in succeeding years. For this reason, it makes sense to amortize the cost of green manures over the other crops in the rotation.

Alternately, green manures can be turned into a cash crop by grazing them with livestock. Grazing animals return 75-95% of the nitrogen they consume to the land in urine and dung. Turning green manures into cash crops by harvesting grain from them negates most of the value of the green manure as significant nutrients are removed with the grain.

Grow what works for your farm

An ideal rotation meets as many of the farm needs as possible. Nitrogen is usually the most limiting soil nutrient. This can be supplied by legume green manures. Other nutrients are less easily added, but can be made more available through green manures; for instance brassicas and legumes can improve phosphorus availability.

Soil fertility is associated with soil organic matter, which includes the bodies of soil organisms, and the plant material they feed on and live within. It is the biological activity of these organisms that cycles nutrients, returning them to plant-available forms. The soil biological activity can be increased by constantly keeping the soil covered – by crops, by green manures, by fall and winter cover crops. Including these crops in rotation improves soil fertility.

Soil tilth, the formation of pores and spaces in the soil, is a function of soil aggregates (clusters of soil particles). Soil microorganisms living on and near plant roots provide the 'glue' needed to hold soil aggregates together. Keeping the soil covered is critical for these microorganisms. Some crops can be more helpful than others in increasing soil tilth. Oats and buckwheat are annual crops generally recognized to leave soil in better tilth. Perennial forages, especially mixtures of grasses and legumes, can be even

more effective at improving soil tilth. Their extensive roots grow and die over a long season, providing an abundant food source for soil organisms, and leaving channels for air and water in the soil.

Tilth can be compromised by compaction, especially when waterlogged, or if heavy machinery is used when soils are wet. Including deep-rooted crops in rotation can reduce this problem. Tilth can also be compromised by excessive tillage. This can be offset by inclusion of forages and green manures in the rotation.

Soil organisms responsible for nutrient cycling do best when they are fed. Ideally, a rotation will include crops that keep the ground covered as much of the season as possible. These include relay crops, cover crops, and forage crops, as well as grain crops and green manures.

Rotations can also be designed to include the needs of livestock – forages for cattle, and grain for swine, poultry and possibly cattle. The benefits of forage in a rotation go far beyond their value as hay. They provide a highly available nutrient source for soil organism, they root deeply in the soil, and manures are a highly available nutrient form. For producers without livestock, it may be worthwhile to make arrangements for the neighbours cattle to graze their land. Importing and grazing forage is one way to bring a whole range of highly available nutrients onto the farm.

PUTTING A ROTATION TOGETHER

The benefits of a sound rotation are best realized by carefully planning the order in which crops are grown. The basic principle of rotation design is to vary crops – to avoid growing similar crops one after another. Growing similar crops back-to-back allows insects, diseases and weeds to build up. Varying crops keeps the pests that do well in that crop from gaining advantage.

Start with a green manure

Rotations can be dynamic. Changes may need to be made to match field and weather conditions each year, or to respond to market trends. However, green manure frequency should be maintained.

An important goal of the green manure in the rotation is to add nitrogen. For green manure legumes grown to feed the soil, the amount of nitrogen added is approximately 2.5% of the aboveground dry biomass. For instance, if sweet-clover produced 4000 lb/ac of dry biomass, it would provide approximately 100 lb/ac of nitrogen. The amount of nitrogen provided is dependent on the growth of the green manure, and thus on weather, soil quality, seeding rates and depths, and on the species chosen.

Of course, nitrogen is not the only nutrient required, but it is the only one that can be replaced without inputs. Deep-rooted green manures such as alfalfa can access nutrients from deep in the soil, and cycle them into shallower soils in which annual crops generally grow. If other nutrients, such as phosphorus or sulphur, are depleted, manure might be the most cost-effective solution. As mentioned above, importing bales of hay, and then bale grazing in the field (with the neighbour's cattle if necessary), can supplement a variety of nutrients, and provide them in plant available forms.

Green manures can also provide excellent weed control. For annual green manures, this is because they are grown for a much shorter season. The green manure itself may or may not suppress weed growth, but when the green manure is incorporated, so is the weed biomass. Weeds generally do not get a chance to go to seed in the time a green manure is left standing. If weeds are maturing too rapidly, it may be wise to terminate the green manure early to avoid weed seed set.

Longer duration green manures tend to be more competitive with weeds, offering good suppression with their abundant biomass, and competition with weeds in the fall and early spring. Sweetclover in its second year, for instance, can grow into a solid stand, 3-5 ft tall. A perennial such as alfalfa suppresses weeds through competition, but mowing also prevents annual weeds from setting seed.

Different green manures provide different options in the rotation. Short-term green manures are not taken to maturity, so they give the producer an opportunity to alter the timing of tillage or grazing, or to even out the workload. Annuals can be seeded early, as some legumes are quite frost tolerant. They can be seeded late, as they do not have to set seed. In fact, warm-season plants that are not hardy in our region can be used as green manures since seed set is not expected or desired. Biennials can be seeded with the preceding crop, providing fall and spring cover, and reducing the stress at seeding time. Perennials can provide more sustained benefits. If green manures are used for only a portion of the growing season, other cover or catch crops can be seeded to provide living plants for soil organisms to consume, reduce erosion, and retain nutrients in the biological system. [See [Green Manure Tool Kit, Pivot and Grow](#)].

Grow a needy crop after the green manure

Nitrogen benefits from green manures are often greatest in the first year following their termination. At this point in the rotation, heavy feeders are most successful. Hemp is a heavy feeder, and does best after an alfalfa or fababeen plowdown; wheat requires plenty of nitrogen to achieve higher protein levels, which bring higher prices. (Protein

may be high in a drought year because drought limits growth before nitrogen begins to limit protein.)

The year after green manure often has the fewest weeds. This may be an optimal time to grow crops that are considered poorly competitive, such as flax, lentils or edible beans. As these crops are often the 'money crops', moving them to a clean field can make economic sense.

Grow pulses when rotations are depleted of nitrogen
Flax is not a heavy feeder, so can be a good choice once nitrogen levels are lower. Weeds are less problematic when nutrients are low.

Short poorly-competitive pulses such as lentil and chickpea might benefit from clean fields. However, as legumes they can also get a significant advantage if they are grown when the nitrogen is depleted. At that point they have access to nitrogen fixation and the weeds do not. Peas and soybeans can be especially vigorous as the last crop in rotation.

Budgeting the green manure nitrogen

Nitrogen can be budgeted, much like money, with green manures considered to be investments. Green manures release about 50-60% of their nitrogen in the first year, and another 20% in the second year. This is like investments that pay dividends. In the example above, the sweetclover produced 100 lb/ac of nitrogen; and thus 50-60 lb/ac would be available in the first year, and 20 lb/ac in the second. The amount of nitrogen needed by grain crops depends on all the factors that determine the yield of crop – weather, seeding rate, vigour, etc. Some estimates are provided in table 1.

After the sweetclover green manure, with ~50 lb/ac nitrogen available, a heavy feeding crop could be supported. If wheat were placed here in the rotation, it would have a good probability of achieving high protein. If the wheat removed 43 lb/ac N, this would leave 7 lb/ac N of the green manure nitrogen behind. In the next year, an additional 20 lb/ac N would be released from the green manure, to add to the 7 lb/ac N left over from the last year. This 27 lb/ac N would be insufficient for any of the listed crops. This would be a point in the rotation where a pulse may be appropriate. This suggests that a nitrogen budget rotation might be sweetclover green manure – wheat – pea. With only a small drop in yield, a sweetclover green manure – wheat – oat – pea rotation could be considered.

Another rotation that fits this nitrogen budget might be field pea green manure – fall rye - flax – oat – lentil. Field pea producing about 6000 lb/ac N would provide about 150 lb/ac N, with a minimum 75 lb/ac N available in the first year. Fall rye seeded after the green manure would use about 37 lb/ac N, leaving 38 lb/ac N behind. In the second

Table 1. Nitrogen required for various crops at specified yield levels

CROP	YIELD BU/AC	NITROGEN REMOVED LB/AC
WHEAT	30	43
OAT	50	29
BARLEY	50	48
FALL RYE	35	37
FLAX	20	39

year after green manure, an additional 30 lb/ac N would be available. This 68 lb/ac N would be sufficient for a flax crop (39 lb/ac N) followed by an oat crop (29 lb/ac N). At this point nitrogen would be depleted, giving a lentil crop an advantage in weed competition.

Of course, nitrogen isn't always the most limiting factor. In brown soils, water limitation may require a rotation with fewer years between green manures to allow water recharge. Green manures may need to be specifically chosen for water use efficiency (e.g. chickling vetch) or terminated early to avoid excessive water use. This reduces their growth and thus their nitrogen potential. Rotations might also be shortened if they become excessively weedy. There are many factors to consider in balancing the needs of a rotation.

Weed management

Rotations can be used for weed management. Each crop provides opportunities for weeds, between the last tillage and the time the crop is truly competitive, and between harvest and the next tillage. The key to weed management is to change the timing of these opportunities. This way no specific weed gets out of balance. Weeds often resemble the crops in which they grow – annual weeds in annual crops, perennial weeds in perennial crops. By alternating annuals, winter crops and perennials, no particular weed type is favoured. Annual weeds germinate at different temperatures. Early seeded crops offer strong competition to late emerging weeds. Delayed seeding provides good control of early emerging weeds.

Weakly competitive crops offer an opportunity for weeds. Strongly competitive crops should bracket these crops, to

both provide a non-weedy starting point for the weakly competitive crop and to clean up weeds that build in it.

Pest management

Rotations can also be used to reduce disease and insect potential. Growing the same crop for several years in the same field increases the incidence of diseases and insects specific to that crop. Disease organisms will die if they cannot find a suitable host within a certain time. Insects will either die or move on. The goal of rotational pest management is to rotate away from susceptible crops until the inoculum for that disease or insect pest is gone, or greatly reduced.

In general, the more similar crops are, the more diseases they share, see table 2.

Often it is sufficient to alternate between cereals and non-cereals. For soil-borne diseases, the interval between similar crops depends on how quickly the plant material decomposes. Residues decompose more rapidly in the soil than they do on the soil surface. In this case, tillage is beneficial in reducing inoculum.

Some pest insects, such as the flax bollworm, are crop specific. Others, such as grasshoppers, are not. Crop-specific insects can be greatly reduced by crop rotation.

Plan for diversity

Diversity is the underlying theme of rotation design, whether the goal of the rotation is primarily for fertility or weed and pest management. Diversity can be achieved in a number of ways:

- Alternate shallow-rooted with deep-rooted crops
- Alternate heavy and light feeders
- Alternate susceptible crops with those unaffected by the disease or pest.
- Alternate seasonality – annual, winter annual/ biennial, perennial
- Alternate early and late seeding
- Include short- and long-season crops - e.g. green feed, fall rye
- Surround weak competitors with strong competitors
- Consider intercropping

As much as possible, keep the ground covered, with cash crops or with cover crops as well as cash crops.

Providing crop diversity is an excellent way to reduce insect, disease and weed pressures. It also helps to spread the load across the season, so that activities peak at different times in different crops.

Table 2. Diseases of grain crop on the prairies

DISEASE	SUSCEPTIBLE CROPS
Tan spot, dwarf bunt	WHEAT
Net blotch, Spot blotch, Scald,	BARLEY
Leaf rust, stem rust, stripe rust, common bunt, wheat mosaic virus, powdery mildew	WHEAT, BARLEY
Septoria black stem, crown rust	OATS
Septoria leaf spot, Stagonospora leaf and glume blotch, Fusarium crown rot, take-all, Fusarium head blight, ergot, loose smut	CEREALS AND OTHER GRASSES
Mycosphaerella blight, powdery mildew (different species from wheat and barley)	FIELD PEA
Ascochyta	PULSES (Each had own species)
Sclerotinia stem rot	PULSES, MUSTARD, SWEET-CLOVER, FLAX, SUNFLOWER

Innovation can be an important part of the fun and evolution of the farm. A whole-farm rotation plan might include a few acres to play with. This might be the place to experiment with new crops, new techniques, and new products.

Rotations for specific issues

Rotations are powerful. They can be used to address specific issues.

Canada thistle can become problematic, especially if soil is waterlogged or compacted. Including three or more years of alfalfa can virtually eliminate Canada thistle. Likely this is due to the regular mowing for hay, and the strong competitive ability of alfalfa after mowing, and in the fall. Growing a crop for green feed can be useful. The short season of the crop allows more opportunity for tillage. Winter cereals offer good competition in the fall and spring, times that annual crops are not competitive. The early harvest of winter cereals offers a greater season for tillage controls for the Canada thistle.

Quack grass is active at low temperatures, in fall and spring. Sweetclover, fall rye and winter wheat offer competition for the quack grass at those times.

Annual weeds that germinate early can be killed by delayed seeding and pre-seeding tillage. This works best with a short-season crop. Early seeding of frost tolerant crops can assure that they are strongly competitive and have the advantage over late-germinating weed seeds.

Low nitrogen in a field is usually seen as pale leaves, and reduced vigour. This signals the time for legumes, either as pulses or as green manures. Pulses can be quite competitive in fields where the weeds have little access to excess nitrogen.

Low soil organic matter can be a problem, reducing nutrient cycling, water infiltration and retention, and increasing erosion. Using green manures that include cereals as well as legumes can increase organic matter in the soil. Legumes alone are often quite quickly decomposed and do not contribute a lot to stable organic matter. Cereals tend to persist for longer.

Soils prone to erosion need special care. They should be kept covered as much as possible, with perennial forages, or by cover crops when not in cash crops. Black summerfallow is not a good substitute for cover crops. When summer-fallow is deemed necessary, it should be on limited acres, and followed by cover crops to rebuild soil.

AVOID BAD COMBINATIONS

Volunteers

Pulses can make excellent green manures. However, if pulses are also cash crops on a farm, avoid cultivars as green manures that might cause problems if they volunteer in the cash crop. For instance, Indianhead lentils could be hard to clean out of small green lentils, and would be seen as a contaminant. Growing pulses as a crop after using pulses as a green manure also increases the risk of disease.

Many crops volunteer heavily in the year after they are grown. This challenge can be addressed through chaff collection at harvest, stubble grazing after harvest, or delayed seeding of the following crop, with early tillage to remove volunteers. Alternately, the volunteer crop might be considered an intercrop in the crop seeded that year. Problems can be avoided if crops that are especially prone to volunteering, such as flax and mustard, are followed with crops that can be easily separated from them. Growing these crops before the green manure year is also an option.

Weather mismatches

Weather can be unpredictable, but often snow levels and the amount of ground water saturation from last year can be a guide. To the extent that weather can be anticipated, rotations should accommodate weather risks.

Some crops are particularly sensitive to weather. For instance, lentil does very poorly when it is wet. It also suffers severe damage from grasshoppers, which tend to have outbreaks in very dry years. Ideally, lentil prefers moderately dry conditions, and is not a good choice in extreme years. Peas can be fairly grasshopper resistant, but all crops are low yielding in the face of extreme drought. Chickling vetch is fairly drought tolerant. Building soil organic matter, especially with forages, improves water infiltration and retention and reduces the impacts of drought and flooding.

Late seeding can be a useful technique for weed control. However, it increases the risk crops being caught by early frost. Tillage that often accompanies late seeding exposes the soil to the air and can dry it. This is fine in a year with early rains. It is problematic in a drought.

SUMMARY – MAKING IT WORK

The ideal rotation is site specific and may change over time. The basic principle of rotations is diversity. Within that theme, many sequences are possible. The producer is in the best position to determine what works for his or her farm. There are a number of markers of success, e.g. healthy crops, healthy economics, good whole farm functionality. If it's not working, tweak it. Be open to changes that respond to weather and markets, but don't abandon the basic principles and always retain diversity.

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