

SOIL NUTRIENT MANAGEMENT ON ORGANIC GRAIN FARMS IN MONTANA

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cover photos courtesy of Ole Norgaard - sainfoin and pea fields, central Montana



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Maintaining soil fertility and replacing nutrients removed at harvest are inherent challenges in organic production. With the exception of nitrogen (N), which can be added by legumes, nutrients removed at harvest must eventually be replaced or made more available from the soil by altering soil properties. However, since there is a finite amount of each nutrient in the soil, the latter is a short term solution. Ultimately the soil nutrient pool will be depleted and no longer sustain high yields. This bulletin presents options for organic producers to maintain or build nutrient availability. The information should be used together with your management options and goals. Since organic standards change with time and location, be sure to check with your certifying agent before using any product or practice on an organically managed field.

SOIL FERTILITY CHALLENGES FOR ORGANIC PRODUCERS

Plant nutrient availability depends on the crop, soil and climate. Growers often focus on increasing N availability because it generally controls crop yield and quality more than any other nutrient. This may result in overlooking other nutrients and can lead to low N fixation by legumes. However, adding nutrients such as phosphorus (P), potassium (K) or sulfur (S) to organic fields is not easy or inexpensive. Small acreage market growers may have options available that are not economic for large acreage grain or forage producers. Soil nutrients have decreased on some organic fields in Montana and yield and/or quality have sometimes suffered (1, 2). For example, the soil in organic rotation at Montana State University's Post Farm in Gallatin Valley was lower in N, P, K, and S than fertilized no-till soil after 4 years. After 7 years of organic rotation, winter pea nodulation and yield were reduced. Nitrogen fixation had apparently decreased,

most likely because of insufficient P and S, which were low in tissue tests. Also, low grain protein in the organic rotation suggested the legume based N management was not sufficient to maintain grain quality (1).

Nutrient depletion rates depend largely on the crop and its yield. For example, 3 ton/acre of alfalfa removes 30 lb P_2O_5 /acre while a 30 bu/acre spring wheat crop removes 19 lb P_2O_5 /acre. For estimates of nutrients removed by the harvested portion of crops, see *Fertilizer Guidelines for Montana Crops* (3). MSU Extension's *Nutrient Management Modules 2-9* (4) provide information on plant nutrients, and transitioning to organic production is discussed in *From Conventional to Organic Cropping: What to Expect during the Transition Years* (5). Information on how to obtain referenced Extension publications is given at the end of this publication.

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UNDERSTANDING YOUR SOIL

Organic soil fertility management is based on maintaining nutrients in organic reservoirs or plant-available forms rather than adding soluble inorganic nutrients (6). Soil tests can identify limiting nutrients and may help with management decisions. For example, low P levels indicate manure or another P source may be beneficial or that the site is suited for crops efficient at extracting soil P (described below). Even if a grower does not plan on fertilizing, knowing soil nutrient levels can help optimize crop rotations. For example, legumes should be grown in fields low in N and wheat in areas higher in N. However, standard soil tests may underestimate the availability of some nutrients because they do not measure nutrients that will be released from soil during a growing season. Management practices that improve soil health may prove more beneficial than those guided solely by soil test levels. The National Resources Conservation

Service (7) has information to help assess physical and biological attributes of soil health that are not measured by standard soil tests.

An alternative to using soil tests to evaluate N availability is to look at wheat protein. If average protein levels over several years were less than about 12 percent in winter wheat or 13 percent in spring wheat, then yields were likely limited by the lack of N (8) and the grower should consider increasing the frequency of legumes in the rotation. These are general guidelines only, because grain protein at optimum yield varies with cultivar. In addition, moisture stress can increase grain protein, even in N deficient fields.

For more information on soil tests and/or fertilizer calculations, please see *Interpretation of Soil Test Reports for Agriculture* (9) and *Developing Fertilizer Recommendations for Agriculture* (10).

ENHANCING SOIL FERTILITY

INTERNAL NUTRIENT INPUTS: CROPS AND FORAGES

Crop rotation, cover crops (crops often seeded in early fall to reduce soil erosion and retain nutrients on site), grain legumes, and green manures (crops terminated prior to maturity to provide soil organic matter and nutrients) must be the foundation of soil fertility on organic farms (11, section 205.203b). Additional approved materials and livestock integration may be used to supplement, but not replace, these practices.

CROP ROTATION

Good rotations involve crops which use nutrients and water efficiently and break pest cycles (insects, weeds, pathogens). Nutrients and water are used from different areas of the soil depending on both root depth and breadth. For example, pea will use more resources from the upper soil layers, whereas safflower and winter wheat will use more from deeper levels (12). In a Saskatchewan study, barley yields were much higher when grown after pea and canola than wheat (Figure 1). The benefits of alternating cereal grain crops with non-cereal crops increased barley yield after canola versus wheat. Pea provided additional benefits over canola by adding N to the soil.

Planning rotations to take advantage of the N input from a legume is critical. An N building crop should not be followed by fallow or a crop likely limited by other resources such as water or P, because the soil nitrate added by the legume can be lost to leaching (14). A crop with high N demands, such as high protein wheat, is a good crop to follow an N building crop.

GRAIN LEGUMES & GREEN MANURE

General benefits & limitations

The benefits of grain legumes and green manures vary with species, growing conditions and management (Table 1) and can be increased by the application of good agronomic principles (15). Legumes planted in our region include pea, chickling vetch, chickpea, medic and lentil as annuals, sweet clover as a biennial, and alfalfa and sainfoin as perennials. Non-legume green manures include buckwheat and mustards. There is little substitute for experience in determining what works in a given situation. Ask nearby producers for advice; most organic producers are more than willing to share their knowledge.

Only a portion of grain legume and green manure benefits can be attributed to increased soil N. Long term benefits include increased soil organic matter, improved soil structure, aeration, water holding capacity, tilth, and increased soil microbial activity (16). A plant cover of any type (including weeds) helps reduce wind and water erosion and can reduce leaching losses, yet uses water that will then not be available for the next crop.

Legumes offer production system diversity which tends to increase sustainability. They can be harvested as a cash crop and can reduce reliance on outside inputs.

Nutrient benefits

Legumes produce plant available N through N-fixation. By stimulating soil microbial activity, they also increase uptake of other nutrients (such as P and zinc) by non-legumes in rotation (17).

Nitrogen A legume's ability to fix N relies on inoculation with host specific bacteria and is influenced by many factors (Table 1). In our region, a harvested grain legume can supply the next crop with about 0 to 20 lb N/acre. An annual legume green manure can provide somewhat more, about 5 to 40 lb N/acre, and a perennial or biennial legume provides about 40 lb N/acre for the next crop.

Release of N from crop residue, green manure, and livestock manure does not follow the same patterns as inorganic fertilizer. The initial release of plant-available N is determined by N concentration and decomposition rate, which is faster under warm moist conditions. A lush green crop will provide N more quickly than a dry coarse residue (Figure 2). An indicator of lushness is the carbon to nitrogen ratio (C:N). For example, immature alfalfa is very lush with a C:N around 12:1, while after-harvest field pea residue is not, with a ratio over 40:1. Initial plant-available N release is rapid at a C:N below 15:1, and low at a ratio between 25:1 to 40:1. At a C:N above 40:1, microbes tie up N for their own use, which makes the N temporarily unavailable to plants. Therefore, planting crops after a mature or fibrous cover crop should be delayed to give time for microbial breakdown of the residue and gradual release of mineral N.

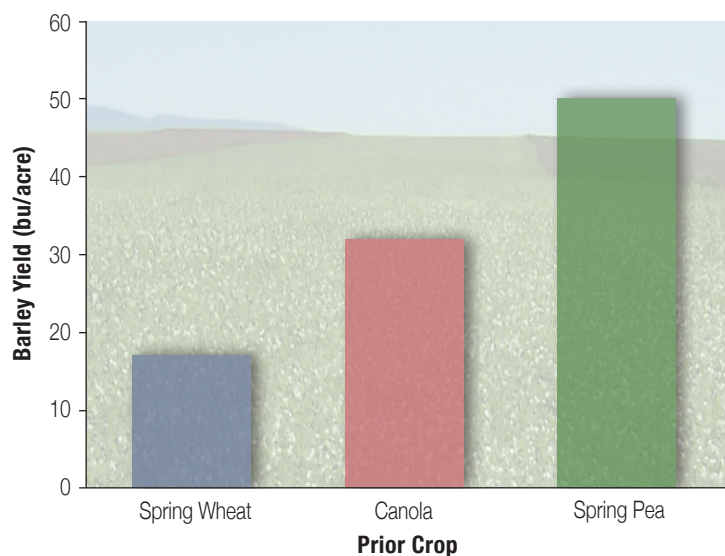


FIGURE 1. Dryland barley grain yield grown on spring wheat, canola, and spring pea stubble in Saskatchewan with no N fertilizer. Modified from the original (13).

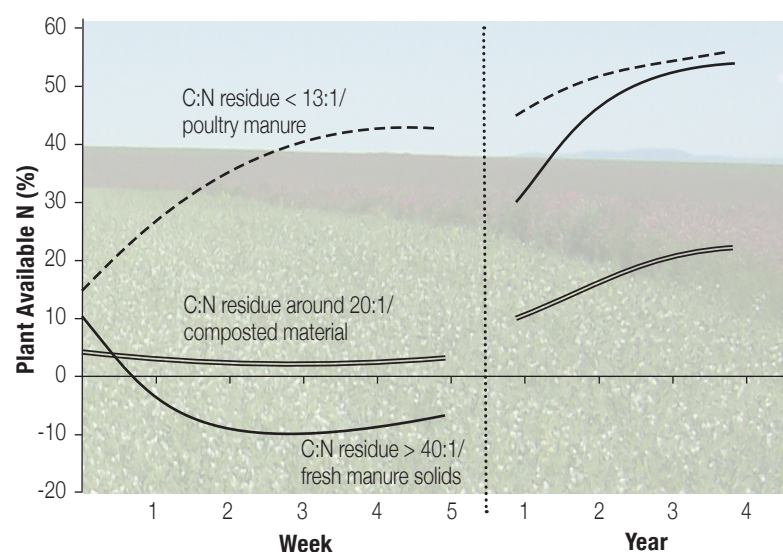


FIGURE 2. General pattern of plant available N released as a percentage of the total N from low C:N material, composted/moderate C:N material and high C:N material (adapted from originals 18, 19 and 20).

Immediate N contributions from legumes are often low. For example, only 14 percent of the N provided by pea green manure was used by spring wheat grown the following season (21). Of the N from pea residue remaining after harvest, 55 percent had been used after 3 years of subsequent cropping with mustard. The rest remained in the soil as organic matter and a source of N for future crops (22).

The amount of N fixed generally increases the longer the crop is growing, yet so does water use. Perennials tend to fix more N than annuals because they have a longer growing season and more established root system. Adding perennials to the rotation appears to limit movement of N below the rooting zone compared to annual grains, and most likely helps retain N on the site as organic matter (23). Unfortunately, deep rooted plants can create a very dry

soil profile that limits subsequent crop establishment and production for up to two years (24).

Annuals generally use less water, but can also contribute less biomass and soil N than biennials or perennials. Although there is variability among legume species' abilities to fix N (25), in our region, a legume's water use largely determines how much the next crop benefits from the legume. Varieties should be selected that mature early to retain soil moisture. Because winter crops mature and can be terminated earlier, they are less likely to become water limited and can produce more biomass, fix more N and leave more stored soil water and more time for N to be released. Research in Montana indicates that wheat grain yields following winter pea are generally higher than following spring pea when both are terminated at first bloom (Figure 3, page 4). However, due to the

TABLE 1. Crop attributes and environmental variables that benefit or limit the ability of seed legumes and green manures to enhance plant available nutrients.

Attribute or Variable	Benefit or Limitation
Crop species and variety	Must be suited to site growing conditions
Legume vs. non-legume	Legumes fix N
Annual vs. perennial	Annuals fix less N, use less water
Winter vs. spring annual	Winter crops fix more N, risk winter kill
Biomass potential	Greater biomass increases organic matter input
C:N ratio	Low C:N provides more N in short term but possibly less in long term
Water availability	No benefit if water, not N, is limiting subsequent crop
Soil pH	Generally not limiting for N fixation at pH > 6.5

risks of poor fall establishment or cold injury, winter legumes are only suggested for areas where winter wheat survival is highly reliable (27).

Growing conditions greatly affect N-fixation potential. Legumes fix little N in soils with adequate available N, such as on sites fertilized with sufficient manure (25). Also, N fixation is slowed at pH levels less than 6.5, and low levels of P, K, S, calcium (Ca), cobalt (Co), boron (B), iron (Fe), copper (Cu), or molybdenum (Mo), which are easily overlooked.

Climate determines which species are suitable for a given site and the N contribution of a crop in a given year. In cool dry conditions, less biomass accumulates, nutrients from the residue only slowly become available, and the N benefit will be minimized since the subsequent crop's growth may be limited by water, not N.

Phosphorus Unlike N, phosphorus cannot be 'produced' on the site and its availability is primarily dependent on soil chemical properties rather than biological processes. In our region's usually calcareous and high pH soils, P is often tied up as relatively insoluble calcium phosphate minerals. Therefore, increasing available P can be difficult. However, crops such as buckwheat, legumes and some mustards are better than cereals at extracting soil P. They acidify the root zone or secrete chemicals from their roots that help access P from the soil and rock phosphate (28). Yet, the effect does not appear to immediately carry over to a subsequent crop. In a 2-year cropping sequence, winter wheat grain yield and P uptake were not higher after spring pea, buckwheat and mustard green manures than after fallow (Figure 4). The potential increase in P availability through green manures is likely a long term process (29) and a limited solution without additional P inputs.

Green manure vs. crop harvest

Whether a crop is terminated early or harvested as a cash crop is influenced by the economic and nutrient needs of a production system. A 25 bu/acre pea or lentil crop can fix approximately 50 to 100 lb N/acre if the initial soil N is low. However, when the seed or legume forage is harvested, much of the fixed N is removed. Seed N can exceed the total amount of N fixed by the plant (25) and nutrients removed by haying can be large. For example, every ton of alfalfa harvested removes about 50, 10, and 42 lb/acre of

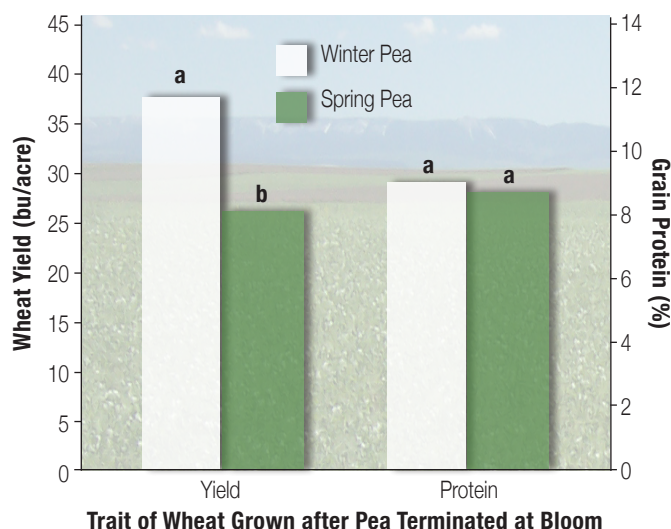


FIGURE 3. Winter wheat grain yield was higher after bloom terminated winter pea than spring pea. Protein was not affected (26). Bars within a trait with the same letters are equal with greater than 90% probability.

N, P_2O_5 and K_2O , respectively. Although a harvested grain legume crop will not benefit subsequent wheat as much as an early terminated legume green manure, grain and forage legumes still help improve long term soil fertility, especially in contrast to fallow.

Green manure termination timing & method

When to terminate Termination timing of green manure can have more influence than the green manure species on subsequent grain production (30). With several species of green manure, termination at bloom conserved water and increased subsequent winter wheat yield when compared to termination at pod (Figure 5). Termination time did not influence grain protein after any of the green manures tested in this study (26).

A 12-year Saskatchewan study found that seeding lentil green manure as early as possible and terminating at bud stage produced the same spring wheat yield as after fallow (31). A gradual increase in grain protein, reduction in fertilizer N requirements, and reduced herbicide and tillage costs to control weeds all created a positive economic return. Conversely, when lentil was terminated at full bloom, the following wheat grain yield was 9 bu/acre less than on fallow.

Though yields may be higher when green manure is terminated early, more soil organic matter and N should accumulate when the crop is allowed to grow

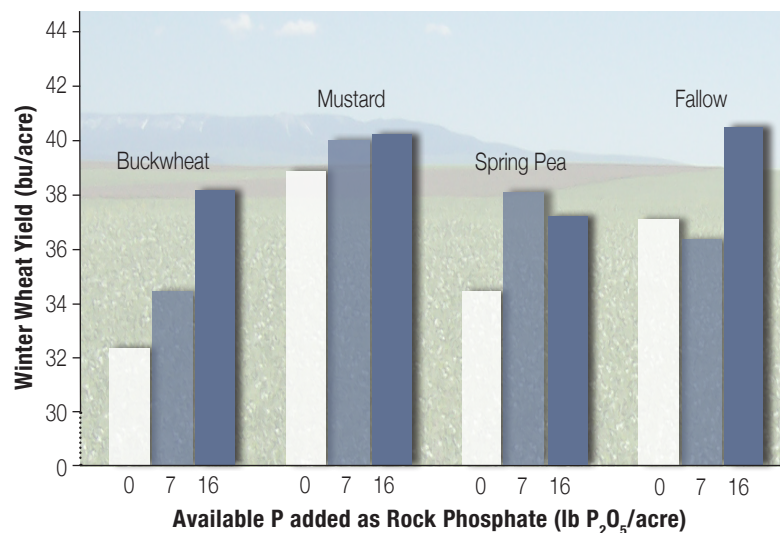


FIGURE 4. Winter wheat grain yield after mustard, buckwheat, spring pea green manure terminated at pod and fallow with different levels of rock phosphate (2).

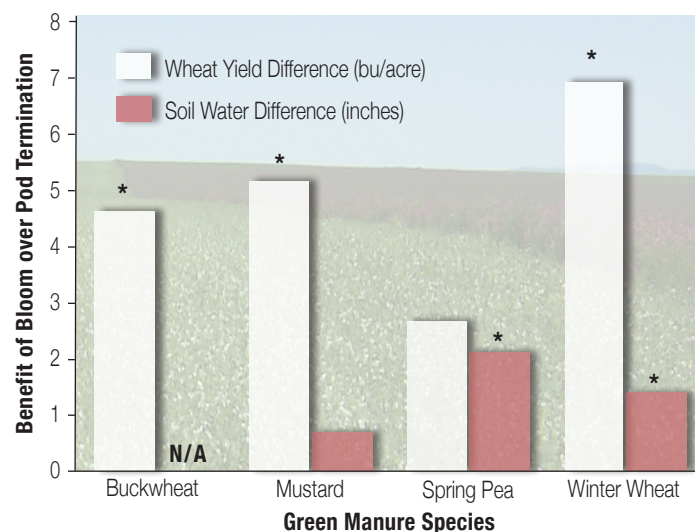


FIGURE 5. Winter wheat yield and soil water to 3.8 ft. at wheat seeding were greater after several GM species were terminated at bloom rather than pod stage. Value is bloom minus pod stage. Asterisk denotes bloom was greater than pod stage with 90% probability, N/A is not available. Adapted from original (26).

longer. In seed legumes, biomass and N fixation peak at seed fill. Forage legumes fix N and add biomass throughout the growing season, with biomass removal and temporary reductions in N-fixation at each cutting (32). The producer needs to weigh the relative importance of long term soil benefits to immediate yields. For maximum yield of the next crop, terminate early. Terminate late to maximize grain protein and to build soil N and organic matter. Wet years or irrigation should allow for later termination of green manure with less negative impact on the subsequent crop.

How to terminate Tillage is generally used to terminate green manure and incorporate some plant material into the soil, accelerating N release (33). This N may be more susceptible to leaching but less susceptible to volatilization than when plant material is left on the soil surface.

The no-till alternative of crimp rolling, which crimps plant stems to stop growth, is still experimental with mixed results. Apparently, if plants are either too supple or too tough, crimping may not successfully stop their growth. Winter pea grown near Bozeman was too supple for effective crimp rolling and recommenced growth within 48 hours. Sweet clover at mid bloom was too woody to crimp properly and also resumed growing (27). However, crimp rolling terminated winter pea at the pod stage. Winter wheat seeded directly into the residue had the same yields

as when seeded after pea terminated by tillage despite increased weed densities (26). Direct seeding into crimp rolled residue can eliminate tillage operations, which helps retain soil moisture and prevent erosion. The unincorporated pea residue may also help germination and survival of wheat under dry fall conditions because it provides soil cover to slow evaporation loss (27).

Vinegar is sometimes used for weed control on small organic farms, but is cost prohibitive on a large scale. Vinegar did not terminate winter pea at the bloom stage despite an application rate that scorched the leaves (26). The plants put out new leaves from the stem tip within a day after application (27). Other termination products or methods may become available for organic growers. With any termination method, leaving untreated strips helps trap snow to recharge soil water.

Non-nutrient considerations

Drought and cold hardiness combined with biomass and growth habit (tall and thin or low and bushy) will affect a crop's ability to suppress weeds or protect soil from wind erosion. Buckwheat, for example, has the growth habit to be a good cover crop, but is susceptible to frost kill and should be planted late. Therefore, it may not reach an optimum biomass for weed suppression.

Annuals are easier to terminate and turn under than well established perennials. Also, breakup of perennial stands often results in severe weed invasion which can limit subsequent crop growth especially in dryland production (5). Fall planted annuals tend to suppress weeds better than spring annuals (26), provide winter soil cover and trap snow. The ability of some crops to disrupt pest cycles, such as mustards which help suppress soil borne pathogens (34), can also influence green manure crop selection. However, mustard grew very poorly in low N soils near Big Sandy, Montana (26).

INTER-CROPPING

Modern farming has traditionally focused on monoculture production, yet intercropping can increase land productivity through efficient resource use, improved pest (weeds, insects, pathogens) control, and reduced risk through crop diversity (16). On a central Montana field with no added N, winter wheat yields were the same when planted alone or with pea or lentil. Total yields per acre were higher in the intercropped than just wheat fields due to the addition of the legume harvest (Figure 6). When selecting species to intercrop, be sure they complement each other in water and nutrient requirements, and break pest cycles, yet have compatible production requirements, such as timing of harvest.

INTEGRATION WITH LIVESTOCK

Legumes can provide livestock forage and fix N for a cereal crop. Self-seeded legumes from the pasture phase may also provide forage before cereal seedbed preparation and some may grow along with the cereal grain crop to supply N. Self-seeding “legume-ley” systems were very successful in Australia

and provided many benefits from improved soil, air and water quality, water use efficiency, and pest management (36). A sharp economic decline in the Australian sheep industry, along with adoption of no-till practices, caused widespread abandonment of legume-ley systems (27).

Identifying suitable legumes for ley-farming has been problematic. Several perennial and biennial legumes grown in northwestern North Dakota produced adequate forage and self-seeded the following year (37). However, when grown for optimal seed production the legumes were terminated late, which reduced wheat yield when compared to fallow. Assorted legumes planted in Montana (38) and Wyoming (36) provided good forage but had poor winter survival or were unable to re-establish largely because of weed pressure. Grazing grain crop residue following harvest is an option to reduce weeds.

Winter wheat grain yields after grazed winter pea were equal to yields after winter lentil green manure and higher than after winter pea and oat grain (Table 2). The grazed pea rotation had the highest net return because the forage value for cattle was higher than the value of the N credit from the lentil green manure (35). Wheat protein did not increase after one year of legume rotation. However, 14 years of wheat in rotation with winter pea grazed by sheep had higher average protein (14.1 percent) than wheat-fallow in Wyoming (12.4 percent, 39).

Grazing rather than haying or plowing legume rotations may be a key to the environmental and economic sustainability of integrated systems (37). Unlike harvested legume crops, livestock grazing keeps most of the nutrients on the pasture, but proper management is necessary to evenly distribute urine and manure.

TABLE 2. Yield and net return of different cropping systems on an organic farm near Stanford, MT in 2007-2008. Net return is based on actual production costs, crop prices and forage value to the farmer (35).

First crop	First crop yield (bu or lb/acre)	Winter wheat yield (bu/acre)	Net return (\$/acre)
Winter lentil green manure	1829	21	332
Oat grain	10	12	160
Winter pea grain	8	14	257
Winter pea forage	2427	22	455

EXTERNAL INPUTS

Farmers striving for sustainability should consider on-site or local manure first, followed by products which are recycled yet require transport, such as bone meal. Inputs such as rock phosphate may become necessary but are a mined, finite resource, and generally contain heavy metals.

MANURE

Use of manure imported from conventional farming operations is allowed by National Organic Program standards with restrictions (11, 40) and can only be used along with other soil-building practices. Manure contains all essential plant nutrients and improves soil quality, tilth, and water and nutrient holding capacity. If manure is readily available, this will likely be your best P, K, and micronutrient source. Applying nine dry tons/acre of two year old steer manure increased winter wheat grain yields by 37 percent on the organic rotation at the Post Farm near Bozeman, Montana (Figure 7, page 8). These plots received no external nutrient inputs for the prior 9 years. Manure was broadcast-incorporated in early October and then the plots seeded to winter wheat.

In Montana, manure application using off-site manure sources must be done without jeopardizing water quality as outlined in state water quality regulations. When using on-site manure sources, rates are determined by the Concentrated Animal Feeding Operations regulations (42). The on-site manure source regulations include a field assessment for potential N and P loss, soil and manure nutrient tests (at least total N, ammonium-N, and P), and the nutrient requirements of the subsequent crop (3).

Manure nutrient content varies greatly, depending on animal type and diet, type and amount of

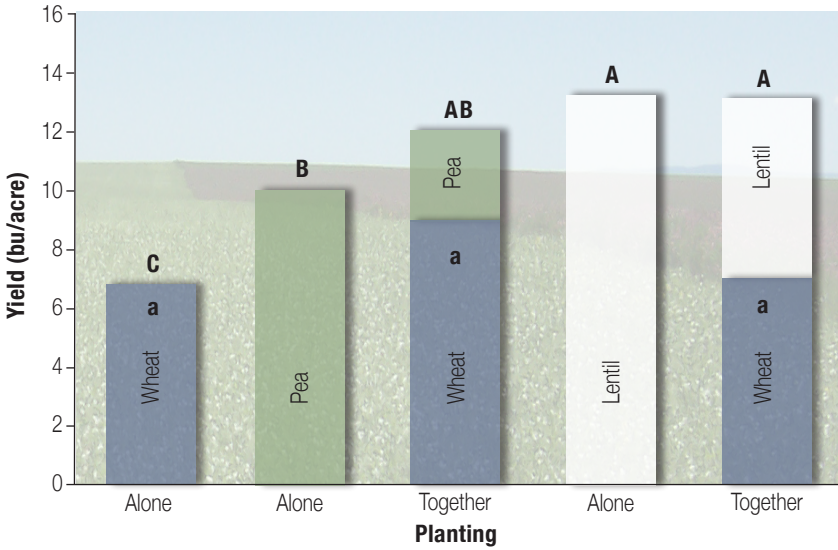


FIGURE 6. Total yield per acre is higher for dryland winter wheat planted with pea or lentil than when planted alone without added N. Results are from a drought year in central Montana. Uppercase letters denote differences among total yields, lower case among wheat yields, with greater than 95% confidence. Adapted from original (35).

bedding, and handling and storage methods (Table 3). These numbers are provided only to enable rough rate calculations. It is best to have your manure source tested for nutrient content. Plant available N depends on the manure source and application method because manure provides readily available N from ammonium-N and long-term N through decomposition of organic material (Figure 2). For example, available N in the year of application can be 22 to 60 lb N/acre for fresh and 11 to 16 lb N/acre for composted cow manure (manure that no longer emits an ammonia odor) applied at 33 wet ton/acre (49). Slurry cow manure (2 to 8 percent total solids) typically has more immediately available N than solid cow manure (19); however, sprayed liquid manure can lose up to 50 to 70 percent of the ammonium-N within hours of application through ammonia

TABLE 3. N, P, K, and S content of common nutrient sources. For more detailed information on manure nutrient content see 43.

Nutrient source	N (%)	P ₂ O ₅ (%)	K ₂ O (%)	S (%)
Manure ¹	0.6-4.5	0.4-5.5	0.5-4	0.04-0.25 ²
Fertilizer:				
Rock phosphate ³	0	0.3-4	0	0
Blood meal ⁴	12	1-2	0-1	
Bone meal ⁴	1-6	11-30	0	
Gypsum ⁵	0	0	0	17
Greensand ⁵	0	1	7	

¹ Manure nutrient content based on dry weight data from 44; ² 45; ³ 46. Only available P₂O₅ is noted, while dissolution and diffusion of P from apatite minerals will likely contribute more available P over time. For example, some rock phosphates are 3% available P₂O₅, but 20% total P₂O₅. All organic amendments have variable nutrient content. ⁴ 47; ⁵ 48.

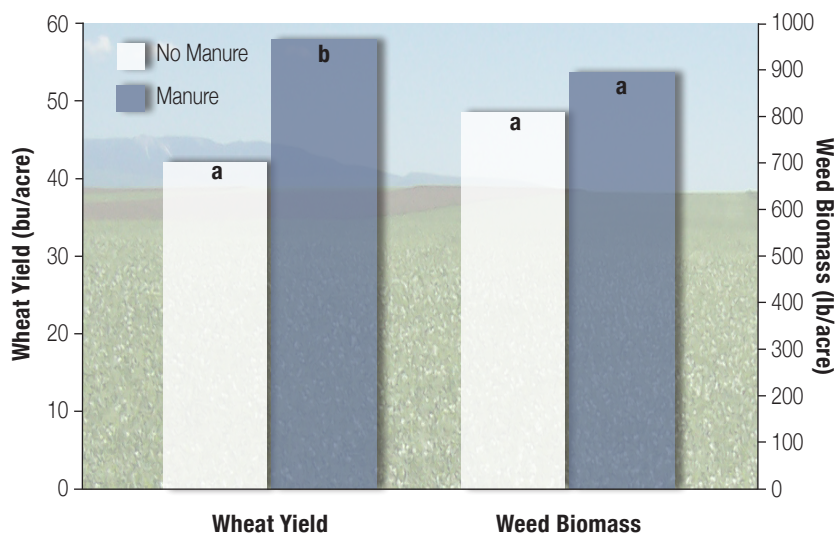


FIGURE 7. Effects of aged steer manure on winter wheat grain yield and weed biomass in Gallatin Valley organic plots (41).

volatilization (50). Solid manure can lose 80 percent of its ammonium-N to volatilization if not incorporated within 7 days and is best incorporated immediately. However, it continues to provide N over many years through decomposition (Figure 2). Plant-available N release averages 2 to 7 percent per year following the application year (19). This rate may increase as the soil biota adapt with repeated manure applications. Composted manure generally provides N at a slow steady rate (Figure 2).

About 30-85 percent of manure P will be available the first year, the rest remains in the soil unless there is erosion loss (51, 52). The large range is due to differences in manure type and abilities of different soils to retain P. Organic material from manure or crop residue helps keep P plant available by slowing processes that create relatively insoluble phosphates and increasing the rate of P moving into solution (53).

It is easy to over apply P if manure is applied to match the crop's N need. When a field becomes too high in P, the producer should limit further manure applications and/or seed crops with high P demands. One strategy is to apply manure until the soil test P level is above the 'critical level' (Olsen P = 16 ppm) but below levels considered detrimental to the environment (Olsen P > 60 to 150 ppm). Legume green manures could then be used to supply N if needed until P levels fall below the critical level, at which point manure could again be applied.

Manure must be carefully managed to prevent over- or under-application and to account for the cumulative environmental effects of application as well as storage. Manure should be applied as close to the time of crop nutrient uptake (see 54) as possible under National Organic Program guidelines, and not when the ground is frozen, snow-covered, or saturated. Manure may increase weed populations due to undigested weed seeds, but not always (Figure 7). Subsurface banded liquid manure tends to produce fewer weeds than broadcast applications and composted manure may produce fewer weeds than fresh manure (49). There are excellent resources to help producers properly use manure (4, 19, and 50).

FERTILIZERS & AMENDMENTS

Fertilizers generally target particular nutrients and should come with a guaranteed analysis of at least available N, P, and K; whereas amendments generally contain low available amounts of several nutrients, yet provide a variety of non-nutrient benefits. Compost is an example of an amendment that improves soil quality and nutrient content and is a viable option for small market gardens with high revenue potential, but not for large farms. Our focus here is on fertilizers.

To selectively add P, producers can use rock phosphate or bone meal. Unfortunately, both of these products are high in calcium resulting in low P solubility in neutral to high pH soils and rock phosphate generally contains heavy metals such as lead and cadmium. The amount of available P from rock phosphate varies greatly among sources (46). In P deficient soils it is possible to increase plant available P from rock phosphate by adding elemental S (up to 355 lb/acre; 55). The S needs to be in close contact with the rock phosphate to be effective. Composting rock phosphate with organic material may also increase P availability (56). Rock phosphate is not always effective at enhancing P nutrition (2) or cost-effective in increasing yields the year of application (57). In Montana, P from rock phosphate was more available to a crop planted a few months after rather than at the same time as fertilization (2). Therefore, if rock phosphate is used, it should be added well before the growing season, built up over time, or banded with the seed. Bone meal adds N as well as P, and if used to meet N requirements then crop P needs are generally fulfilled (58). Bone meal should contain fewer heavy

metals, and unlike rock phosphate, is a renewable resource.

Other nutrients such as K, S, and micronutrients generally do not limit crop growth as frequently as N or P. They are most often supplied by greensand (glauconite) and gypsum (Table 3). Greensand is a common source for K and adds micronutrients, but potassium-chloride (KCl) is a more economical source of K for large acreages. Gypsum (or elemental S) supplies both Ca and S without affecting soil pH, yet may reduce available K and magnesium (16). The producer must be sure when adding any product that it does not jeopardize the field's organic status.

SOIL ACTIVATORS & INOCULANTS (NON-TRADITIONAL PRODUCTS)

Several soil additives are marketed which have little or no nutrient content but may enhance crop production. They may stimulate existing soil microbes or add new beneficial organisms that improve nutrient availability and/or uptake (59). For example, inoculating legume seed with the correct *Rhizobium* bacteria to promote nodulation is important if the necessary bacteria are not present in the soil.

Similarly, microbes such as arbuscular mycorrhiza (AM) colonize the plant roots and have been found to increase growth, P uptake, and/or the amount of N fixed by legumes. Benefits vary with species of AM and crop (60). Some crops such as sunflowers and legumes are highly dependent on AM, while others such as canola and mustard do not support AM. Adding or encouraging AM may be a short term alternative to adding P to promote growth and N fixation. Practices which encourage AM colonization include seeding crops that support AM, such as perennial forages, reduced tillage, and minimal application of highly soluble P (16). Many soil bacteria and fungi, such as *Penicillium* species, have the potential to release phosphates into plant available forms and increase P availability (61). In low phosphate soils (Olsen P < 10 ppm), *Penicillium* species applied alone or along with rock phosphate have improved wheat (57, 62) and canola yield (63). However, irradiated peat is often used to produce and carry *Penicillium* inoculants. This is not allowed in organic fields (section 205.105(f) National Organic Program Final Rule, 11). Similarly, some inoculants are genetically modified organisms which are not allowed in organic production. However, products that are acceptable under United States organic standards may become available.

There are too many products marketed as amendments, activators or inoculants to all be scientifically evaluated. Be cautious about product claims. Additives could be ineffective or detrimental depending on how they affect soil microbes. Look for local or regional field trials to evaluate the potential costs and benefits of products for your production system, or try out a product on one seeder pass and monitor yield on and off that pass. Iowa State University offers a website to locate research on various non-traditional products tested in the north central Great Plains (64). In general, these products should be used with caution and tested on a small portion of your fields before wide scale adoption.

ECONOMICS

The economically optimum soil fertility management practice depends on the scale and potential return on the investment. These should be considered for the whole system over several years rather than by the single crop in each phase (1), and include the nutrient value, long term benefits, and management costs such as number of passes on a field. Products and practices should be evaluated in terms of their ability to amend existing yield limitations for a reasonable cost. Oregon State University offers a tool for comparing the cost, nutrient value, and N availability of organic materials (65). For example, to add 40 lb N/acre using alfalfa pellets would require 800 pounds of pellets. At \$27 per 50 lb bag, this would cost \$432 per acre, which might be reasonable for a market garden but not for large scale grain production.

Calculations for large farms become complex. As an example, if green manure seeding eliminates tillage passes on fallow then the benefit of those reduced tillage passes, as well as N fixed, is part of the value of replacing fallow with green manure. If the producer adds livestock grazing of the green manure, which can help control weeds and produces an income but reduces N and soil organic matter input, there are additional costs and revenues to include in the analysis.

SUMMARY

Organic fields will require inputs to maintain soil fertility in the long term. Grain legumes and green manures that supply N to the soil become the foundation of organic crop rotations and should be present 25 to 50 percent of the time. Reducing tillage and increasing cropping frequency and diversity improves the soil's N supplying power and minimizes potential for soil degradation and erosion. Reintroduction of livestock grazing may be important for the economic and environmental stability of agricultural systems in our region. Manure is an excellent source of many nutrients, but may not be locally available in sufficient quantities. Practices that encourage microbes which increase soluble P, such as AM, should be encouraged, though inoculants should be used with caution until more data are available. Integrated use of crop rotation practices, livestock grazing, and fertilizers/amendments have the potential to improve soil quality and increase sustainability of organic crop production.

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