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Chapter 15

Organic Soil Amendments for Sustainable Agriculture:

Organic Sources of Nitrogen, Phosphorus, and Potassium

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Sustainable agriculture, which is characterized by farming profitably while minimizing damage to the environment, is not easy to practice. "Conventional" agriculture in the USA is commonly considered to involve practices that have potential to damage the environment. These include tilling the soil excessively, overapplying readily soluble inorganic fertilizers ("chemical fertilizers"), and overapplying pest-control formulations (herbicides, insecticides, fungicides, etc.). "Sustainable" agriculture attempts to find alternatives to such practices, alternatives that are economically feasible but have less potential to cause environmental damage.

Switching from "conventional" to "sustainable" agriculture involves more than just simple substitutions, such as replacing an insecticide with a predator insect or replacing potassium chloride fertilizer with greensand. Because it attempts to be more "in tune with nature" than conventional agriculture, sustainable agriculture requires more information about environmental characteristics and the environmental impacts of agricultural practices. To the extent that agriculture incorporates environmental considerations, it becomes more complex and information-intensive, and it is considered to require greater levels of management effort and skill. For example, cultural and biological pest control requires detailed information about a pest's life cycle and economic threshold levels of infestation of the crop. Similarly, using chicken manure to replace urea as an N source requires knowledge about the release pattern of organic N from the manure and synchronization of that release into the soil with the N-demand pattern of the crop.

Adequate levels of soil fertility and plant nutrients are important to farming, whether the practices are considered "conventional" or "sustainable." A 1987 survey (WSARE 1995) showed that half of the farmers attempting to practice "sustainable agriculture" nationwide have experienced crop nutrient deficiencies. Although sustainable farming is often a much broader concept than "organic" farming, sustainable farming also emphasizes use of organic materials as soil amendments and sources of plant nutrients.

Nitrogen

Nitrogen is needed by all plants, usually in large quantities. Nitrogen is so important to plant growth, and thus to the world's food and fiber production, that Nobel prizes were awarded in the early 1900s to the two German scientists who invented the process of making ammonia (NH_3) by combining atmospheric nitrogen gas (N_2) and hydrogen (H_2) from natural gas. Average N concentrations in the plant needed for normal growth are about 3% for corn and coffee, 4% for tomato, and 2% for macadamia. If plants do not have enough N, they are stunted, with small leaves that may be pale yellow-green (chlorotic), sometimes completely yel-

Table 15-1. Total nutrient contents of some commonly used organic fertilizers[1]

Material	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu
	% dry weight						ppm (mg/kg) of dry weight			
Poultry (broiler) manure[a]	4.4	2.1	2.6	2.3	1.0	0.6	1000	413	480	172
Composted chicken (layer) manure [b]	2.3	3.5	2.9	15.5	1.3					
Dairy cow manure[a]	2.4	0.7	2.1	1.4	0.8	0.3	1800	165	165	30
Swine manure[c]	2.1	0.8	1.2	1.6	0.3	0.3	1100	182	390	150
Sheep manure[c]	3.5	0.6	1.0	0.5	0.2	0.2	-	150	175	30
Horse manure[c]	1.4	0.4	1.0	1.6	0.6	0.3	-	200	125	25
Feedlot cattle manure[d]	1.9	0.7	2.0	1.3	0.7	0.5	5000	40	8	2
Young rye green manure	2.5	0.2	2.1	0.1	0.05	0.04	100	50	40	5
Spoiled legume hay	2.5	0.2	1.8	0.2	0.2	0.2	100	100	50	10
Cowpea green manure[e]	3.6	0.4	3.5	1.5	0.4					
Leucaena green manure[e]	3.8	0.2	1.7	1.1	0.3					
Sewage sludge:										
Anaerobically digested[f]	5.2	0.6	0.06	1.5	0.3	–	15,000	80	1000	400
Primary[f]	1.8	0.4	0.03	0.8	0.1	-	8000	200	450	300

[a]Composition estimated from means of approximately 800 and 400 samples analyzed by the University of Maryland manure analysis program from 1985 to 1990.
[b]Silva, J.A., et al. 1995. The use of composted poultry manure as a fertilizer. In: Hawaii Agriculture: Positioning for Growth. College of Tropical Agriculture and Human Resources, University of Hawaii at Manoa.
[c]Calculated from North Carolina Cooperative Extension Service Soil Fact Sheets prepared by Zublena et al. (1993).
[d]Composition based on average analysis reported in Eghball and Power (1994), Beef cattle feedlot manure management. J. Soil and Water Conserv. 49:113–122.
[e]Hue, N.V., and I. Amien. 1989. Aluminum detoxification with green manures. Commun. Soil Sci. Plant Anal. 20:1499–1511.
[f]Hue, N.V., and S.A. Ranjith. 1994. Sewage sludge in Hawaii: Chemical composition and reactions with soils and plants. Water, Air, and Soil Poll. 72:265–283.
[1]Modified from N.C.Brady and R.R. Weil, 1999, The nature and properties of soils.

low or red-tinted. Nitrogen is also a component of chlorophyll; less N results in less chlorophyll, and thus less green color, less photosynthesis, and less crop growth.

Because proteins are continually being synthesized and degraded in plant tissues, N is quite mobile in the plant and will move from older leaves to younger leaves to meet the nutritional need of the most actively growing parts. The consequence is that nitrogen deficiency will begin in older leaves and then progress upward toward the growing point (Photo 15-1, p. 48).

In soils, N must be present as either NH_4^+ or NO_3^- before plants can absorb and use it. That is why urea, $[(NH_2)_2CO + 2H_2O \longrightarrow 2NH_4OH + CO_2]$, and ammonium nitrate have been so popular as N fertilizers in conventional farming systems. In strictly "organic" farming systems, however, you cannot use urea or ammonium nitrate, or any synthetic chemicals. Alternative N sources must be sought, such as those mentioned in Table 15-1.

On the basis of total N, most organic N sources have between one tenth and one hundredth of the amount contained in urea. If a crop's N requirement is 200 lb N/acre, as it might be for a crop of sweet corn, with urea (at 46% N) you would need:

200 / 0.46 = 435 lb/acre urea

whereas with compost (at 1% N) you would need:

200 / 0.01 = 20,000 lb/acre (10 tons/acre) compost.

This calculation shows that, relative to urea, a large amount of compost is needed to supply N to a crop, and this is true for most organic N sources. In addition, the calculation assumes that, pound for pound, N from the compost is as available for plant uptake as N from urea, which is not true. Unlike urea, which can be hydrolyzed into plant-available NH_4 nearly instantaneously in the soil, N from compost must first be released from its organic substrates, and this process may take from several days to several months. In general, depending on the type of organic material and the environmental conditions, such as temperature and moisture, only 10–50 percent of the N from an organic source would be converted to NH_4 in a six-month period (Hue 1995). Thus, to provide the 200 lb of N that an acre of sweet corn needs over a growing season of approximately three months, you may need to apply from 20 to 50 tons/acre of compost instead of the 10 tons that the calculation indicated! It may be helpful to work through an example with composted chicken manure:

A grower wants to use composted chicken manure having 2.3% N, 3.5% P, and 2.9% K to supply 200 lb N to a 1-acre field. Experiments indicate that only 40% of the N is released in the first year after application.

The amount of N supplied by 1000 lb of chicken manure =
1000 lb x 0.023 = 23 lb N;
this will also supply 35 lb P and 29 lb K.

The amount of N released in one year =
23 lb N x 0.40 = 9.2 lb N

The amount of chicken manure needed to supply 200 lb N in the first year is calculated:

X / 200 lb N = 1000 lb manure / 9.2 lb N

X = 21,740 lb, or 10.9 tons of chicken manure per acre.

One must also be aware that chicken manure can have a high salt content, which can "burn" plants if the manure is applied in large quantity, such as above 40 tons per acre. Soils amended with manure should be tested for salt content by measuring the soil solution electrical conductivity.

The conditions under which animal manure has been stored have a marked effect on the amount of N, K, and salts remaining in it. Analyses for nutrient and moisture contents should be done on the material that is to be applied so that one knows how much of each nutrient is applied. Manure should be broadcast and incorporated into the soil for best results.

The availability of other plant nutrients in manure is generally higher than that of the N it contains, and micronutrients may be more available in manure than in inorganic fertilizers. While N is the main nutrient considered with additions of manure, most manure also contains P, which can build up in the soil to excessive amounts with continuous manure applications. In the example above, 21,740 lb/acre of chicken manure added not only 500 lb of N but also 760 lb of P and 630 lb of K. Unlike N and K, soil P does not leach in most tropical soils but remains adsorbed to soil particles. The amount of P used by a crop is relatively small, so soil phosphorus is not depleted rapidly and can build up in the soil. Therefore, the soil P level should be monitored by regular soil analyses to ensure that it is not becoming too high.

Crediting nutrient contributions from organic fertilizers including crop residues, composts, and animal manure

Organic fertilizers release N over time—as much as several years from the time of application. Fertilizer additions to any particular crop should consider the cumulative effects of previous applications of organic nutrient sources, which will continue releasing N. This residual N storage pool and its rate of release should be estimated, and the amount expected to become available during the present cropping period should be deducted from the amount of N scheduled to be applied to the crop. Thus one should keep records of the dates, types, amounts, and nutrient contents of the organic materials (animal manure, green manure, compost, etc.) applied to a field. With this information and the information in Table 15-1, reasonable estimates can be made of the residual N that will be supplied. Following is an example of such a calculation.

A grower applies 21,740 lb/acre of chicken manure containing 2.3% N. Therefore, 0.023 x 21,740 = 500 lb N is added per acre. If another crop will be grown in the second year and this crop requires 150 lb/acre N, the residual N from the first year must be estimated.

In the second year, according to Table 15-2, 15% of this nitrogen would be released: 500 lb N x 0.15 = 75 lb N would be available for the second crop so the amount of N required is reduced by this amount: 150 lb N – 75 lb N = 75 lb N required for the second crop.

The grower is going to use dairy manure with 2.4% N for the second crop. The amount of dairy manure required is calculated in the following manner:

The amount of N supplied by 1000 lb of dairy manure =
1000 lb x 0.024 = 24 lb N

The amount of N released in the first year is 35% of the total applied (Table 15-2); therefore,

24 lb N x 0.35 = 8.4 lb N per 1000 lb of dairy manure, released in the first year

The amount of dairy manure needed to provide 75 lb N/acre in the first year:

X / 75 lb N = 1000 lb manure/8.4 lb N

Table 15-2. Rates of release of mineral nitrogen from various sources of organic nitrogen applied to soils[1]

The values are percent of organic N present in the original material. For example, if 10 tons of poultry litter initially contains 600 lb (3.0%) N in organic forms, 50% (300 lb of N) would be mineralized in the first year. Another 15% (0.15 x 600 = 90 lb N) would be released in the second year. These percentages are approximate and may need to be increased for warm climates or sandy soils.

Organic nitrogen source	First year	Second year	Third year	Fourth year
Poultry floor litter	50	15	8	3
Dairy manure (fresh solid)	35	18	9	4
Swine manure lagoon liquid	50	15	8	3
Lime-stabilized, aerobically digested sewage sludge	40	12	5	2
Anaerobically digested sewage sludge	20	8	4	1
Composted sewage sludge	10	5	3	2
Activated, unstabilized sewage sludge	45	15	4	2
Cowpea green manure[a]	60	20	2	0

[a] Hue, N.V. 1998. Unpublished data.

[1]Modified from N.C.Brady and R.R. Weil, 1999, The nature and properties of soils.

X = 8,930 lb, or 4.5 tons of dairy manure per acre must be applied for the second crop.

The amount of N contributed by other forms of organic N applied previously can be estimated in a similar manner. These estimates assume that the temperature, moisture, and microbial activity will be favorable for the mineralization of organic N to inorganic N during the cropping period.

You may wonder if it is practical or economical to apply almost 11 tons of chicken manure to each acre of your land for a crop of sweet corn. Fortunately, such large applications are required only during the transition period (one or two years) from conventional farming to an organic farming system. After about two years of using manure, compost, or green manure as the N source, the release of N from previous years' applications reduces the ongoing application requirements significantly. That is why many organic farmers have seen their crop yields increase with time (WSARE 1995).

Synchronization

The need for N fertilizers is reduced significantly if the period of the crop's greatest need for N can be timed to coincide with the release of N from organic materials applied to the soil. Using human nutrition as an example, we know that babies and older folks require much less total food intake than teenagers or young adults. The same principle applies to plants. Plants require different amounts of N at different stages of growth: seedlings and senescing plants require much less N than flowering or fruiting plants (Figure 15-1).

We also know that different organic materials have different N-release patterns. For example, the N-release patterns of three organic soil amendments are shown in Figure 15-2. This graph tells us several things.

First, don't count on wood-based composts as a source of N. In fact, adding such composts to soils may even cause N deficiency in fast growing crops such as tomato or lettuce, as shown in Photo 15-2, p. 48.

Second, N from chicken manure and chicken-manure based compost is readily available right after application, but its availability decreases with time. The graph shows that chicken manure can provide a large quantity of N during the first four to six weeks after application. Thus, its application should be synchronized so that period of release occurs during the crop's period of fastest growth.

Third, the green manure shown in Figure 15-3 took about two weeks to start releasing N. It released the most N between the third and seventh weeks after application. The release remained low and nearly constant for another month (between weeks 7 and 11), then started to increase again. We believe that this second phase comes from the decomposition of materials in the green manure that were initially resistant to micro-

Figure 15-1. A hypothetical plant N-demand growth curve

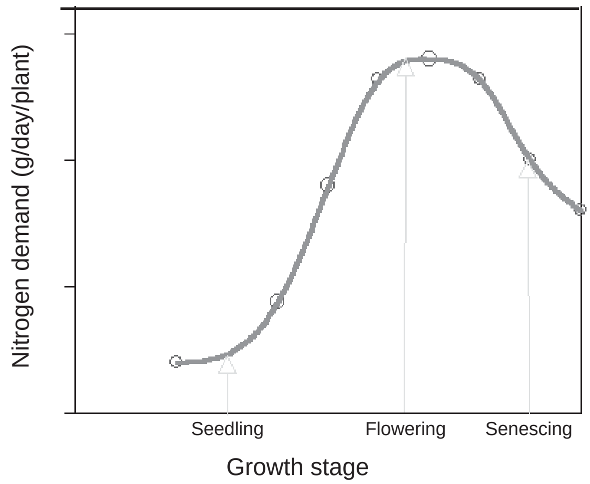
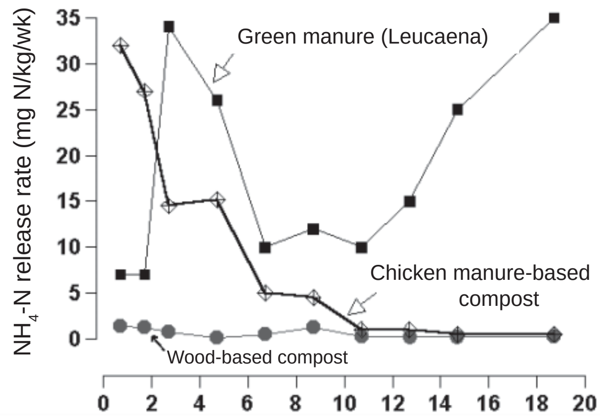


Figure 15-2. Nitrogen release patterns of three organic fertilizer materials (Deenik, Knowlton, and Hue, unpublished)



bial degradation.

Figure 15-3 shows that the release patterns of the N contained in various organic soil amendments can differ greatly. In contrast to the easily predicted release of N from readily soluble synthetic fertilizers, successful use of organic soil amendments such as compost, green manure, or animal manure as N sources requires greater and more specialized knowledge about the material, the crop, and the environmental conditions that effect them and their interaction.

General properties of N from organic sources

The availability of N declines as materials age or are composted. It has been estimated that in warm regions such as Hawaii, N release rates per year for the four years after application are 30, 10, 5, and 5 percent for fresh (not composted) manure or sewage sludge and 15, 5, 3, and 3 percent for composts (Hue 1995).

Nitrogen from poultry manure (not composted) is more quickly available than N in manure of cows, horses, or sheep. This is because poultry manure contains significant amounts of uric acid, which is readily decomposable. Also, roughage in the diet of cattle and horses results in manure that is less readily decomposed due to its content of lignin and cellulose.

The presence of bedding or litter lowers animal manure N content by dilution, and its effect on N availability cannot be easily predicted.

Moist manure, when exposed to the air, undergoes significant loss of N as volatile ammonia (NH_3). Nitrogen losses after spreading manure can be significantly reduced by incorporating the manure into the soil (even shallow incorporation is adequate).

Nitrogen in compost is in a more stable form than N in manure. Thus, there is a decreased likelihood of losing N from a compost application. On the other hand, composts containing less than 1.5% N supply little or no N to crops during the first few weeks after application.

Green manure crops—fast growing plants such clovers, vetches, mustard, and rye—are incorporated into the soil while they are still young and green. At that stage, often only a month or two after sowing, the carbon-nitrogen ratio of the green manure plant tissue is low, and its N can be rapidly released to benefit the following crop.

Cover crops and ridge tillage in sustainable farming

Cover crops grown in rotation with economic crops include grasses (e.g., annual ryegrass, buckwheat) and N-fixing legumes (e.g., clover, vetch). In contrast to short-duration green manure crops, cover crops are often left in the ground for an entire season between economic crops. In the U.S. mainland, for example, rye is often used as a winter cover crop to conserve N and control weeds. A properly managed legume cover crop can fix up to 150–200 lb/acre N in three to six months (Bugg and Miller 1991). A cover crop takes up soil N that might otherwise be lost by leaching or denitrification if the field were left fallow; this reduces potential nitrate pollution and conserves the N in organic form, which becomes available to subsequent crops when the cover crops are incorporated into the soil. Cover crops also serve to reduce soil erosion.

Intercrops can also provide these benefits and, if the intercrop is an economic crop, it can be harvested as well. For example, corn yield and N uptake in a humid tropical region of India increased by 15–20 percent due to intercropping with soybean or cowpea, a yield comparable to that from adding 80 lb/acre of fertilizer N.

The rate of N release from incorporated cover crops depends on many factors, including the carbon-nitrogen ratio of the material, its degree of incorporation into the soil, and the soil temperature and moisture content. In general, cover crop tissues are more mature at the time of incorporation than those of green manure crops, and the carbon-nitrogen ratio of the older material is much higher. The soil microorganisms that begin decomposing the added material may use up all its N in their metabolic processes as they utilize the carbon-containing material for food. Thus, little N may be immediately available from the incorporated material, and some soil N may also be used by the microbes. This storing of N in microbial biomass is referred to as "N immobilization." The time required for N release to exceed N immobilization varies with the factors mentioned above. Depending upon the timing of the period of maximum N need in the subsequent crop, the farmer has to decide if supplemental fertilizer N is needed, and if so, how much.

Along with crop rotation and intercropping, ridge tillage is often practiced in sustainable farming. This technique tills only a zone of soil 15–20 cm wide and 5–10 cm deep at planting time (Figure 15-4). The practice creates a desirable seedbed environment and buries crop residues and weeds in the area between rows. Subsequent between-row cultivation a couple of weeks after planting promotes mineralization of soil organic residues, controls weeds, and reforms the ridge with a raised bed for future crops.

In addition to providing N and other nutrients, added animal manure, green manure, compost, and cover crop residues can also improve soil tilth and moisture-holding capacity, but the timing of their effects and the mechanisms of their actions may differ.

Phosphorus

Phosphorus (P) is needed by plants in much smaller quantities than nitrogen, but like N deficiency, P deficiency in soils commonly limits crop production. Phosphorus is a structural component of DNA and RNA, genetic materials essential for growth and reproduction. P-containing compounds, mainly adenosine diphosphate (ADP) and adenosine triphosphate (ATP), are the internal energy source for plant and animal metabolic processes. Inadequate P supply results in decreased synthesis of RNA, the protein maker, leading to depressed growth.

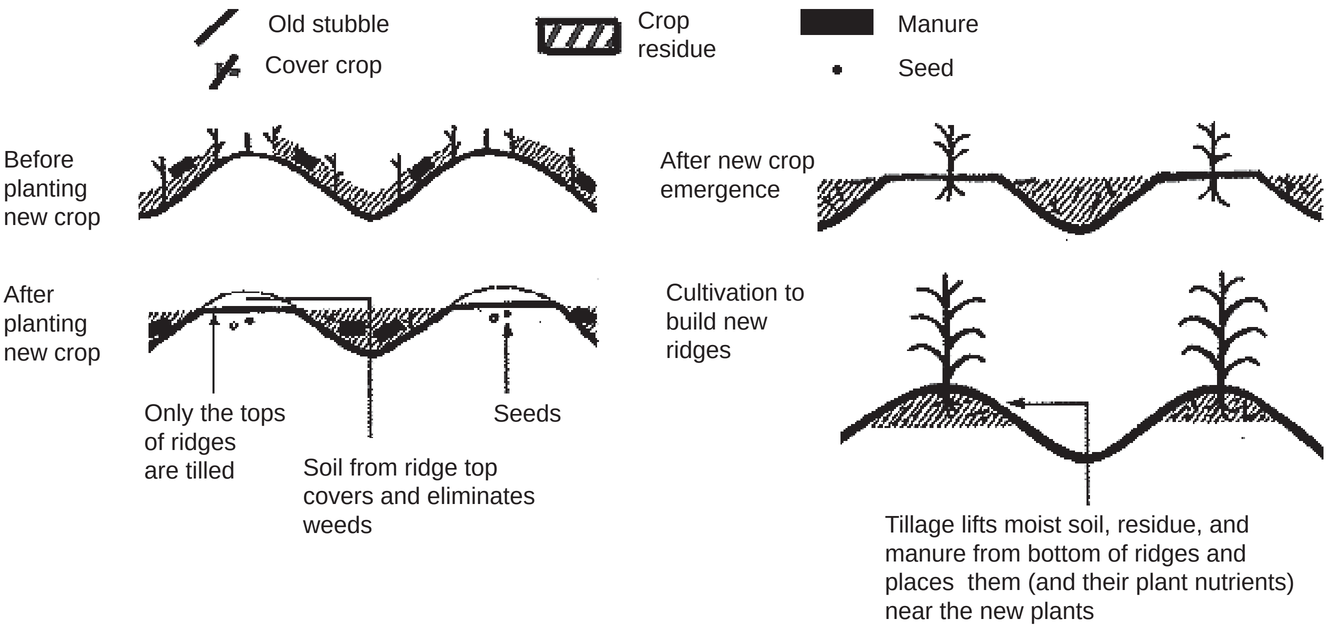
P-deficient plants, therefore, are stunted, with limited root systems and thin stems. In many plants such as corn, guava, and tomato, P-deficient seedlings look stunted, and older leaves may turn purple because of an accumulation of anthocyanins (purple pigments) (Photo 15-3, p. 48). Fruit trees deficient in P have fewer and shorter new shoots and malformed fruits and seeds. Thus, not only low yields but also poor crop quality are the results of P deficiency.

Internally, most plants need from 0.2 to 0.5% P (on a dry-matter basis) for normal growth. Macadamia is an exception—iron chlorosis may occur if P is greater than 0.15% in leaves. Table 15-3 lists the sufficiency range of P in index-tissue leaves of selected crops.

Plants extract P from the soil solution in the form of orthophosphate ion ($H_2PO_4^-$ or HPO_4^-). There is strong competition between plants and soil minerals for these forms of P when they are free in the soil solution, and the soil usually wins. This is especially so for the highly weathered soils of Hawaii and the tropics, most of which contain large amounts of iron oxides, aluminum oxides, or amorphous alumino-silicate clays. These soil minerals "fix" P firmly through a process known as sorption, making the P virtually unavailable for plant uptake. Table 15-4 shows the amounts of P that growers must apply in order to provide enough P for first-time growing of many vegetables, including lettuce and tomato. These data illustrate the variability of the P-fixing capacity of soils.

The amount of P required as fertilizer varies depending on how much P the soil has in the first place. That is why you need a soil test before trying to amend soils or fertilize crops. In fact, by adding P to the soil

Figure 15-3. Ridge tillage (adapted from WSARE 1995).



year after year, you might build up soil P to the point that it becomes detrimental to plants because of excess—this has happened on several vegetable farms in the Waianae area of Oahu. One positive thing about the P-fixation phenomenon is that once you have built your soil P to an adequate level, that level will remain for many years without any additional P applications. The reason for this is that unlike N, P does not move easily with water, and loss from leaching is minimal.

Various sources of P fertilizer can be used to build up the soil P level. In conventional farming, commonly used fertilizers are treble superphosphate ($Ca[H_2PO_4]_2$) and diammonium phosphate (DAP), both of which contain about 20% P (46% P_2O_5). These fertilizers dissolve quickly in water and thus can produce levels of soil-solution P high enough that crops can compete for P with the soil's P-fixation capacity. However, these P fertilizers are not acceptable in organic farming because they are produced by chemical processes. Table 15-5 shows the P content of selected materials that are acceptable to the organic farming community in most areas. Among these materials, the first two (rock phosphate and bone meal) have reasonably high total P contents: between 20 and 30 percent. However, the phosphate in these two sources is very insoluble and thus is much less readily available to plants than phosphate in treble superphosphate. P in rock phosphate and bone meal has the formula $Ca_5(OH)(PO_4)_3$, which is hydroxy apatite (or apatite, for short), the same material that bones and teeth are made of. Our teeth are evidence that apatite is quite durable and very hard to dissolve in water, meaning that it provides very little phosphate to your crop in the short term.

Rock phosphate is thus a source of P for long-term soil improvement. No noticeable effect from its application can be expected within weeks or months, unless huge amounts of it are used. Its solubility—and thus its availability to plants—depends strongly on soil pH and the particle size of the material applied. Rock phosphate is more effective in acid soils than in calcareous or alkaline soils, more effective when its particle size is fine than coarse, and more effective in the presence of mycorrhizal soil fungi than without these symbionts.

Compared to rock phosphate, the P content of organic fertilizers such as chicken manure, compost, and sewage sludge is relatively low. Large amounts of these materials are needed to meet crop P requirements. Yet, pound for pound, P from these organic sources is more

Table 15-3. Examples of sufficiency levels of P in crop leaves.

Crop	Plant P (%)
Cabbage	0.4 – 0.6
Coffee	0.2 – 0.3
Corn	0.3 – 0.5
Head lettuce	0.4 – 0.6
Macadamia	0.08 – 0.10
Soybean	0.3 – 0.5
Sugarcane	0.2 – 0.3
Tomato	0.3 – 0.8

Table 15-4. Examples of P applications required for good growth of most vegetables in Hawaii soils that are being cultivated for the first time.

Soil (series / order)	P applied (lb/acre)
Hilo / Andisol	2000
Halii / Oxisol	1600
Paaloa / Ultisol	1200
Lualualei / Vertisol	100

readily available to plants—sometimes even more readily—than P from treble superphosphate. Our recent research has shown that organic matter from manure interacts with clay minerals and reduces P sorption by the soil, thereby enhancing P availability to plants (Hue 1990).

Potassium

Potassium (K), like N, is needed in large quantities by most crops (Table 15-6). K is required in plants for maintaining the water content of cells—it helps keep plant tissues turgid. K plays an important role in plant water relations by regulating the osmotic potential of cells and the closing and opening of leaf stomata, the openings in the leaf surface that allow moisture to escape, cooling the plant. K is involved in water uptake from the soil, water retention in the plant tissues, and transport of water in the xylem and photosynthates in the phloem. K affects cell extension—with adequate K, cell walls are thicker, thereby improving plant resistance to lodging (falling over), pests, and diseases. Fruits and vegetables grown with adequate K seem to have longer postharvest storage life.

K-deficient plants have low resistance to disease, and their seeds and fruits are small and shriveled. In tomato, K deficiency results in smaller fruits with incomplete flesh development; in corn, maturity is delayed and ears are smaller (Photo 15-4, p. 49).

The most readily observed K deficiency symptom is scorching (“firing”) of leaf tips and edges, as shown in Photo 15-9 (p. 49) for soybeans. In alfalfa and clovers, the first signs of K deficiency show up as small white or yellowish spots around the outer edges of the leaves. As the deficiency intensifies, the leaf edges turn yellow, then brown, and finally the leaf dies (Photo 15-5).

In soils, K is quite mobile compared to P. It is in ionic form (K^+) in the soil solution and is absorbed by roots in that form. Although K^+ can be retained to some extent by negative charges on clay surfaces, it can be easily displaced into the soil solution by calcium or magnesium ions (Ca^{2+}, Mg^{2+}) when gypsum or dolomite are applied. Therefore, K not taken up by plants may be lost by leaching. One way to reduce K leaching is to incorporate organic soil amendments such as compost or green manure. Organic materials usually have a large cation exchange capacity, enabling them to retain potassium ions effectively. Among soil types, K deficiency occurs more often in sandy than in clayey soils, more often in highly weathered soils than in young soils, and—to cite a local example—more often in the soils of the Hilo coast than in the soils of the Kona coast, due to more leaching of K in the high-rainfall Hilo climate.

If soil is low in K, what can you do? Commercial fertilizer such as KCl (potassium chloride, muriate of potash) is an easy choice in conventional farming but is not acceptable in organic farming, where alternative K sources must be used (Table 15-7).

Potassium magnesium sulfate and polyhalite are potassium minerals found in natural deposits. Sul-Po-Mag® is a commercial formulation consisting of the double salt of potassium and magnesium sulfates (22% K_2O, 11% Mg, 22% S). Polyhalite is a double salt of calcium and potassium sulfates. Both K sources are very soluble, similar to KCl. In terms of plant response, these materials are as good as or even better than KCl or gypsum. Large deposits of polyhalite occur in Utah,

Table 15-5. Phosphorus concentration in P sources acceptable for most "organic" farming systems.

P source	Total P (%)
Rock phosphate	17 – 26
Bone meal	20 – 30
Fish meal	5 – 10
Wood ash	2 – 5
Poultry manure	0.5 – 1.5
Green manure	0.2 – 0.5
Compost	0.2 – 0.5
Sewage sludge	0.4 – 2.5

Texas, Poland, and Egypt, but it is not widely available because its commercial use is under development.

Wood ash contains about 5% K that is readily available (and alkaline), while green-sand has about 7% K that has very low availability. Green-sand can be used to build up the soil K reserve, but it is doubtful that it can meet the K requirement of a rapidly growing crop.

Organic fertilizer options

A surprisingly large selection of organic fertilizers is available to home gardeners. Some are free for the taking and may be found on your property; others are available from garden supply centers. Use Table 15-7 to select amendments that have the characteristics you need. The table lists the N-P-K ratio and the sulfur (S), magnesium (Mg), and calcium (Ca) content, if any. It also indicates whether or not the fertilizer supplies micronutrients. For materials that you might incorporate in bulk or include in compost, the carbon-nitrogen ratio is included. The table also includes information on whether nutrients are slowly or rapidly available and whether there are any precautions that should be observed in using a particular amendment.

Knowledge is the key

Sustainable agriculture seeks close harmony with nature. The challenge of sustainable agriculture is that it is information-intensive and requires the farmer to have a deep and detailed understanding of natural processes. Because of its special requirements, farmers practicing sustainable agriculture may need to develop more management skills than even modern "conventional" agriculture requires.

Table 15-6. Potassium sufficiency range in selected crops.

Crop	Tissue K (%)
Banana	3.0 – 5.0
Cabbage	4.5 – 7.5
Coffee	2.0 – 3.0
Corn	1.5 – 3.0
Lettuce	4.0 – 7.5
Papaya	3.0 – 5.0
Tomato	3.0 – 5.0

Adapted from Tamimi et al. 1994.

Table 15-7. Potassium concentration in soil amendments acceptable for most "organic" farming systems.

Potassium source	Total K (%)
Sul-Po-Mag (Mg, K, SO_4)	22
Polyhalite (Ca, K, SO_4)	10 – 15
Wood ash	5 – 10
Greensand	5 – 7
Green manure	2 – 5
Seaweed meal	2 – 3
Compost	0.5 – 2

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Table 15-7. Organic fertilizer options. (Reprinted from *Growing Fruits and Vegetables Organically*, © 1994 by Rodale Press, Inc. Permission granted by Rodale, 400 S. 10th St., Emmaus, PA 18098. Information in brackets has been modified from the original table.)

Amendment	N-P-K ratio	Other nutrients	C/N ratio	Comments
Alfalfa hay	2.6 - 0.6 - 2.2	0.3% S; 1% Ca; 0.02% Mg; micronutrients	16	Well balanced, slowly available. Contains growth stimulants
Alfalfa meal or alfalfa pellets	2.7 - 0.5 - 2.8	0.2% S; micronutrients	15	Well balanced, more rapidly available than alfalfa hay. Contains growth stimulants.
Blood meal	13 - 2 - 0	Not a significant source of other nutrients	3	Rapidly available N. Stimulates microbes.
Bonemeal	3 - 2 - 0.5	24% Ca	-	Rapidly available P source. Mildly increases pH.
Compost (dry, commercial)	1 - 0.8 - 1	0.4% S; 0.2% Ca; 0.1% Mg; micronutrients	10–17	Balanced, slow release. Good choice for busy gardener.
Compost (homemade)	1 - 0.5 - 1 to 2 - 1 - 2	0.4% S; 0.2% Ca; 0.1% Mg; micronutrients	10–17	Balanced, slow release.
Cottonseed meal	6 - 2 - 2	Not a significant source of other nutrients	7	Rapidly available N source. May contain pesticides.
Egg shells	1.2 - 0.4 - 0.1	0.4% Ca; micronutrients	-	Should be crushed. Good compost addition.
Epsom salts	0 - 0 - 0	13% S; 10% Mg	-	Rapidly available Mg and S source.
Feather meal	11 - 0 - 0	Not a significant source of other nutrients	4	Rapidly available N source.
Fish emulsion	5 - 2 - 2	5% S	4	Rapidly available N source.
Fish meal	10 - 4 - 4	Not a significant source of other nutrients	4	Rapidly available N source.
Granite meal	0 - 4.0 - 0	Micronutrients	-	Very slow release of P Use to build soil reserves.
Grass clippings (fresh)	0.7 - 0.3 - 0.8	0.1% S; 0.2% Ca; 0.1% Mg	33	Balanced, slow release.
Greensand	0 - 0 - 7	Micronutrients	-	Very slowly available source of K. Use to build reserves.
Gypsum	0 - 0 - 0	17% S; 22% Ca	-	Slowly available source of S and Ca. Does not affect pH. Improves alkaline soil structure. Increases plant growth in acid soils.

Amendment	N-P-K ratio	Other nutrients	C/N ratio	Comments
Kelp meal	1 - 0.2 - 2	3% S; micronutrients	-	Slow release of K and micronutrients. Contains growth stimulants.
Lime, oyster shell	0 - 0 - 0	38% Ca; 1% Mg	-	Slow release of Ca. Used to increase pH.
Limestone (dolomitic)	0 - 0 - 0	20% Ca; 10% Mg	-	Slow release of Ca and Mg. Used to increase pH.
Limestone (high - Ca)	0 - 0 - 0	26–36% Ca; 2–7% Mg	-	Slow release of Ca. Used to increase pH.
Manure, cow (dry)	2.0 - 1.0 - 2.4	0.5% S; 0.2% Ca; micronutrients	18	Best when composted.
Manure, horse	2 - 1 - 2.5	1% S; 0.2% Ca; micronutrients	22	Slow release when dry; rapid release when fresh.
Manure, poultry (dry)	4 - 3 - 1	0.2% S; 2% Ca; 0.3% Mg	7	Very rapidly available N and P. Should be composted; fresh manure will burn plants.
Oak leaves	0.8 - 0.4 - 0.1	Micronutrients	Variable	Very slow release. Improves soil structure.
Orchard grass (hay)	2 - 0.6 - 2.7	0.3% S	24	Balanced, slow release.May need rapidly available N source added.
Rock phosphate (hard rock)	0 - [15] - 0	[33]% Ca; micronutrients	-	Slowly available P and Ca. Will increase pH. Used to build reserves.
Sawdust	0.2 - 0.2 - 0.3	Not a significant source of other nutrients	Very high	Use only when well rotted. Add a rapidly available N source. Good soil conditioner and mulch for [acid-loving plants].
Soybean meal	6 - 1 - 2	0.8% Mg; micronutrients	7	Rapidly available nitrogen.
Sulfur ("flowers")	0 - 0 - 0	99.5% S	-	Used to lower high pH.
Sul-Po-Mag[®]	0 - 0 - 22	19% S; 10% Mg	-	Rapidly available K and Mg. Don't use with dolomitic lime.
Weeds (fresh)	2.4 - 0.8 - 3.8	2.3% Ca; micronutrients	17	Balanced, slow release.

continued . . .

Table 15-7. (continued)

Amendment	N-P-K ratio	Other nutrients	C/N ratio	Comments
Wheat straw	0.6 - 0.2 - 1	0.2% S; 0.2% Ca; 0.05% Mg; micronutrients	78	Very slow release.Used to improve soil structure. Should be applied with a rapidly available N source.
Wood ashes (leached)	0 - 1.6 - 5	15% Ca; micronutrients	-	Low P content, but rapidly available. Good source of K and Ca. Will increase pH. Can injure microorganisms. Do not use more than ½–¾ lb per 100 ft^2.
Wood ashes (unleached)	0 - 1.7 - 7	15% Ca; micronutrients	-	Low P content, but rapidly available. Good source of K and Ca. Will increase pH. Can injure microorganisms. Do not use more than ½–¾ lb per 100 ft^2.
Wood chips (deciduous)	0 - 0.2 - 2 to 0 - 1 - 3	Not a significant source of other nutrients	Very high	Very slow release. Do not apply without a rapidly available N source. Used to improve soil structure. May take >1 year to decompose.
Worm castings (Biocast)	0.5 - 0.5 - 0.3	Micronutrients	-	Excellent for improving soil structure.

Organic farming is a form of agriculture in which agricultural land is cultivated without the use of artificial fertilisers, or artificial pesticides, growth regulators and livestock feed additives. Genetically modified organisms and engineered nanoparticles are forbidden as well. The use of agricultural machines (running on either biofuels or fossil fuels) is allowed. The goals of organic farm systems include the maintenance of soil fertility, efficient usage of water, maximizing soil fertility, and Hue, N.V. and Silva, J.A. (2000) Organic soil amendments for sustainable agriculture: Organic sources of nitrogen, phosphorus and potassium. Plant nutrient management in Hawaiâ€™s Soils, approaches for tropical and subtropical agriculture. In: Silva, J.S. and Uchida, R., College of Tropical Agriculture and Human Resources, University of Hawaii, Manoa. has been cited by the following article: TITLE: Phosphorus fixing capacity of the Oxic Rhodustalfâ€"alfisol soil in the Chotanagpur plateau region of Eastern India. AUTHORS: Prabir Ghosal, Trishit Chakraborty, Pabitra Banik. KEYWORDS: P-Fixing Capaci...Â Assessment of soil quality using soil organic carbon and total nitrogen and microbial properties in tropical agroecosystems.