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Chapter 6 Role of Plants in Manure Management

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Chapter 6 Role of Plants in Manure Management

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651.0600 Introduction

Agricultural operations commonly produce by-products. Animal manure is an example of a by-product that can be used as a plant nutrient. With proper management, manure can be a resource to improve soil and plant health in a way that results in economic returns. Manure management systems that are properly planned, designed, installed, and maintained prevent or minimize degradation of soil, water, and air resources while providing organics and chemical elements for plant growth.

The objectives of a complete system approach to manure management are to:

- recycle nutrients in quantities that benefit plants
- build levels of soil organic matter
- limit nutrient or harmful contaminant movement to surface and groundwater
- not contaminate food crops with pathogens or toxic concentrations of metals or organics
- facilitate the attenuation and transformation of nonessential elements and compounds into harmless forms

This chapter describes the role of plants in the management of nutrients from manure applications. The function and availability of plant nutrients as they occur in manure is described, and the effects of trace elements and metals on plants are introduced. General guidance is given so the nutrients of the manure can be converted to plant-available form and the nutrients harvested in the crop can be estimated. The impact of excess nutrients, dissolved solids, and trace elements on plants is given in relationship to manure application.

651.0601 Manure as a resource for plant growth

The primary objective of applying manure to land is to recycle plant nutrients contained in the manure into harvestable plant forage, fruit, or dry matter and to prevent manure contributions to air and water quality degradation. An important consideration is the relationship between the plant's nutrient requirement and the quantity of nutrients in the applied manure. A plant does not use all the nutrients available to it in the root zone. The fraction of the total that is assimilated by the roots varies depending on the species of plant, growth stage, depth and distribution of its roots; moisture conditions; soil temperature; microbial activity; types of soil biota; and many other factors. The uptake efficiency of plants generally is not high, often less than 50 percent. Plants that build a symbiotic relationship with vascular arbuscular mycorrhizae (VAM) can greatly increase nutrient uptake. Perennial grasses tend to be more efficient in nutrient uptake than row crops. They grow during most of the year including the period of waste application, and they have extensive and deep root systems, which maximize the nutrient removal from the applied manure.

Another major objective in returning manure to the land is to improve soil health by enhancing the soil's organic matter content. Organic matter is approximately 58 percent carbon. As soils are cultivated, the organic matter in the soil is depleted, and after several years of continuous cultivation and low returns of crop residue, the organic matter content of most soils decreases dramatically. This loss of organic carbon greatly decreases the soil's ability to hold the key plant nutrients of nitrogen, phosphorus, and sulfur. These nutrients may move out of the root zone into ground and surface water and diminish future crop growth. The amount of crop residue that is produced and returned to the soil is further reduced, aggravating the problem and increasing dependency on petroleum-based fertilizers to maintain production. Soil disturbance, even for the rapid incorporation of manure, should be avoided when trying to restore organic matter to the soil.

Approximately 65 percent of the carbon in organic residue is released to the atmosphere as carbon dioxide by the respiration of soil microbes. The humus that remains has a carbon nitrogen ratio of approximately 10:1. If there is not sufficient nitrogen present, the percentage of carbon from the biomass that is released as carbon dioxide increases beyond 65 percent. With crop residues that have high carbon to nitrogen ratios, such as corn stalks or small grain straw, the amount of humus formation can actually be increased by providing a nitrogen source such as manure or a leguminous cover crop.

651.0602 The plant-soil system

The plant-soil system has advantages for using nutrients in by-products from agricultural systems. For centuries, manure has been spread on the soil to recycle nutrients with a positive effect on plant growth. Soils have the ability to retain plant nutrients contained in the manure, and manure provides a more complete energy source for soil organisms. Soil absorption is an important storage mechanism for plant nutrients, and the soil absorption capacity is enhanced when the soil organisms utilize the manure for a food substrate. Micro-organisms that feed on the carbon in the organic matter convert manure nutrients into a form usable by plants.

Mostly through their roots, plants absorb nutrients from the soil solution that are mineralized from the manure, and then the plants transform the soluble chemical elements into more plant tissue. Soil microbes are the drivers of this nutrient cycle, and nutrients are sequestered in the soil ecosystem, minimizing their transport through leaching and runoff. This is the basis for addressing some of today's water quality concerns. Without these biologically driven transformations, some of the nutrients could contribute to water contamination. Cropping systems that provide continuous ground cover and that utilize cover crops and diverse rotations, along with carefully calculated nutrient budgets, can be tailored for planned manure application levels and plant nutrient needs. A holistic nutrient management plan can increase plant uptake of nutrients and reduce or eliminate nutrient losses from the plant-soil ecosystem.

(a) Nutrient transformation

Plant uptake is not the only form of nutrient transformation that takes place in the soil-plant system. The chemical compounds derived from waste material can be transformed by the following processes:

1. Absorption by the roots and assimilated by the plant.
2. Metabolization by soil micro-organisms to become a part of the soil organic component, or to become gasses like nitrogen gas that is released to the atmosphere, or to become ions suspended in the soil solution.

3. Adsorption to soil minerals or attached to soil exchange sites.
4. Transportation off the field as solutes in runoff water.
5. Become attached to eroding mineral or organic material.
6. Leach downward through the soil toward the groundwater.
7. Escape from plant tissue into the atmosphere.

Plants can play a role in all of these processes. Processes 4, 5, 6, and 7 are nutrient transport mechanisms. Plant species and cultivars can be selected and managed to interrupt many of these mechanisms. As an example, conservation tillage and planting on the contour with grass sod cover decreases the movement of soluble nutrients in runoff by increasing soil infiltration (process 4). Soil conservation actions reduce erosion, which interrupts process 5. Deep, fibrous-rooted cover crops that can actively take up nutrients beyond the normal growing season of most agricultural crops interrupt process 6 by preventing escape of leaching soluble nutrients. Actively growing vegetation can also help minimize denitrification through transpiration that can reduce periods of soil saturation and indirectly reduce denitrification.

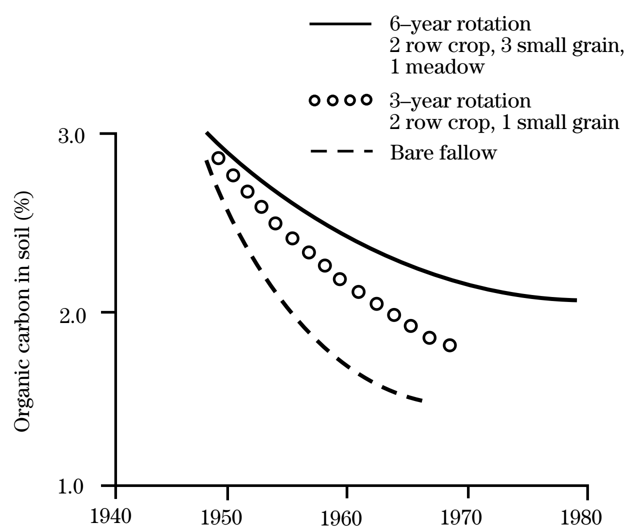
Plants can also be selected for their propensity to uptake a certain nutrient. Several crops are heavy users of nitrogen and accumulate nitrate, which is very soluble and leachable. Recent studies have shown that grass species vary significantly in their ability to remove and transform nitrogen within the soil. Alfalfa removes potassium and nitrogen in larger quantities and at a deeper rooting depth than most agricultural crops. Legumes do not require applications of nitrogen, and those that can be harvested, like soy beans, can be used in rotations to remove excess phosphorus that can accumulate through manure applications. Nutrient removal from the soil by the removal of vegetative matter is maximized when large quantities of live biomass are removed from the field. Hay, silage, and the removal of residue from multiple crops within a crop season can effectively mine nutrients from the soil. When biomass is harvested for energy purposes, it is generally recommended that the harvest be delayed until the nutrients in the plants are translocated back to the root system. Biomass harvest for energy purposes would not maximize nutrient removal from the field.

In other cases, plants may act as a catalyst or provide a better environment to promote nutrient transformation processes. Plant growth moderates soil temperature, reduces evaporation from soil surface, provides organic matter as an energy source of carbohydrates, and aggregates soil particles that promote high soil aeration. All this provides a better climate for a wide variety of soil micro-organisms, which aids process 2.

Process 3 is aided by plant growth as well, but generally, this comes very slowly. The classic example is the difference in the cation exchange capacity (CEC) between a prairie soil and a forest soil derived from the same parent material. Prairie soils have a much higher organic matter content and CEC, at least double to sometimes nearly quadruple that of the forest soil (Jenny 1941). Yet, what takes centuries to build up can be quickly depleted by erosion and excessive tillage (fig. 6–1). High-residue crops in crop rotations help to prevent large decreases in soil organic matter content and have beneficial effects on nutrient retention (Wild 1988).

Denitrification is a classic example of nutrient transformation where microbial degradation and eventual escape of nitrogen gas occurs. The soil microbes that accomplish this require the presence of nitrate-nitrogen, an organic carbon source, and changing

Figure 6–1 The effects of different farming systems after three decades on the carbon content of soils from broken out sod ground



aerobic and anaerobic soil conditions. About one unit of organic carbon is required for each unit of nitrate-nitrogen to be denitrified (Firestone 1982). Where the nitrogen in the manure is in the organic or ammonium form, an aerobic condition must be present to convert the nitrogen to the nitrate form. During the aerobic process, the organic carbon will be oxidized by aerobic bacteria in the soil, leaving less carbon available for anaerobic microbial use when the system goes anaerobic. Denitrification in manure-treated soils can release nitrogen gasses either as dinitrogen or as nitrous oxide, depending on conditions. The interactions are complex and not fully understood. Nitrous oxide tends to be released from manure-treated soils when soils thaw and when they are between 40 percent and 60 percent saturation. Tillage can decrease the formation of nitrous oxide due to increased aeration until the soils reconsolidate. In highly saturated soils, nitrous oxide is more likely to be further reduced to N_2.

Plant residue and roots are major sources of organic carbon for these microbial processes. The presence of living plants stimulates denitrification. This is attributed to low oxygen levels in the soil area immediately surrounding respiring plant roots, creating the condition in which denitrifying anaerobes can exist and to root excretions that can serve as a food source of decomposable organic carbon for the denitrifying bacteria.

(b) Soil supports plant growth

Soil is the normal medium for terrestrial plant root growth. A plant's roots absorb nutrients and water from the soil. Roots anchored in the soil hold the plant erect. The soil must provide the environment in which roots can function. Optimum plant growth depends on the soil having the biological, chemical, and physical conditions necessary for the plant root system to penetrate the soil and readily absorb nutrients and water. Plants require soil pore space for root extension. Plant root metabolism also depends upon sufficient pore space to diffuse gases such as oxygen and carbon dioxide. This allows for efficient root respiration, which keeps the root in a healthy condition for nutrient uptake.

Manure feeds the micro-organisms that contribute to soil structure and pore space. However, soil compaction can occur in moist soils when manure is applied with heavy equipment. This can result in a decrease in soil pore space, retarding the diffusion of gases through the soil matrix. Manure application systems utilizing control traffic farming methods can minimize compaction from application equipment. High concentrations of soluble salts in some manure can limit or stop plant growth. Salts can disperse clays at the soil surface, sealing the surface from infiltration and resulting in crusting, which will limit the water available to the plants. Tillage also diminishes infiltration and promotes crusting.

651.0603 Plant nutrient uptake

Almost any element in the soil solution is taken into the plant to some extent, whether needed or not. An ion in the soil goes from the soil particle to the soil solution, through the solution to the plant root, enters the root, and moves from the root through the plant to the location where it is used or retained. The process of element uptake by plants is complex and not totally understood, however, we are generally confident that:

- The process is not the same for all plants or for all elements.
- The complete process occurs within a healthy root system adequately supplied with carbohydrates and oxygen.
- The essential elements must be in an available form in the root zone in balanced amounts.
- Uptake varies from element to element and from crop to crop.
- Soil conditions, such as temperature, moisture supply, soil reaction, soil air composition, microbial activity, CEC, and soil structure, affect the rate at which elements are taken up.

(a) Essential plant nutrients

Plant growth can require up to 20 chemical elements. Plants get carbon, hydrogen, and oxygen from carbon dioxide and water. Nitrogen, phosphorus, potassium, sulfur, calcium, and magnesium are needed in relative large quantities. These elements are called macronutrients. Boron, chlorine, cobalt, copper, iron, manganese, molybdenum, silicon, sodium, vanadium, and zinc are needed in small amounts, or not at all, depending on the plant (Tisdale, Nelson, and Beaton 1985). These elements are called micronutrients or trace elements.

Macronutrients and micronutrients are taken from the soil-water solution. Nitrogen is partly taken from the air by nitrogen-fixing plants associated with soil bacteria. As a whole, the 20 elements listed are termed "essential elements;" however, cobalt, silicon, sodium, and vanadium are essential elements for the growth of only particular plant species.

(b) Nonessential elements

Besides the 20 essential elements, other elements nonessential for plant growth must be monitored where municipal sludge is used as a soil amendment. These, too, are referred to as "trace elements." Because these elements occur as impurities, they are often inadvertently applied to soils through additions of various soil amendments. Animal waste can contain certain elements that can be considered essential or nonessential, depending on the plant. Nickel, arsenic, and copper have been found in poultry litter, and excessive quantities of these can lead to plant toxicity. Dairy manure has elevated levels of aluminum.

(c) Nitrogen

Nitrogen is the element that most often limits plant growth. About 98 percent of the planet's nitrogen is in the Earth's primary rock. Nearly 2 percent is in the atmosphere, but it is 79 percent inert. Even though nitrogen is abundant, it is not always abundant in the form used by plants, and it is still the nutrient most frequently limiting crop production. This is because the plant available forms of nitrogen in the soil are constantly undergoing transformation. Crops remove more nitrogen than any other nutrient from the soil. The limitation is not related to the total amount of nitrogen available, but to the form the crop can use. Essentially, all of the nitrogen absorbed from the soil by plant roots is in the inorganic form of either nitrate (NO_3) or ammonium (NH_4). Herbaceous plants generally utilize nitrogen in the nitrate form, while trees and other woody perennial plants use a significantly higher percentage of ammonium. Also, young plants generally absorb ammonium more readily than nitrate; however, as the plant ages, the reverse is true. Under favorable conditions for plant growth, soil micro-organisms generally convert ammonium to nitrate, so nitrates generally are more abundant when growing conditions are most favorable. Once inside the root, ammonium and nitrate are converted to other compounds or transported to other parts of the plant. Most of the nitrogen in plants is in the organic form, which is incorporated into amino acids—the building blocks of proteins. By weight, nitrogen makes up from 1 to 4 percent of the plant's harvested material. However, excess nitrogen can lead to plant nutrient depletion. Because nitrogen leaches in an anion form, it will carry with it cations, such as calcium, potassium, and magnesium, and the amount of nutrient loss from the rooting zone by leaching can be considerable.

(d) Phosphorus

Phosphorus concentration in plant leaves ranges between 0.2 and 0.4 percent (Walsh and Beaton 1973). Phosphorus is important for plant growth because of its role in ribonucleic acid (RNA), the plant cells genetic material, and its function in energy transfer with adenosine triphosphate (ATP). Phosphorus is available for absorption by plants as soluble ions that are also subject to leaching. These orthophosphate ions (H_2PO_4 and HPO_4) react quickly with other compounds in the soil to become much less available for plant uptake. Phosphorus immobility in soils is caused, in part, by presence of hydrous oxides of aluminum and iron. Other causes include the presence of calcium; high clay content, particularly the kaolinitic type; high amounts of volcanic ash or allophone; and organic matter. Maintaining a soil pH between 6.0 and 6.5 achieves the most plant-available phosphorus in a majority of soils. Once equilibrium is established, the concentration of orthophosphate ions in the soil solution is usually less than 0.05 milligrams per liter.

Because of its relative immobility, phosphorus can be applied in excess of the crop's annual nutrient need. The excess phosphorus builds soil phosphorus residual that can be beneficial in soils that readily fix phosphorus into an insoluble form that is unavailable for plant uptake. This phosphorus reservoir, if allowed to rise, gives a corresponding rise in the soluble phosphorus content in the soil. Knowing the extent of the factors limiting phosphorus availability helps determine the upper limit at which phosphorus loading can occur before soluble phosphorus leaching becomes a water quality concern.

Because organic phosphorus is more mobile through the soil profile than its inorganic counterparts, manure applications can increase phosphorus leaching. This would be particularly true on coarse-textured soils that have a low CEC and low content of iron, aluminum, and calcium.

While additional available phosphorus from manure applications rarely becomes directly toxic to the plant, it can hinder plant growth in indirect ways. Phosphorus toxicity depends on the plant species, phosphorus status of the plant, concentration of micronutrients, and soil salinity. Poor growth in plants that have high phosphorus levels can cause reduced nodulation in legumes, inhibition of the growth of root hairs, and a decrease in the shoot to root ratio (Kirkham 1985). In addition, high phosphorus levels can inhibit the growth of beneficial soil fungus that contributes to nutrient transfer from the soil to the plant.

(e) Potassium, calcium, and magnesium

Potassium, calcium, and magnesium have similar reactions in the soil. Upon mineralization from the organic material, each element produces cations that are attracted to negatively charged particles of clay and organic matter. The similar size and uptake characteristic can cause plant fertility problems. An excess of any one of these elements in the soil impacts the uptake of the others. It is, therefore, extremely important not to create nutrient imbalances by overapplying one of these elements to the exclusion of the others.

Potassium is much less mobile than nitrogen, but it is more mobile than phosphorus. Potassium leached from the surface soil is typically held in the uppermost part of the subsoil and returned to the surface via plant root uptake and translocation to aboveground plant parts. Leaching losses of potassium are generally insignificant except in sandy and organic soils. Sandy soils have a low CEC and, generally, do not have clayey subsoil that can re-adsorb the leaching potassium. Potassium can leach from organic soils because the bonding strength of the potassium cation to organic matter is weaker than that to clay (Tisdale, Nelson, and Beaton 1985). Some potassium is leached from all soils, even in the humid regions in soils that have strong fixing clays, but the losses do not appear to have any environmental consequences. Calcium and magnesium can occur in drainage water, but this has not been reported to cause an environmental problem. In fact, it can be beneficial in some aquatic systems. Total dissolved salts content may increase.

(f) Sulfur

Part of the sulfur applied to well-drained soils is oxidized by soil bacteria and fungi into the sulfate ion that plants can absorb. Sulfate concentrations between 3 and 5 milligrams per liter in the soil are adequate for plant growth. Sulfates are moderately mobile and may be adsorbed on clay minerals, particularly the kaolinitic type, and on hydrous oxides of aluminum and to a lesser extent iron. If the soils in the manure management system are irrigated, sulfates can leach into the subsoil and even into groundwater. Under poor drainage conditions, sulfates are converted mainly to hydrogen sulfide and lost to the atmosphere. They are converted to elemental sulfur in waterlogged soils in some instances.

(g) Trace elements

Trace elements are relatively immobile once they are incorporated into the soil. The one nonmetal, boron, is moderately mobile and moves out of the rooting depth of coarse-textured, acidic soils and soils that have a low organic matter content. The levels of plant available forms of all these elements are generally very low in relation to the total quantity present in soils. Some of these elements are not available for most plants to take up.

Soil reaction has the greatest influence on availability of trace elements that are taken up by plants. Except for molybdenum, the availability of trace elements for plant uptake increases as the soil pH decreases. The opposite occurs for molybdenum. For most agricultural crops, a pH range between 6.0 and 7.0 is best; however, there are always exceptions, and soils with coarse surface textures often show deficiencies of zinc and manganese at pH of 6.5 and above. As soil acidity increases, macronutrient deficiencies and micronutrient toxicity can occur depending on the nutrient, its total quantity available in the soil, and the plant in question. In alkaline soils, crops can suffer from phosphorus and micronutrient deficiencies.

Two nonessential elements of primary concern in municipal sludge are lead and cadmium. At the levels commonly found in soils or sludges, these elements have no detrimental effect on plant growth; but, they can cause serious health problems to the people or animals eating plants that are sufficiently contaminated with them. Lead can be harmful to livestock that inadvertently ingest contaminated soil or recently applied sludge while grazing. Cadmium, on the other hand, is taken up by some plants quite readily (table 6–1). If the plants are eaten, this element accumulates in the kidneys and can cause a chronic disease called proteinuria. This disease is marked by an increase of protein content in the urine. As seen in table 6–1 for cadmium uptake, plants differ in their capacity to absorb elements from the soil. They also differ greatly in their tolerance to trace element phototoxic effects.

Nickel is a nonessential element in the soil that can be toxic to plants in high concentrations. Hydrolytic acid reacts with nickel to inhibit the activity of the urease molecule and interfere with plant metabolism of urea.

Table 6–1 Relative accumulation of cadmium into edible plant parts by different crops (USEPA 1983)*

High uptake	Moderate uptake	Low uptake	Very low uptake
Lettuce	Kale	Cabbage	Snapbean family
Spinach	Collards	Sweet corn	Pea
Chard	Beet roots	Broccoli	Melon family
Escarole	Turnip roots	Cauliflower	Tomato
Endive	Radish globes	Brussels sprouts	Pepper
Cress	Mustard	Celery	Eggplant
Turnip greens	Potato	Berry fruits	Tree fruits
Beet greens	Onion		
Carrots			

* The classification is based on the response of crops grown on acidic soils that have received a cumulative cadmium (Cd) application of 4.5 pounds per acre. It should not be implied that these higher uptake crops cannot be grown on soils of higher Cd concentrations. Such crops can be safely grown if the soil is maintained at pH of 6.5 or greater at the time of planting because the tendency of the crop to assimilate heavy metals is significantly reduced as the soil pH increases above 6.5.

Zinc and copper are two essential elements that can also become toxic to plant growth if their concentrations in the soil are excessive. These elements become competitive with each other and with other micronutrients at the carrier sites for plant root uptake. Excessive concentrations of either element in the available form induce a plant nutrient deficiency for the other. High soil concentrations of copper or zinc, or both, can also induce iron and manganese deficiency (Tisdale, Nelson, and Beaton 1985).

Cadmium, copper, nickel, lead, and zinc have been targeted by the U.S. Environmental Protection Agency (EPA) when sludge is applied to agricultural land. Table 6–2 shows their recommended cumulative soil limits in kilograms per hectare and in pounds per acre. Note that these loading limits depend on the soil's CEC and a plow layer pH maintained at 6.5 or above. Application of wastes that have these elements should cease if any one of the elements' soil limit is reached (USEPA 1983). Some States have adopted more conservative limits than those shown in table 6–2. State regulations should be consulted before designing a waste utilization plan.

Aluminum, antimony, arsenic, boron, chromium, iron, mercury, manganese, and selenium can be harmful to plant growth and in high enough concentrations in plant tissue they can harm plant consumers; but, they do not usually occur in sludge in high enough concentrations to pose a problem or they are only minimally taken up by crops (USEPA 1983).

Table 6–2 Recommended cumulative soil test limits for metals of major concern applied to agricultural cropland [1/] (USEPA 1983)

Metal	Soil CEC, meq/100g [2/ 3/]		
	<5	5 to 15	>15
	lb/acre (kg/ha)		
Pb	500 (560)	1,000 (1,120)	2,000 (2,240)
Zn	250 (280)	500 (560)	1,000 (1,120)
Cu	125 (140)	250 (280)	500 (560)
Ni	125 (140)	250 (280)	500 (560)
Cd	4.4 (5)	8.9 (10)	17.8 (20)

1/ Table 6–2 values should not be used as definitive guidelines for fruit and vegetable production.

2/ Interpolation should be used to obtain values in CEC range 5–15.

3/ Soil plow layer must be maintained at pH 6.5 or above at time of each sludge application.

(h) Synthetic organic compounds

Municipal sludge synthetic organic compounds, such as chlorinated hydrocarbon pesticides, can be slow to decompose and may be of concern from a human or animal health standpoint. Polychlorinated biphenyls are common in sludge. Federal regulations require soil incorporation of any sludge that has more than 10 parts per million of polychlorinated biphenyis wherever animal feed crops are grown. Polychlorinated biphenyls are not taken up by plants, but can adhere to plant surfaces and be ingested by animals and humans when the contaminated plant parts are eaten. Pesticide uptake by crops is minimal, and concentrations in wastes would be much less than that typically and intentionally applied to control pests on most cropland (USEPA 1983).

651.0604 Balancing plant nutrient needs with manure application

Manure managers must balance the application of manure and residual elements in the soil with the need of the plants and the capacity of the microbes in the soil to transform the chemical elements into plant available forms. Lack of nutrients available in form for the plant to uptake can cause a deficiency in plants, and excess nutrients can cause toxicity. Both situations decrease plant growth. An excess can also find its way through the food chain and be hazardous to the consumer. Elements that are not transformed or retained in the soil can leave the system and become a contaminant to surface and groundwater. In applying manure to the land for plant nutrients, remember that the nutrient content of manure is highly variable, representative sampling is difficult, and laboratory procedures that indicate nutrient amounts are subject to errors. This is why it is difficult to apply manure nutrients with the precision of commercial fertilizer; however, with planned and measured applications of manure over several years, a landowner is able to achieve a reasonable balance between nutrients applied to the field by the manure and nutrients removed from the field by the crop.

(a) Deficiencies of plant nutrients

The deficiency of nutrients to the plants from manure applications can occur by either the shortage of supplied elements contained in the manure or by the interference in the uptake of a nutrient caused by the excessive supply of another nutrient. In the first case, an analysis of the manure can be used to help determine the amount of nutrients being supplied, and this amount is balanced with the crop's requirements. Using the NRCS National Conservation Practice Standard (CPS), Code 590, Nutrient Management with a nutrient budget worksheet will help assure that all essential nutrients are being supplied to the crop. For the second case, an example in the section 651.0604(b) shows the antagonism that excessive uptake of ammonium ion from manure has on the calcium ion. High levels of copper, iron, and manganese in the waste material can cause a plant deficiency of zinc caused by blockage of Zn uptake sites on the root by the other ions.

(b) Excesses of plant nutrients, total dissolved solids, and trace elements

The tolerance of plants to high levels of elements in plant tissue must also be considered when applying manure to cropland. Heavy applications of waste can cause elevated levels of nitrates in plant tissue that can lead to nitrate poisoning of livestock consuming that foliage. The ability to accumulate nitrates differs from plant to plant or even within cultivars of a species. Concentrations of nitrate nitrogen in plant dry matter less than 0.1 percent is considered safe to feed livestock. Large applications of manure on tall fescue, orchardgrass, and sudangrass can cause nitrate buildup. Cattle grazing these plants can, thus, be poisoned. When the concentration of nitrate nitrogen in the dry harvested material exceeds 0.4 percent, the forage is toxic.

Urea contained in manure is unstable. As manure dries, the urea breaks down into NH_4 and NH_3. The release of gaseous NH_3 from manure can result in NH_3 toxicity. Exposure of corn seeds to NH_3 during the initial stages of germination can cause significant injury to the development of seedlings. High levels of ammonium and NH_3 in the soil interferes with the uptake of the calcium ion, causing plants to exhibit calcium deficiency (Hensler, Olsen, and Attoe 1970). High levels of NH_4 and NH_3 also cause problems for earthworms and other soil organisms. Part of the NH_4 released is adsorbed on the cation exchange sites of the soil, releasing calcium, potassium, and magnesium ions into solution. High levels of these ions in the soil solution contribute to an increase in the soluble salt level and pH.

Up to 50 percent of manure nitrogen is in the NH_4 form. To prevent toxicity from occurring on young plant seedlings, the manure can be incorporated into the soil to absorb the NH_4 on the cation exchange sites or allowed to air dry on the soil surface. Surface drying greatly reduces the level of NH_4 by volatilization, but because this results in a loss of the nitrogen, this typically does not reflect efficiency in nutrient utilization. Applying manure at rates based on nitrogen requirements of the crop helps to avoid excess NH_4 buildup in the seed zone. A 0.25-inch rain or irrigation application should be sufficient to dissipate high concentrations of NH_3 in the seed zone. Side-dressing manure on corn is an effective way to apply inorganic nitrogen that is quickly available for plant growth (Klausner and Guest

1981). Injecting manure into soil conserves more of the NH_4 nitrogen during periods of warm, dry weather and prevents NH_3 toxicity to the growth of plants (Sutton, Nelson, Hoff, and Mayrose 1982).

The soluble salt content of manure and sludge is high and must be considered when these wastes are applied to cropland. The percent salt in waste may be estimated by multiplying the combined percentages of potassium, calcium, sodium, and magnesium as determined by laboratory analysis by a factor of two (USEPA 1979).

$$\% \text{ salts} = (\%K + \%Ca + \%Na + \%Mg) \times 2$$

Under conditions where only limited rainfall and irrigation are applied, salts are not adequately leached out of the root zone and can build up high enough quantities to cause plant injury. Plants that are salt sensitive or only moderately tolerant show progressive decline in growth and yields as levels of salinity increase (figs. 6–2, 6–3, and 6–4).

Some plant species are tolerant to salinity once established, but are sensitive during germination. If manure or sludge is applied to land in areas that receive moderate rainfall or irrigation water during the growing season, soluble salts in the waste will be dispersed through the profile or leached below the root zone. If manure or sludge is applied under a moisture deficit condition, salt concentrations can build up.

After prolonged application of manure, the soil electrical conductivity should be tested. A soil test of the electrical conductivity of saturated paste extract can be used to measure the total salt concentration in the soil. Conductivity values of 2 mmhos/cm or less are considered low in salts and suitable for all crops. Above values of 4 mmhos/cm, plant growth is affected except for all but the most tolerant crops (figs. 6–2, 6–3, and 6–4). At these high conductivity values, irrigation amounts need to be increased to leach salts. Added water percolating through the profile may then cause concern with leaching of nitrates, and manure application rates may have to be adjusted (Stewart 1974).

Figure 6–2 Effect of soil salinity on growth of field crops

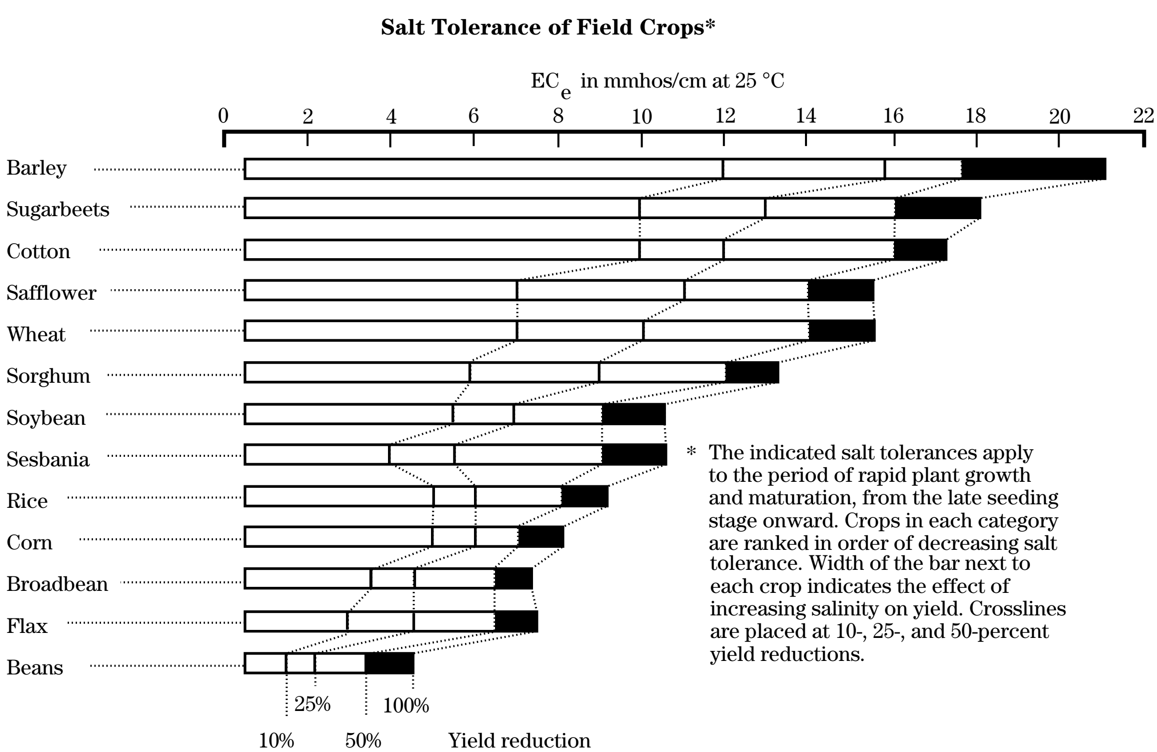


Figure 6–3 Effect of soil salinity on growth of forage crops

Salt Tolerance of Forage Crops*

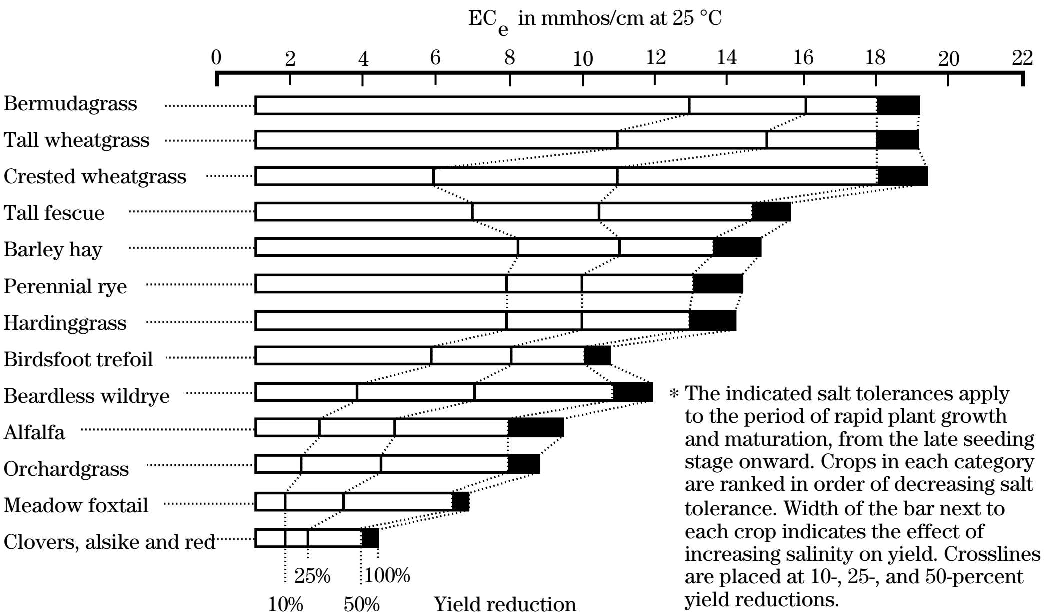
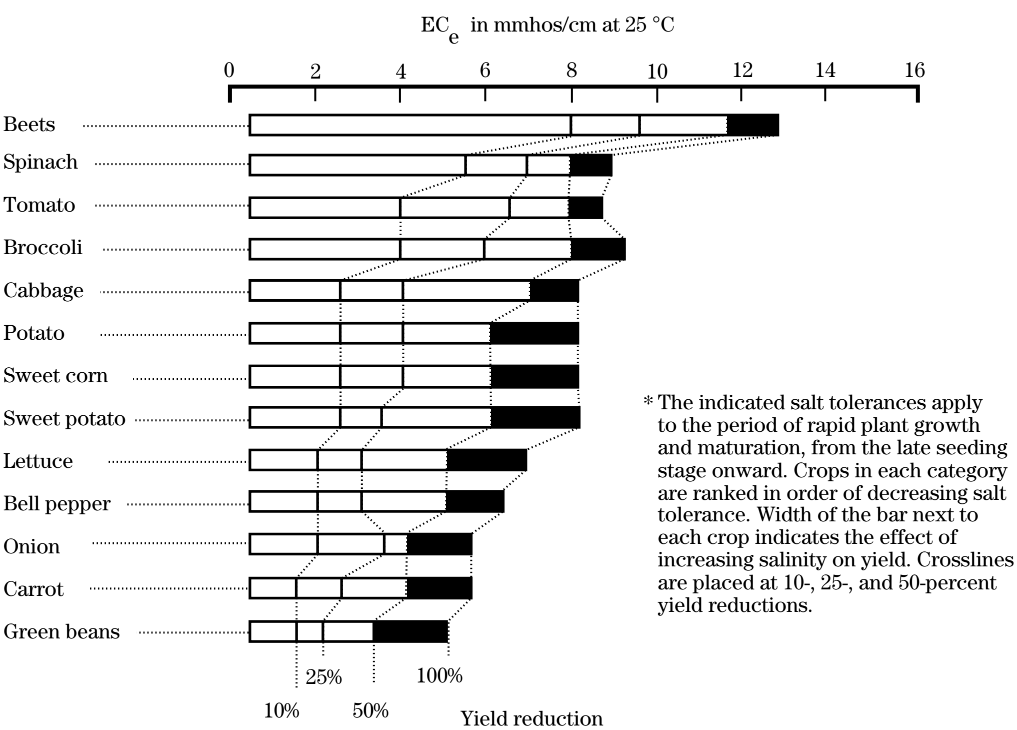


Figure 6–4 Effect of soil salinity on growth of vegetable crops

Salt Tolerance of Vegetable Crops*



Trace element toxicity is of concern with waste application on agricultural land. Animal manure can have elevated amounts of aluminum, copper, and zinc. Sewage sludge can have elevated concentrations of several elements, most notably aluminum, cadmium, chromium, copper, iron, mercury, nickel, lead, and zinc. The element and concentration in the sludge depends on the predominant industry in the service area. If wastes with elevated levels of trace elements are applied over a long period of time at significant rates, trace element toxicity can occur in plants. Micronutrient and trace element toxicity to animals and humans can also occur where cadmium, copper, molybdenum, and selenium levels in plant tissue become elevated.

Table 6–3 lists some general crop growth symptoms and crops most sensitive to the given trace elements. If such symptoms should occur, a plant tissue test can be done to confirm which element is at fault. Many of the symptomatic signs are similar for two or more elements, making it extremely difficult to know with certainty which element is in excess from observation of outward symptoms. Much of the toxicity of such trace elements is because of their antagonistic action against nutrient uptake and use by plants. Table 6–4 shows the interaction among elements within plants and adjacent to the plant roots.

Table 6–3 General effects of trace element toxicity on common crops (Kabata and Pendias 1984)

Element	Symptoms	Sensitive crop
A1	Overall stunting; dark green leaves; purpling of stems; death of leaf tips; and coralloid and damaged root system	Cereals
As	Red-brown necrotic spots on old leaves; yellowing and browning of roots; depressed tillering	(No information)
B	Margin or leaf tip chlorosis; browning of leaf points; decaying growing points; and wilting and dying-off of older leaves	Cereals, potatoes, tomatoes, cucumbers, sunflowers, mustard
Cd	Brown margin of leaves; chlorosis; reddish veins and petioles; curled leaves; and brown, stunted roots	Legumes (bean, soybean), spinach radish, carrots, and oats
Co	Interveinal chlorosis in new leaves followed by induced Fe chlorosis and white leaf margins and tips; and damaged root tips	(No information)
Cr	Chlorosis of new leaves; injured root growth	(No information)
Cu	Dark green leaves followed by induced Fe chlorosis; thick, short, or barbed-wire roots; depressed tillering	Cereals and legumes, spinach, citrus, seedlings, and gladiolus
F	Margin and leaf tip necrosis; chlorotic and red-brown points of leaves	Gladiolus, grapes, fruit trees, and pine trees
Fe	Dark green foliage; stunted growth of tops and roots; dark brown to purple leaves of some plants ("bronzing" disease of rice)	Rice and tobacco
Hg	Severe stunting of seedlings and roots; leaf chlorosis; and browning of leaf points	Sugarbeets, corn, and roses
Mn	Chlorosis and necrotic lesions on old leaves; blackish-brown or red necrotic spots; accumulation of MnO_2 particles in epidermal cells; drying tips of leaves; and stunted roots	Cereals, legumes, potatoes, and cabbage
Mo	Yellowing or browning of leaves; depressed root growth; depressed tillering	Cereals
Ni	Interveinal chlorosis in new leaves; gray-green leaves; and brown, stunted roots	Cereals
Pb	Dark green leaves; wilting of older leaves; stunted foliage; and brown, short roots	(No information)
Rb	Dark green leaves; stunted foliage; and increasing amount of shoots	(No information)
Se	Interveinal chlorosis or black spots at Se content at about 4 mg/L and complete bleaching or yellowing of younger leaves at higher Se content; pinkish spots on roots	(No information)
Zn	Chlorotic and necrotic leaf tips; interveinal chlorosis in new leaves; retarded growth of entire plant; injured roots resemble barbed wire	Cereals and spinach

Table 6–4 Interaction among elements within plants and adjacent to plant roots

Major elements	Antagonistic elements	Synergistic elements	Trace elements	Antagonistic elements	Synergistic elements
Ca	AI, B, Ba, Be, Cd, Co, Cr, Cs, Cu, F, Fe, Li, Mn, Ni, Pb, Sr, Zn	Cu, Mn, Zn	Cu	Cd, Al, Zn, Se, Mo, Fe, Ni, Mn	Ni, Mn, Cd
Mg	Al, Be, Ba, Cr, Mn, F, Zn, Ni, Co, Cu, Fe	Al, Zn	Zn	Cd, Se, Mn, Fe, Ni, Cu	Cu, Zn, Pb, Mn, Fe, N
P	Al, As, B, Be, Cd, Cr, Cu, F, Fe, Hg, Mo, Mn, Ni, Pb, Rb, Se, Si, Sr, Zn	Al, B, Cu, F, Fe, Mn, Mo, Zn	Cd	Zn, Cu, Al, Se, Mn, Fe, Ni	Cu, Zn, Pb, Mn, Fe, N
K	Al, B, Hg, Cd, Cr, F, Mo, Mn, Rb	(No evidence)	B	Si, Mo, Fe	Mo, Fe
S	As, Ba, Fe, Mo, Pb, Se	F, Fe	Al	Cu, Dc	(No evidence)
N	B, F, Cu	B, Cu, Fe, Mo	Pb	—	Cd
C1	Cr, I	(No evidence)	Mn	Cu, Zn, Mo, Fe, Ar, Cr, Fe, Co, Cd, Al, Ni, Ar, Se	Mo
			Fe	Zn, Cr, Mo, Mn, Co, Cu, Cd, B, Si	Cd, B
			Mo	Cu, Mn, Fe, B	Mn, B, Si
			Co	Mn, Fe	(No evidence)
			Ni	Mn, Zn, Cu, Cd	Cu, Zn, Cd

651.0605 Application of manure and sludge

(a) Field and forage crops

Manure and sewage have been used for centuries as fertilizers and soil amendments to produce food for human and animal consumption. Generally, manure and sludges are applied to crops that are most responsive to nitrogen inputs. Field crops that are responsive include corn, sorghum, cotton, tobacco, sugar beets, and cane.

Sewage sludge should not be used on tobacco. The liming effect of the sludge can enhance the incidence of root diseases of tobacco. It can also elevate cadmium levels in tobacco leaves, rendering it unfit for marketing (USDA 1986).

Cereal grains generally do not receive fertilizer application through manure because spreading to deliver low rates of nitrogen is difficult. Small grains are prone to lodging (tipping over en masse under wet, windy conditions) because of the soft, weak cell walls derived from rapid tissue growth.

Legumes, such as alfalfa, peanuts, soybeans, and clover, benefit less by manure and sludge additions because they fix their own nitrogen. The legumes, however, use the nitrogen in waste products and produce less symbiotically fixed nitrogen. Alfalfa, a heavy user of nitrogen, can cycle large amounts of soil nitrogen from a depth of up to 6 feet. More than 500 pounds per acre of nitrogen uptake by alfalfa has been reported (Schuman and Elliott 1978; Schertz and Miller 1972). The great danger of using manure and sludges on legume forages is that the added nitrogen may promote the growth of the less desirable grasses that are in the stand. This is caused primarily by introducing another source of nitrogen, but it can also be a result of the physical smothering of legume plants by heavy application cover of manure.

Grass tetany, a serious and often fatal disorder in lactating ruminants, is caused by low magnesium content in rapidly growing cool-season grasses. Cattle grazing on magnesium deficient forage develop health problems. High concentrations of nitrogen and potassium in manure applications to the forages aggravate the situation. Because of the high levels of available nitrogen and potassium in manure, early season applications on mixed grass-legume forages should be avoided until the later growing legume is flourishing because legumes contain higher concentrations of magnesium than grasses.

Perennial grasses benefit greatly by the addition of manure and sludges. Many are selected as vegetative filters because of their efficient interception and uptake of nutrients and generally longer active growing season. Others produce large quantities of biomass and thus can remove large amounts of nutrients, especially nitrogen, from the soil-plant system.

Bermudagrass pastures in the South have received annual rates of manure that supply more than 400 pounds of nitrogen per acre without experiencing excessive nitrate levels in the forage. However, runoff and leaching potentials are high with these application rates, and they must be considered in the utilization plan.

Grass sods also accumulate nitrogen. An experiment in England carried out for 300 years at Rothamsted showed a steady increase in soil nitrogen for about 125 years before leveling off when an old plowed field was retired to grass (Wild 1988). However, where manure is spread on the soil surface, any ammonia nitrogen in the waste generally is lost to the air as a gas unless immediately incorporated.

Grass fields used for pasture or hay must have manure spread when the leaves of the plants are least likely to be contaminated. If this is done, the grass quality is not lessened when harvested mechanically or grazed by animals (Simpson 1986).

Spreading manure immediately after harvest and before regrowth is generally the best time for hay fields and pastures in a rotation system. This is especially important where composted sludge is applied on pasture at rates of more than 30 tons per acre. Cattle and sheep ingesting the compost inadvertently can undergo copper deficiency symptoms (USDA 1986).

Some reports show that manure applied to the soil surface has caused ammonium toxicity to growing crops (Klausner and Guest 1981). Young corn plants 8 inches high showed ammonia burn after topdressing with dairy manure during a period of warm, dry weather. The symptom disappeared after a few days with no apparent damage to the crop. This is very similar to corn burn affected during sidedressing by anhydrous ammonia. Liquid manure injected between corn rows is toxic to plant roots and causes temporary reduction in crop growth. Warming soil conditions dissipate the high ammonium levels, converting the ammonium to nitrates, and alleviate the temporary toxic conditions (Sawyer and Hoeft 1990).

It is a good practice to follow manure applications in the fall with a winter cover crop. The manure nutrients feed the cover crop, and the cover crop holds the nutrients in the rooting zone until spring planting, preventing leaching. In the mean time, the cover crops are producing organic matter in the soil through its roots that far exceed the amount of organic matter in the manure. Manure, winter cover crops and reduced tillage are the fastest way to build soil health.

(b) Horticultural crops

Vegetables and fruits benefit from applications of manure; however, care must be taken because produce can be fouled or disease can be spread. Surface application of manure to the soil around fruit trees will not cause either problem, but spray applications of liquid waste could.

Manure or sludge applied and plowed under before planting will not cause most vegetables to be unduly contaminated with disease organisms as long as they are washed and prepared according to good food industry standards. However, the scab disease may be promoted on the skin of potatoes with the addition of organic wastes. Composted manure can be used to avoid excessive scabbing if it is plowed under before the potatoes are planted (Martin and Leonard 1949). Additional guidelines for the use of municipal sludge are in table 6–5.

Table 6–5 Summary of joint EPA/FDA/USDA guidelines for sludge application for fruit and vegetable production (USEPA 1983)

Annual and cumulative Cd rates	Annual rate should not exceed 0.5 kg/ha (O.446 lb/acre). Cumulative Cd loadings should not exceed 5, 10, or 20 kg/ha, depending on CEC values of <5, 5 to 15, and >15 meq/l00g, respectively, and soil pH.
Soil pH	Soil pH (plow zone—top 6 inches) should be 6.5 or greater at time of each sludge application.
PCBs	Sludges that have PCB concentrations of more than 10 ppm should be incorporated into the soil.
Pathogen reduction	Sludge should be treated by pathogen reduction process before soil application. A waiting period of 12 to 18 months before a crop is grown may be required, depending on prior sludge processing and disinfection.
Use of high-quality sludge	High-quality sludge should not contain more than 25 ppm Cd, 1,000 ppm Ph, and 10 ppm PCB (dry weight basis).
Cumulative lead (Pb) application rate	Cumulative Pb loading should not exceed 800 kg/ha (714 lb/acre).
Pathogenic organisms	A minimum requirement is that crops to be eaten raw should not be planted in sludge-amended fields within 12 to 18 months after the last sludge application. Further assurance of safe and wholesome food products can be achieved by increasing the time interval to 36 months. This is especially warranted in warm, humid climates.
Physical contamination and filth	Sludge should be applied directly to soil and not directly to any human food crop. Crops grown for human consumption on sludge-amended fields should be processed using good food industry practices, especially for root crops and low-growing fresh fruits and vegetables.
Soil monitoring	Soil monitoring should be performed on a regular basis, at least annually for pH. Every few years, soil tests should be run for Cd and Ph.
Choice of crop type	Plants that do not accumulate heavy metals are recommended.

(c) Vegetated treatment practices

Vegetated treatment practices are designed strips or areas of vegetation growing down-gradient of a source of contaminated runoff, such as an animal production facility, a feedlot, or cropland where manure has been applied. These areas can filter nutrients, sediment, organics, agrichemicals, and pathogens from runoff received from the contributing areas.

Five processes are involved in the removal of the elements in the run-on water. The first process is deposition of sediment (solid material) in the strip. A vegetated filter strip is composed of grasses or other dense vegetation that offers resistance to shallow overland flow. The decrease in flow velocity at the upslope edge of the vegetated filter strip greatly reduces the sediment transport capacity, and suspended solids are deposited. In the second process, the vegetation provides for surface run-on water to enter the soil profile. Once infiltrated into the soil, the elements are entrapped by the chemical, physical, and biological processes and are transformed into plant nutrients or organic components of the soil. In the third process, some soluble nutrients moving with the run-on water can be directly absorbed through the plant leaves and stems, and in the fourth, the thick, upright vegetation adheres solid particles that are being carried in the runoff, physically filtering them out. Finally, the nutrients attenuated in the vegetated area are taken up by the plants and can be removed from the area with the harvest and removal of the plant biomass. In all of the processes, the nutrients taken from the run-on water by the plants transform a potential pollutant into vegetative biomass that can be used for forage, fiber, or mulch material.

Results from recent research show that vegetated treatment areas have a wide range of effectiveness (Adam, Lagace, and Vallieres 1986; Dillaha et al. 1988; Doyle and Stanton 1977; Schwer and Clausen 1989; Young, Huntrods, and Anderson 1980). Variations in effectiveness are associated with individual site conditions, both the vegetated area and contributing area.

Land slope, soils, land use and management, climate, vegetation type and density, application rates for sites periodically loaded, and concentration and characteristics of constituents in incoming water are all important site characteristics that influence effectiveness. Operation and management of the contributing area, along with maintenance of the vegetated area, influence the ability of the total system to reduce the concentration and amount of contaminants contained in the runoff from the site. Knowledge of site variables is essential before making planning decisions about how well vegetated treatment areas perform.

Research and operation sites exhibit certain characteristics that should be considered in planning a vegetated treatment area:

- It is desirable that sheetflow be maintained. Concentrated flow should be avoided unless low velocity grass waterways are used.
- Hydraulic loading can be carefully controlled to maintain desired depth of flow.
- Application of process-generated wastewater must be periodically carried out to allow rest periods for the vegetated area. Temporary storage of wastewater provides rest periods and for climatic influences.
- Unless infiltration occurs, removal of soluble constituents from the run-on water will be minimal.
- Removal of suspended solids and attached constituents from the run-on can be high, in the range of 60 to 80 percent for properly installed and maintained areas.
- Vegetated treatment areas should not be used as substitute storage and containment practices. They generally are not a stand-alone practice.
- Maintenance that includes proper care of the vegetation and removal of the accumulated solids must be performed.
- Proper siting is essential to assure uniform slopes can be installed and maintained along and perpendicular to the flow path.

Vegetated treatment areas can be designed with settling basins and temporary storage with a controlled release to achieve a water and nutrient balance over the area that results in a nondischarging practice. If a water and nutrient balance cannot be attained and a discharge from the manure management system is prohibited by regulations, the effluent from the vegetated area must be captured and managed as other contaminated runoff. It may be possible to circulate the effluent back through the treatment area.

Runoff from a land application area where manure has been properly applied to provide nutrients for an agricultural crop is commonly allowed. As with any runoff from crop or pasture land, this runoff may still carry nutrients, sediment, and pathogens. Control buffer strips and filter strips can be placed across the path to further clean the water leaving these fields. The criteria for planning, design, implementation, and operation and maintenance of vegetated treatment practices for livestock operations and manure application sites are in CPS Codes 323, Control Buffer Strips; 393, Filter Strip; and 635, Vegetated Treatment Area.

(d) Constructed wetlands

Constructed wetlands work much like upland vegetated treatment areas, but while vegetated treatment areas can be designed and managed with other practices to prevent a discharge, constructed wetlands are usually discharging practices. Contracted wetlands can be used as a pretreatment to a vegetated treatment area to greatly reduce the needed size of the area for a nutrient balance. Constructed wetlands use wetland vegetation and the associated wetland ecosystem to volatize nitrogen and attenuate phosphorus. The phosphorus can be removed with the wetland plants, or the wetland can be designed for 10 or more years of phosphorus storage in the sediment and dendrites. Natural wetlands are also good at removing contaminates from water passing through them, but wastewater from agricultural operations should not be discharged into natural wetlands for treatment. The criteria for planning, design, implementation, and operation and maintenance of constructed wetlands are in CPS Code 656, Constructed Wetland. Additional information can be found in the National Engineering Handbook, Part 637, Chapter 3, Constructed Wetlands.

(e) Forestland for agricultural waste treatment

Forestland provides an area for recycling agricultural wastewater. Wastewater effluent has been applied to some forest sites over extended periods of time with good nutrient removal efficiency and minimal impact on surface or groundwater. On most sites, the soil is covered with layers, some several inches thick, of organic material. This material can efficiently remove sediment and phosphorus from the effluent. Nitrogen in the form of nitrates is partly removed from the wastewater in the top few feet of the soil, and the added fertility contributes to increased tree and understory growth. Caution must be taken not to over apply water that will leach nitrates out of the root zone and down toward the groundwater. Digested sludge also has been applied to forestland.

Considerable amounts of nutrients are taken up by trees. Many of these nutrients are redeposited and recycled annually in the leaf litter. Leaves make up only 2 percent of the total dry weight of northern hardwoods. Harvesting trees with leaves on increases the removal of plant nutrients by the following percentages over that for trees without leaves:

Calcium = 12%
Potassium = 15%
Phosphorus = 4%
Nitrogen = 19%

Whole tree harvesting of hardwoods removes almost double the nutrients removed when only the stemwood is taken. Stemwood, the usual harvested bole or log taken from the tree for lumber, makes up about 80 percent of the aboveground biomass (Hornbeck and Kropelin 1982).

Riparian forest buffers are effective ecosystems between utilization areas and water bodies to control transport of contaminants from nonpoint sources (Lowrance, Leonard, and Sheridan 1985). No specific literature has been reported on using these areas for utilization of nutrients in agricultural waste. These areas should be maintained to entrap nutrients in runoff and protect water bodies. They should not be used for waste spreading.

Only 10 percent of the nitrogen in a 45-year-old Douglas fir forest ecosystem is in the trees. The greater part of the nutrient sink in a coniferous forest is in the tree roots and soil organic matter. Although nitrogen uptake in forests exceeds 100 pounds per acre per year, less than 20 percent net is accumulated in eastern hardwood forest. The greater part of the assimilation is recycled from the soil and litter. Continued application rates of agricultural waste should be adjusted to meet the long-term sustainable need of the forestland, which generally is a half to two-thirds that of the annual row crops (Keeney 1980).

651.0606 Nutrient removal by harvesting of crops

The nutrient content of a plant depends on the amount of nutrients available to the plant and on the environmental growing condition. The critical level of nutrient concentration of the dry harvested material of the plant leaf is about 2 percent nitrogen, 0.25 percent phosphorus, and 1 percent potassium. Where nutrients are available in the soil in excess of plant sufficiency levels, the percentages can more than double.

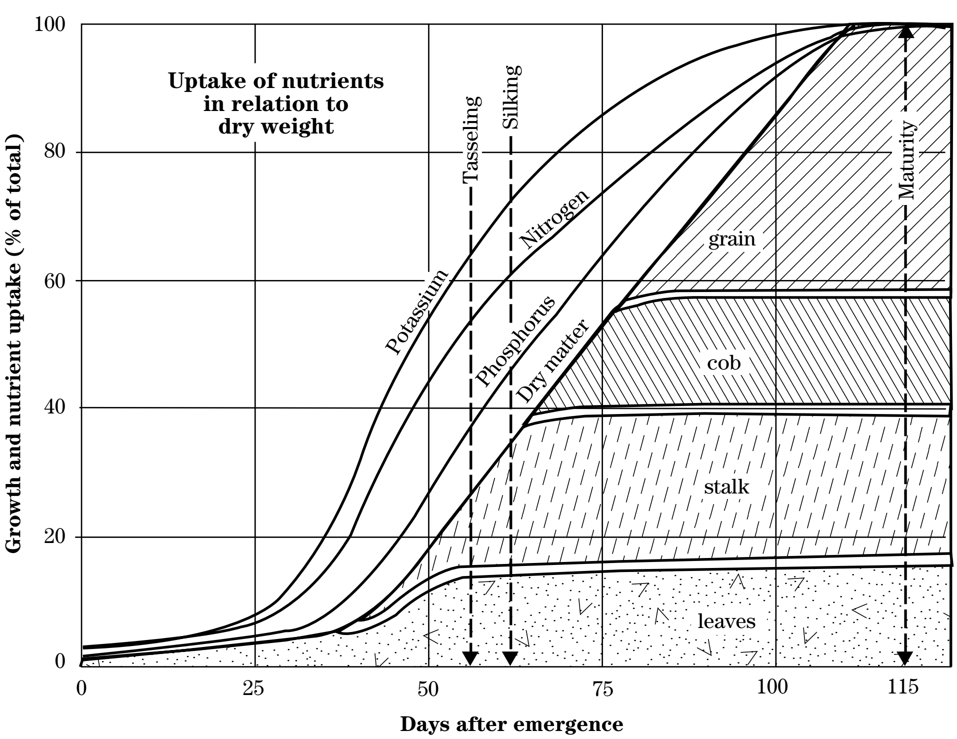
In forage crops, the percent composition for nitrogen can range from 1.2 to 2.8 percent, averaging around 2 percent of the dry harvested material of the plant. However, the concentrations in the forage crops can reach as high as 4.5 percent if there are high concentrations of nitrogen in the soil (Walsh and Beaton 1973).

The total uptake of nutrients by crops from manure applications increases as the crop yields increase, and crop yields for the most part increase with increasing soil nutrients, provided toxic levels are not reached or nutrient imbalances do not occur. The total nutrient uptake continues to increase with yield, but the relation does not remain a constant linear relationship.

Two important factors that affect nutrient uptake and removal by crop harvest are the percent nutrient composition in the plant tissue and the crop biomass yield. In general, grasses contain their highest percentage of nutrients, particularly nitrogen, during the rapid growth stage of stem elongation and leaf growth.

Nitrogen uptake in grasses, like corn (fig. 6–5), follows an S-shaped uptake curve with very low uptake the first 30 days of growth, but rises sharply until flowering, then decreases with maturity.

Figure 6–5 Growth and nutrient uptake by corn (adapted from Hanaway 1962)



Harvesting the forage before it flowers would capture the plant's highest percent nutrient concentration. Multiple cuttings during the growing season maximize dry matter production. A system of two or three harvests per year at the time of grass heading would optimize the dry matter yield and plant tissue concentration, thus, maximizing nutrient uptake and removal.

(a) Nutrient removal calculation

The Crop Nutrient Tool in the USDA PLANTS Database can be used to calculate the approximate removal of nitrogen, phosphorus, and calcium by agricultural crops. This tool may be found at http://plants.usda.gov/npk/AboutNutrient. In a similar way, table 6–6 can be used to approximate the removal of calcium, magnesium, sulfur, copper, manganese, and zinc. Typical crop yields are given only as default values and should be selected only in lieu of local information. The PLANTS Crop Nutrient Tool and table 6–6 show the nutrient concentrations that are average values derived from plant tissue analysis values, which can have considerable range because of climatic conditions, varietal differences, soil conditions, and soil fertility status. Statewide or local data should be used in lieu of the table values where available. The conversion factors for phosphates and potash from elemental P and K are:

$$\text{lb P} \times 2.3 = \text{lb } P_2O_5$$

$$\text{lb K} \times 1.2 = \text{lb } K_2O$$

Table 6–6 Nutrients removed by harvested part of the crop (Kilmer 1982; Morrison 1959; Sanchez 1976; USDA 1986)

Crop	Dry wt. (lb/bu)	Typical yield/acre plant part	Average concentration of nutrients (%)					
			Ca	Mg	S	Cu	Mn	Zn
Grain crops			**% of the dry harvested material**					
Barley	48	50 bu 1 T. straw	0.05 0.40	0.10 0.10	0.16 0.20	0.0016 0.0005	0.0016 0.0160	0.0031 0.0025
Buckwheat	48	30 bu 0.5 T. straw	0.09 1.40		0.01	0.0009	0.0034	
Corn	56	120 bu 4.5 T. stover	0.02 0.29	0.10 0.22	0.12 0.16	0.0007 0.0005	0.0011 0.0166	0.0018 0.0033
Oats	32	80 bu 2 T. straw	0.08 0.20	0.12 0.20	0.20 0.23	0.0012 0.0008	0.0047 0.0030	0.0020 0.0072
Rice	45	5,500 lb 2.5 T. straw	0.08 0.18	0.11 0.10	0.08	0.0030	0.0022 0.0316	0.0019
Rye	56	30 bu 1.5 T. straw	0.12 0.27	0.18 0.07	0.42 0.10	0.0012 0.0300	0.0131 0.0047	0.0018 0.0023
Sorghum	56	60 bu 3 T. stover	0.13 0.48	0.17 0.30	0.17 0.13	0.0003	0.0013 0.0116	0.0013
Wheat	60	40 bu 1.5 T. straw	0.04 0.20	0.25 0.10	0.13 0.17	0.0013 0.0003	0.0038 0.0053	0.0058 0.0017
Oil crops			**% of the dry harvested material**					
Flax	56	15 bu 1. 75 T. straw	0.23 0.72	0.43 0.31	0.25 0.27		0.0061	
Oil palm		22,000 lb 5 T. fronds and stems	0.19	0.09 0.36		0.0043	0.0225	
Peanuts	22–30	2,800 lb 2.2 T. vines	0.04 1.00	0.12 0.38	0.24 0.36	0.0008	0.0040 0.0051	
Rapeseed	50	35 bu 3 T. straw	1.47	0.66 0.06	0.68	0.0001	0.0008	

Table 6–6 Nutrients removed by harvested part of the crop (Kilmer 1982; Morrison 1956; Sanchez 1976; USDA 1985)—continued

Crop	Dry wt. (lb/bu)	Typical yield/acre plant part	Average concentration of nutrients (%)					
			Ca	Mg	S	Cu	Mn	Zn
Oil crops—continued			**% of the dry harvested material**					
Soybeans	60	35 bu	0.29	0.29	0.17	0.0017	0.0021	0.0017
		2 T. stover	1.00	0.45	0.25	0.0010	0.0115	0.0038
Sunflower	25	1,100 lb	0.18	0.34	0.17		0.0022	
		4 T. stover	1.73	0.09	0.04		0.0241	
Fiber crops			**% of the dry harvested material**					
Cotton		600 lb lint and 1,000 lb	0.13	0.27	0.20	0.0040	0.0073	0.0213
		seeds burs and stalks	1.40	0.40	0.75			
Pulpwood		98 cords		0.02				
		bark, branches		0.02				
Forage crops			**% of the dry harvested material**					
Alfalfa		4 tons	1.40	0.26	0.24	0.0008	0.0055	0.0053
Bahiagrass		3 tons	0.43	0.25	0.19			
Big bluestem		3 tons		0.20				
Birdsfoot trefoil		3 tons	1.75	0.40				
Bluegrass-pastd.		2 tons	0.53	0.23	0.66	0.0014	0.0075	0.0020
Bromegrass		5 tons	0.47	0.19	0.19	0.0008	0.0052	
Clover-grass		6 tons	0.92	0.28	0.15	0.0008	0.0106	
Dallisgrass		3 tons	0.56	0.40				
Guineagrass		10 tons		0.43	0.20			
Bermudagrass		8 tons	0.37	0.15	0.22	0.0013		
Indiangrass		3 tons	0.15					
Lespedeza		3 tons	1.12	0.21	0.33		0.0152	
Little bluestem		3 tons		0.20				
Orchardgrass		6 tons	0.30	0.24	0.26	0.0017	0.0078	
Pangolagrass		10 tons		0.29	0.20			
Paragrass		10.5 tons	0.39	0.33	0.17			
Red clover		2.5 tons	1.38	0.34	0.14	0.0008	0.0108	0.0072
Reed canarygrass		6.5 tons	0.36					
Ryegrass		5 tons	0.65	0.35				
Switchgrass		3 tons	0.28	0.25				
Tall fescue		3.5 tons	0.30	0.19				
Timothy		2.5 tons	0.36	0.12	0.10	0.0006	0.0062	0.0040
Wheatgrass		1 ton	0.36	0.24	0.11			
Forest			**% of the dry harvested material**					
Leaves								
Northern hardwoods		50 tons	0.29					
Douglas fir		76 tons						

Table 6–6 Nutrients removed by harvested part of the crop (Kilmer 1982; Morrison 1956; Sanchez 1976; USDA 1985)—continued

Crop	Dry wt. (lb/bu)	Typical yield/acre plant part	Average concentration of nutrients (%)					
			Ca	Mg	S	Cu	Mn	Zn
Fruit crops			**% of the fresh harvested material**					
Apples		12 tons	0.03	0.02	0.04	0.0001	0.0001	0.0001
Bananas		9,900 lb	0.23	0.30				
Cantaloupe		17,500 lb		0.34				
Coconuts		0.5 ton—dry copra	0.21	0.36	0.34	0.0010		0.0076
Grapes		12 tons		0.04				
Oranges		54,000 lb	0.06	0.02	0.02	0.0004	0.0001	0.0040
Peaches		15 tons	0.01	0.03	0.01			0.0010
Pineapple		17 tons	0.02	0.18	0.04			
Tomatoes		22 tons	0.02	0.03	0.04	0.0002	0.0003	0.0001
Silage crops			**% of the dry harvested material**					
Alfalfa haylage (60% dm)		10 wet/5 dry	0.97	0.33		0.36	0.0009	0.0052
Corn silage (35% dm)		20 wet/7 dry	0.36	0.18		0.15	0.0005	0.0070
Forage sorghum (30% dm)		20 wet/6 dry	0.37	0.31		0.11	0.0032	0.0045
Oat haylage 40% dm)		10 wet/4 dry	0.31	0.24		0.18		
Sorghum-sudan (50% dm)		10 wet/5 dry	0.43	0.34		0.04		0.0091
Sugar crops			**% of the fresh harvested material**					
Sugarcane		37 tons	0.05	0.04		0.04		
Sugar beets tops		20 tons	0.11 0.18	0.08 0.19		0.03 0.10	0.0001 0.0002	0.0025 0.0010
Tobacco			**% of the dry harvested material**					
All types		2,100 lb	3.75	0.90	0.70	0.0015	0.0275	0.0035
Turf grass			% of the dry harvested material					
Bluegrass		2 tons	0.53	0.23	0.66	0.0014	0.0075	0.0020
Bentgrass		2.5 tons	0.65	0.27	0.21			
Bermudagrass		4 tons	0.37	0.15	0.22	0.0013		
Vegetable crops			**% of the fresh harvested material**					
Bell peppers		9 tons	0.04					
Beans, dry		0.5 ton	0.08	0.08	0.21	0.0008	0.0013	0.0025
Cabbage		20 tons	0.05	0.02	0.11	0.0001	0.0003	0.0002
Carrots		13 tons	0.05	0.02	0.02	0.0001	0.0004	
Cassava		7 tons	0.26	0.13				
Celery		27 tons						
Cucumbers		10 tons	0.02					
Lettuce (heads)		14 tons						
Onions		18 tons	0.07	0.01	0.12	0.0002	0.0050	0.0021
Peas		1.5 tons	0.08	0.24	0.24			
Potatoes		14.5 tons	0.01	0.03	0.03	0.0002	0.0004	0.0002
Snap beans		3 tons	0.05	0.10	0.11	0.0005	0.0009	

Table 6–6 Nutrients removed by harvested part of the crop (Kilmer 1982; Morrison 1956; Sanchez 1976; USDA 1985)—continued

Crop	Dry wt. (lb/bu)	Typical yield/acre plant part	Average concentration of nutrients (%)					
			Ca	Mg	S	Cu	Mn	Zn
Vegetable crops			**% of the fresh harvested material**					
Sweet corn		5.5 tons	0.07	0.06				
Sweet potatoes		7 tons	0.03	0.06	0.04	0.0002	0.0004	0.0002
Table beets		15 tons	0.03	0.02	0.02	0.0001	0.0007	
Wetland plants			**% of the dry harvested material**					
Cattails		8 tons						
Rushes		1 ton						
Saltgrass		1 ton						
Sedges		0.8 ton	0.66					
Water hyacinth			3.12					
Duckweed								
Arrowweed								
Phragmites								

(b) Nutrient removal examples

How much nitrogen, phosphorus, and potassium is removed from a 40-acre field with a cropping rotation of alfalfa harvested at 6 tons per acre, grain corn at 180 bushels per acre, and silage corn at 22 tons per acre?

Entering this information into the USDA PLANTS Crop Nutrient Tool yields these results.

Nutrients removed in harvested part (lb/acre) user specified yield level				Nutrients removed in harvested part (lb/acre) at user specified yield level and user specified acres			
Crop	**Nitrogen**	**Phosphorus**	**Potassium**	**Nitrogen**	**Phosphorus**	**Potassium**	**Acres**
Corn—field, for grain (shelled, yellow dent, grade #1)	142.7276	27.2844	30.0259	5709.1035	1089.9501	1201.0302	40
Alfalfa, for hay	302.3612	28.33	229.7635	12094.4487	1133.1978	9190.5418	40
Corn—field, for silage (mature)	170.5032	49.8164	136.3415	6829.1296	1992.6547	5453.6615	40

How much sulfur is removed from a field when rye grain is harvested with a yield of 30 bushels per acre?

From table 6–6, the amount of sulfur in the harvested rye is 0.42 percent. Therefore, the amount of copper removed from the field in the harvested straw is:

$$0.42\%\ S \times 30\ \text{bu/acre} \times 56\ \text{lb/bu} = 7\ \text{lb S/acre removed}$$

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