Michael Fields Agricultural Institute

Soil Organic Matter Budgeting in Sustainable Farming
with applications to southeastern Wisconsin and northern Illinois

(Interim Draft with Revised Tables)

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Michael Fields Agricultural Institute is a public, non-profit education and research institute committed to promoting resource-conserving, ecologically sustainable and economically viable food and farming systems. Its mission is to enhance the fertility of the soil, the quality of food, the health of animals and the strength of the human spirit by revitalizing the culture of agriculture.

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1. Introduction

Current agricultural practices have resulted in a rapid decline in soil fertility and quality. For sustainable production soils should have a good structure, should provide crops with the necessary nutrients, should suppress soil borne pathogens and keep soil moisture available to plants. Organic matter is often considered the key to achieving these goals because of its beneficial capacities.

The quantity of organic matter in a soil is a major indicator of its quality. The amount of young, biologically active organic matter is important because it helps feed crops, maintains soil structure and improves the overall quality of the soil. Under the current farm practices in our country this active soil organic matter is depleted by narrow rotations that focus on cash crops, leaving little room for soil-building crops. Sustainable farming, however, forms the important basis for long-term profitability because it maintains quality soils that can provide long-term stable yields.

To achieve soil quality we should treat our organic matter like a bank account. A bank account lets us deposit, save and withdraw something we value. For sustainability it is important to deposit in the account of active organic matter in the soil on a regular basis. Thereby, we build ***cultural fertility***. Saving something for the future will most likely pay off through less disease pressure and stable yields, which will contribute to a more stable income for the farmer over time.

2. Our soils

Soil organic matter is only a small part of the total soil (Fig. 1). Organic matter comprises plant and animal residues in different stages of decomposition (including substances no longer identifiable). The more stabile, complex portion of the organic matter found in the soil is generally referred to as soil humus.

> ***The Concept of Cultural Fertility***
>
> Certain practices cause changes to occur in soil characteristics that relate directly to crop production and yields. Yields are affected by the accumulated or cultural soil fertility which is the result of management practices over many years. This includes the effects of rotations, manure applications and tillage. Farmers can run down or build up their cultural soil fertility. The existence of cultural fertility becomes apparent to farmers when they begin to substitute organic matter management for N fertilizers. It is shown by the crop yields, soil structure and stability, soil workability and also the reliability and health of crops (Koepf, 1996).

Although soil organic matter comprises only a small fraction of the total mass of most soils, this dynamic soil component influences soil properties to an extent far out of proportion to the small quantity present. Maintaining a sufficiently high level of quality organic matter is therefore one of the most critical objectives of soil management and really important for sustainable farmers as they depend to a high extent on their soil organic matter levels to provide sufficient nutrients to their crops. Therefore careful soil management is essential for measuring up to the high expectations and production levels of modern farming. This includes improving physical (structure), chemical (nutrient availability) and biological (soil flora and fauna) properties of soils. Crops show the effects of good organic matter management. They are more likely to resist weeds and disease problems in a healthy soil. Mistakes with maintaining soil structure or inadequately fertilization will be visible in a standing crop.

3. Soil organic matter and soil health

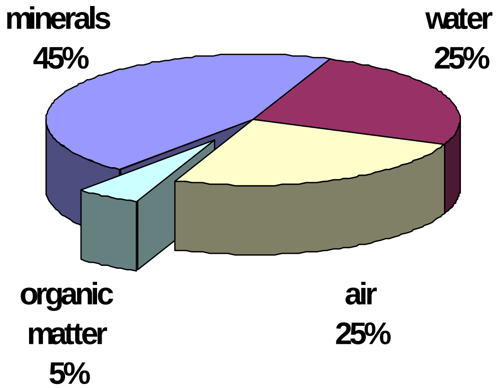


Fig. 1. The major components of the soil.

3a. Soil structure

In general soil organic matter has a balancing effect on soils. By improving soil structure, organic matter causes a better distribution of water, air and solid particles in soils. It also improves the water infiltration, the water holding capacity and drainage, aeration, and root penetration. This means more water will be available to a crop in periods of drought, and runoff or erosion will be prevented (Fig. 3). Organic matter forms stable bonds with mineral soil particles to hold the crumbs in a soil together (Fig. 4.). Crumbs or aggregates are also held together by lime and glue-like substances produced by soil organisms. The natural binding of humus molecules and clay particles results in a further improvement of soil structure.

On loamy and clay soils organic matter reduces the cohesion and stickiness of clods, making these soils easier to cultivate. On sandy soils organic matter improves the cohesion of particles improving the aggregate stability of these soil.

The ideal crumb structure of a soil is built by the life processes of the soil organisms. These soil organisms mix organic matter and soil particles and excrete the glue-like substances that bind them together. The soil organisms get their essential food from organic matter. This is the key for a good soil structure.

Factors affecting soil organic matter

A number of environmental factors (*climate, natural vegetation, texture, etc.*) affect the amount of soil organic matter and its quality (Fig. 2). At low temperatures, plant growth outstrips decomposition; in warm soils nutrient release is accelerated and residual organic matter accumulation is lower than in cooler soils. Similarly, soil organic matter content increases as effective moisture becomes greater. On a local scale, texture and drainage determine organic matter. All else being equal, soils high in clay and silt generally have more organic matter than do sandy soils.

In addition to environmental conditions, *management practices* can highly influence the amount of organic matter. *Cropping* results in lower levels of organic matter than were present in the natural systems existing before cultivation. Part of the plant material is removed from the land, which lowers the residue input into the soil. C*rop rotations* and the *quality of residues* determine to what extent effective organic matter remains in a soil. Also, *soil tillage* aerates the soil, breaks up organic residues and speeds up the decomposition of organic matter. *Soil organisms* break down the residues and are able to transform them into other substances. The number and composition of these organisms are essential to forming organic matter.

Soil structure coupled with adequate supplies of active organic matter may stimulate root growth (Fig. 5). Under these conditions, nutrients and oxygen might be more easily available to the roots. A less stressed rooting system is also more likely to resist diseases. A well-rooted soil in turn is likely to hold soil particles together.

3b. Soil organic matter and crop yields

In a sustainable agriculture organic matter is the key to making essential nutrients available to crops. Poor soil structure and an idle soil

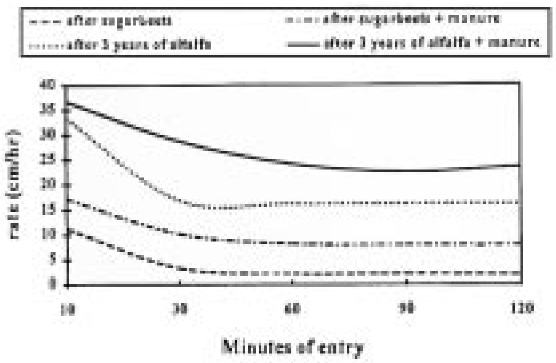


Fig. 3. Cropping effect on the water infiltration rate (after Mazurak, 1955)

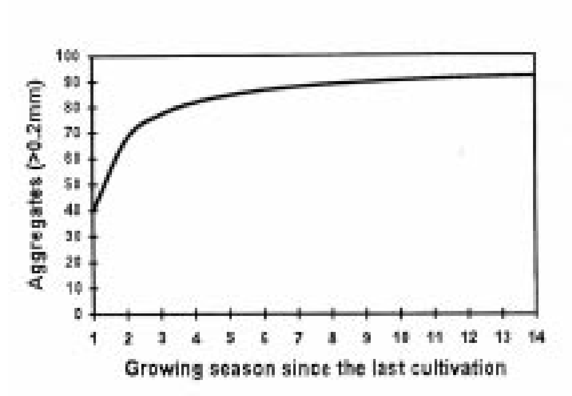


Fig. 4. Effect of cultivation on the stable aggregates (adapted from Jastrow, 1987)

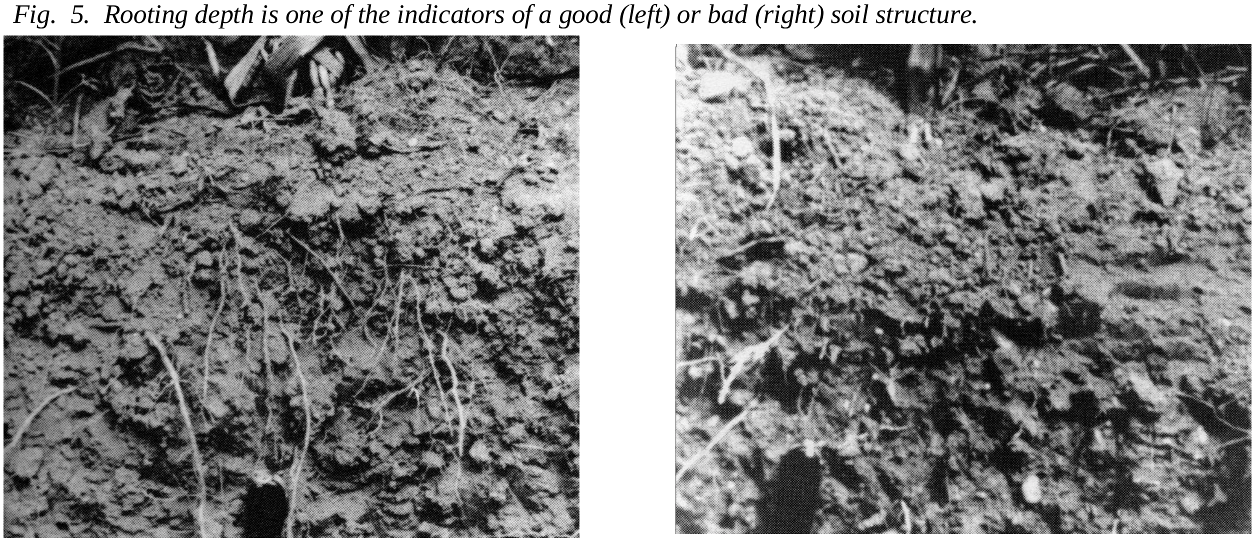
life can be disguised for a time in conventional agriculture by excessive fertilizer and pesticide use. Within sustainable practices a long-term strategy with a sound crop rotation and balanced fertilization is needed to build a healthy soil over the years.

During decomposition or mineralization (Fig. 6) organic matter is modified by soil organisms into simpler compounds. In this process, part of the carbon that makes up organic matter is released as carbon dioxide. Nutrients that were tied up in the organic matter are also released.
Nutrients like nitrogen, phosphorus, sulfur and micronutrients come available during this process. Potassium will be mainly available in an inorganic form.

Microorganisms can create new, complex, humus-like structures that are more resistant to further decomposition. Microorganisms can use nitrogen, phosphorus and potassium to form new compounds, or plant roots can take up these nutrients. But nutrients in the soil moisture might be lost during periods of abundant rainfall through leaching. Increasing the quantity of active organic matter in the soil will increase the amount of microbes living in the soil and these microbes will help to absorb excess nitrate that is present in the soil.

Nutrient losses from the sustainable system through leaching are also limited by organic matter since organic matter accounts for between 20 and 90 percent of the capacity of the

Fig. 5. Rooting depth is one of the indicators of a good (left) or bad (right) soil structure.



soil to absorb nutrients.

Regular soil analysis provides information on soil pH, phosphorus, potassium, magnesium and probably micronutrient levels. But, often it is difficult for farmers to interpret soil tests and integrate their results into a rational program for organic management. Advice that is based on experience with conventional farming systems may recommend rates of application of nitrogen containing fertilizers or lime that are too high. Soil tests need to be reinterpreted based on ecological insights and experience.

In a sustainable farming system the fertilization of the soil is actually a more important principle than the fertilization of the crop. The most important source of nitrogen comes from mineralization of crop and manure residues and the active organic matter fraction in the soil.

Nitrogen should not be a limiting factor in a sustainable system if there are sufficient quantities of nitrogen fixing legumes in the rotation. Free-living micro-organisms can also fix atmospheric nitrogen. Nitrogen washes out of the atmosphere with rain and snow and also makes a contribution. The timely mineralization of nitrogen from organic matter is dependent on adequate moisture and warmth. Organic matter budgeting as outlined in Chapter 5 can help one design and estimate nitrogen release in different phases of a crop rotation.

How much organic matter do I have?

A sufficiently high organic matter content (preferably more than 3%) is important for the availability of nutrients through mineralization. Assuming a humus content of 3% the total amount of organic matter per acre in the top foot will be 43,560 ft^2 x 1.0 ft x 87.357 lb/ft^3 (1.4g/cm^3) x 3% = 114,158.1 lb. = 57.1 tons. A typical soil organic matter contains approximately 5% organic N. The amount of soil organic matter likely to be mineralized in a given year depends on the soil texture, climate, management practices and quality of the organic matter. Values around 2% are typical for fine-textured soils. This results in a total annual nitrogen mineralization of 113 lb/acre. Note that this number excludes any mineral nitrogen in spring, deeper soil layers and green manures.

3c. Soil life and diseases

Organic matter is the source of food for a whole web of organisms in the soils (Fig. 7). These organisms in turn are able to give the soil its structure, mobilize nutrients, bind atmospheric nitrogen and suppress soil borne pathogens (Table 1). Organic matter feeds earthworms that in turn improve the aggregate stability and aeration of a soil.

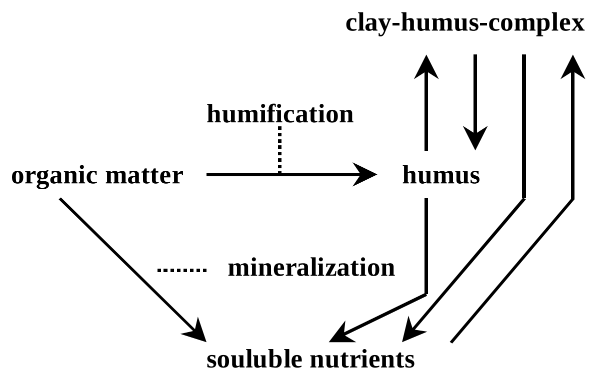


Fig. 6. Processes in organic matter formation and turnover (after Megers, 1993)

The active soil life is breathing and releasing carbon dioxide (CO_2). A principal prerequisite for microbial soil life is the availability of organic matter.

Organic matter stimulates a balanced community of soil organisms. This community can suppress soil borne diseases. Addition of fully mature compost to the soil is an effective means for controlling many soil borne diseases (Hoitink and Pahy, 1986) (Table 2).

4. *Building a healthy soil*

4a. Targeting active soil organic matter

Residues and manures are slowly broken into smaller and smaller pieces. As this occurs they change their chemical characteristics and rate of turnover, becoming essentially mixed digestion products from soil organisms and plants. The different stages in the decomposition process can be considered from the standpoint of qualitatively different fractions of organic matter. Depending on their age, size and chemical composition they will have quite different characteristics, which in turn will determine the characteristics of a soil. Perhaps the most useful approach to *defining soil organic matter quality* is to recognize these different fractions of organic matter and how they vary in their susceptibility to microbial metabolism.

A model identifying four such fractions, expressed as carbon in plant residues and soil organic matter is illustrated in Fig. 8. In this approach we focus on *labile, active* and *passive* fractions. The ***labile*** fraction of soil organic matter consists of materials that are easily decomposable and that can be metabolized by organisms within a few weeks to a few years. Components include living biomass, fine particulate detritus, most of the polysaccharides and nonhumic and other labile fractions. It is characterized by a high C/N ratio. This fraction is comprised most of the readily available food and mineralizable nitrogen. Adding fresh plant material and animal residues increases the quantity of labile organic matter, but it is also

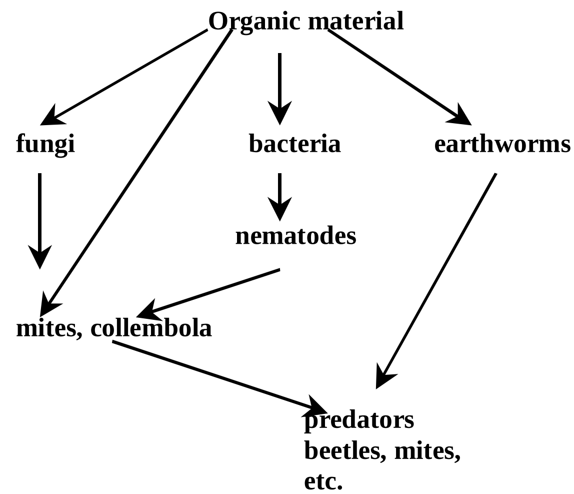


Fig. 7. A food web based on organic matter (after Melgers, 1993)

rapidly lost when additions are reduced or tillage is intensified. This fraction comprises less than 10 percent of the soil organic matter. The ***passive*** fraction of soil organic matter consists of very stable materials remaining in the soil for hundreds or even thousands of years. This fraction includes most of the humus physically protected in clay-humus complexes. This fraction accounts for 50 to 90 percent of the organic mater in most soils, and its quantity is increased or diminished only slowly. This fraction is responsible for much of the cation exchange capacity and water-holding capacity contributed to soil organic matter.

The ***active*** fraction is an intermediate state of soil organic matter between the labile and passive fractions. It makes up 20

Table 1 The underground animal stock

Component	typical numbers or length (in one handful of soil)	typical biomass (pounds/acre)
plant roots	60 - 150 in. (annual crops) 1,500-3,000 in (perennial grasses)	3,000 (annual crop) 15,000 (perennial grasses)
bacteria	300 million - 50 billion	400 - 4,000
fungi	0.5 - 100 million	500 - 5,000
actinomycetes	100 million - 2 billion	400 - 4,000
nematodes	1,000 - 10,000	5 - 50
protozoa	100,000 - 50 million	5 - 100
arthropods	100 - 1,000	1 - 10
earthworms	0 - 2	10 - 40

after: Cavigelli et al., 1998

to 50 percent of the total soil organic matter. This fraction includes very finely divided plant tissue, high in lignin, and other slowly decomposable and chemically resistant components. The turnover of this fraction occurs typically in about two decades. The active organic matter is very important for maintaining the soil's fertility. It is used by microorganisms to bind aggregates in the soil together to give good structure. Manures and types of perennial forage are important for maintaining the quantities of active organic matter in the soil. The active fraction is an important source of mineralizable nitrogen and other plant nutrients. But it has also beneficial effects on the structure and stability that gives soil, good tilth leading to enhanced water infiltration, resistance to erosion, and ease of tillage.

Studies have shown that different fractions of soil organic matter play quite different roles in soil management and in the carbon cycle. In many cases, changes in soil management result in relatively small effects on soil organic matter, but have pronounced effects on certain soil properties and aspects of soil productivity attributed to soil organic matter. A method is available to isolate the active fraction in our soils. Cambardella and Elliott isolated a particulate organic matter fraction (POM) that they suggest corresponds to the characteristics of the active (intermediate) pool in soil organic matter models (Collins et al., 1997). Scanning electron microscopy suggests that the POM fraction is composed mostly of root fragments in various stages of decomposition. Experiments showed that 20 years of wheat cropping reduced the POM fraction from about 40 percent in native prairie to 18 to 25 percent in cultivated soils (Collins et al., 1997). A 30-year crop rotation experiment in Moldova shows that it is largely the manure that contributes to POM formation. In addition, a sound rotation that includes legumes is necessary.

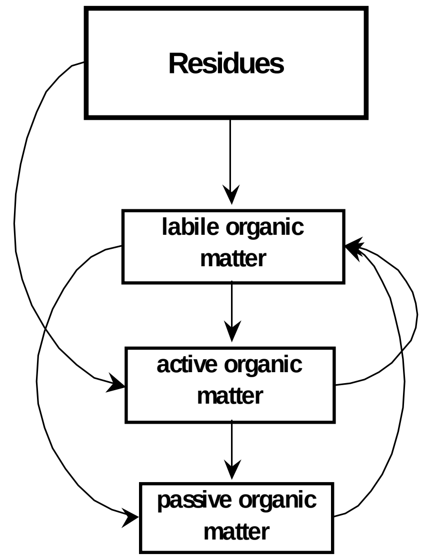


Fig. 8 Organic matter quality may result from the distribution of different fraction of organic matter.

From discussion regarding these different fractions, we can conclude that achieving a par-

Table 2. Diseased of vegetable crops that have been at least partially controlled by the use of organic manures

Disease	Crop
Pythium root rot	beets, cabbage, lettuce, peas, radishes, spinach, tomatoes, turnips
Rhizoctonia root rot	asparagus, beans, cabbage, carrots, peas, rhubarb, strawberries
Fusarium root rot and Fusarium wilt	asparagus, beans, cabbage, cucumbers, lettuce, peas, peppers, tomatoes
Verticillium	cucumbers, horseradish, peppers
Scab (Streptomyces)	potatoes

After Baker and Cook, 1982 and Scharpf, 1971

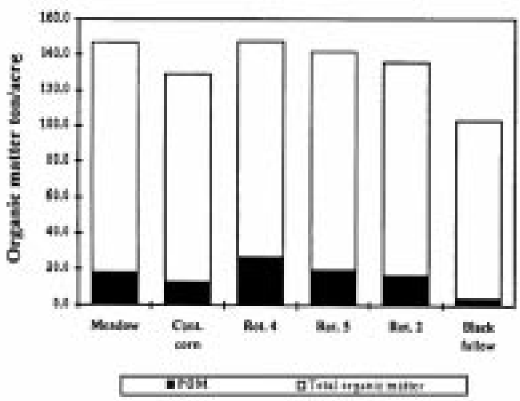


Fig 9. Effects of the crop rotation on the total and active organic matter fraction in the soil (0-20 cm) as determined by the Particulate Organic Matter (POM) method Results are from a 30 year crop rotation experiment on a chernozem soil in Beltsy, Moldova. Compared are continuous meadow, continuous corn receiving 11t/ha/yr of cow manure, and three mixed rotations with winter wheat, sugar beet, sunflower, corn, and legumes receiving 9.2 t/ha (rotation 4), 4.8 t/ha (rotation 5) and 0.7 t/ha (rotation 2) of cow manure per year, respectively. The black fallow treatment results in the lowest fraction of active organic matter (adapted from Boinchan, 1998).

ticular level of total organic matter is far less important than maintaining a substantial proportion of organic matter in the active fraction. This is essential for maintaining soil tilth and nitrogen release to crops.

4b. Understanding residues and their quality

Formation of organic matter in our soils is largely determined by the amount and quality of the residues that are incorporated into the soil (Fig. 10). Within conventional agriculture much research and focus have been oriented toward increasing yields. For some crops this has meant the amount of residues was increased as well (Table 3). The question remaining is whether these residues and the management accompanying them are enough to keep a balance in the organic matter.

Surprisingly little attention has been given to the amount of roots different crops produce. Recent research in organic matter management suggests that it is mainly the roots that contribute to the formation of active organic matter. Crops with considerable amount of roots, like perennial forage, are known to be real soil builders. The root mass formed by these crops can be very high.

Not only the quantity of residues is important but also the quality. The chemical composition determines whether they contribute to the formation of organic matter. Nitrogen, carbon and lignin have been shown to be substances that determine to a large extent the value of residues in the soil. Carbon rich materials like straw (C/N ratio of 40 to 100) tend to initially break down slower than nitrogen rich materials like alfalfa or vegetable residues with a much lower C to N ratio (5 to 20). Microorganisms need, however, a certain amount of nitrogen and preferably a C/N ratio around 10 to multiply. As carbon rich materials decompose, these organisms are likely to tie up the nitrogen available in the soil. Decomposition of carbon rich materials like straw can therefore result in a shortage of nitrogen for plant uptake. In addition, a less efficient microbial metabolism can occur during the decomposition, which results in a larger loss of carbon as CO_2 during respiration. This leaves less material to form quality organic matter.

Another indicator of the chemical quality of residues is lignin found in the plant cell walls. This resistant, woody material can slow down the decomposition process. It is found in straw but also in animal manures. Animals tend to excrete the lignin taken in with their food. The higher lignin content of ruminant manures together with a C/N ratio between 15 and 30 make their manures a substance that can be very valuable for the soil and for forming organic matter in that soil.

4c. Cover crops and green manures

Cover crops and green manures generally contribute to soil organic matter formation. Their contribution to building the soil greatly depends, however, on the age of these crops. If seeded into a row crop or sequentially seeded after the main crop they can contribute to the quality of the soil simply by keeping the soil covered and thus limiting erosion. This planted canopy will prevent soil structure loss by breaking the force of raindrops in rainstorms. The roots penetrating the soil will enhance soil life and structure. In the fall, the cover crops continue to take up nutrients and thereby prevent leaching from the system.

A cover crop worked into the soil will act as a green manure by providing the following crop with essential nutrients. The length of the growing season of the green manure and its maturity will determine its nutrient contribution to the next crop and its effect in building soil organic matter.

During the growth of a green manure the biomass will increase but the nitrogen concentration of tops and roots will generally decrease. Young material with a higher N concentration (low C/N ratio) will therefore provide nitrogen for the following crop but contribute little to the organic matter formation due to the limited biomass and low C/N ratio of the residues.

If the green manure is left to grow in the field for a longer period, it will form more biomass. Worked into the soil this more mature material will do a much better job in forming organic matter, but little nitrogen may become available in the short run for the following crop.

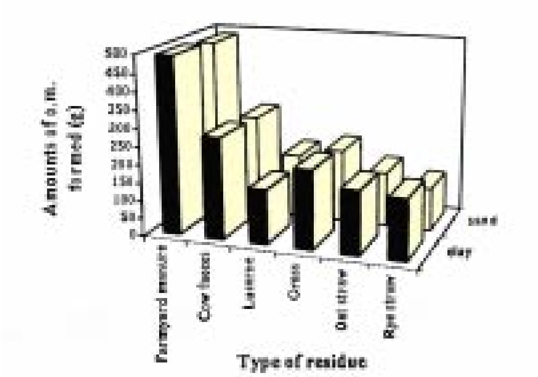


Fig. 10. Amounts of organic matter formed after ten annual additions of 100 g rersidue of different crops (adapted from de Haan, 1977)

A balance needs to be created between these soil building practices and destructive practices such as tillage. Perennial legumes, grasses, tillage practices and regular manure applications are really important for creating a healthy balance and creating a healthy soil over time.

4d. Compost and manure

Manure and compost can make a strong direct contribution to building soil. The composting of manure can be managed to produce young organic matter with a high value for soils. Fresh manure and young, rich composts may be a valuable source of nutrients (especially nitrogen) for crops. They may also have strong effects on stimulating the formation of crumbs in the soil. Older, finished composts are more stabile and release less nitrogen to crops. They build active organic matter in the soil and stimulate root growth. During the composting pro-

Table 3. Amount of residues from different crops.

Crop	Crop residue (lb/a)
Corn	6100 - 9100
Soybean	2500 - 5000
Wheat	2400 - 4500
Oats	1600 - 2400
Cover crop (clover)	900 - 4900
Cover crop (oats, rye)	1000 - 5500

Source: Organic matter in temperate agroecosystems. Paul, Paustain, Ellitott and Cole (eds.) 1996.

cess a kind of digestion takes place. This digestion consists of decomposition, transformation and curing (maturing) processes. Organic matter and nutrients, air, moisture and living organisms are the most important ingredients for a successful composting process. The materials used, the method of composting and temperature during the process determine the final product. Fully mature compost looks like rich soil. The plant residues are no longer recognizable as such.

Table 4 indicates the preferred conditions for a good composting process. Best results can be obtained if original materials are used with a C/N ratio of about 25 to 40:1. A higher C/N ratio than this, caused by adding large quantities of sawdust or straw, results in a slow composting process in which large losses of CO_2 occur due to a less efficient process at the microbial level. As compost matures the C/N ration will decrease to 10 to 15:1

Materials with a low C to N ratio result in a quick transformation with high temperatures in the compost piles in which losses of nitrogen to the atmosphere as ammonia are very likely. The result might be a product with a high nitrogen supplying capacity to crops but less ability to build soil (Table *5).*

It is not our purpose to discuss composting process techniques and methods here in detail. Many good books and papers are available on this subject. However, the final product can have pronounced effects on the organic matter formation in our soils.

Maturity of the compost influences how it performs in the soil (Table 6). Relatively young compost that is 2 to 3 months old is likely to have a more direct plant feeding capacity. If the C/N ratio of the product is high (>20), a serious tie-up of nutrients might occur in the soil. Materials with a low C/N ratio release N more quickly. This means that nitrate and ammonium are directly available for plant uptake, but are also easily lost through leaching and volatilization. Such materials are suited for some vegetable crops, corn and wheat.

More mature compost that has been composted for about 12 months is more likely to act as a soil builder. The contribution to the active fraction of organic matter is likely to be higher. Nutrients become available more slowly and nutrient losses are less likely.

5. Organic matter budgeting

5a. *Concepts at work in this management system*

Organic matter budgeting is meant as a tool for long-term soil management. With this budgeter, estimates are made of how crop rotations or manure applications affect the amount of active organic matter that residues and manures contribute to soil over time. Estimates are also made as to how much nitrogen becomes available in the soil for plant uptake.

This system is meant to provide a planning tool for farmers to design sustainable farming systems and to help them gain insight into the processes that take place in their soils. The budgeter is not a finished product, but is constantly being refined, improved and adapted to fit different regions. We are dong this work through a series of grant funded, on-farm research

*Table 4. Recommended conditions for composting**

Condition	Range
Carbon to nitrogen (C/N) ratio	25 to 35:1
Moisture content	50 - 60 %
Oxygen concentrations	> 5%
Particle size (inches)	1/8 - 1/2
pH	6.5 - 8.0
Temperature (oF)	130 - 140

* modified after Rynk, 1992.

Table 5. Quality characteristics of a selection of composted and manure residues

Manure	% moisture	C/N	% N	lignin %
Cattle slurry	81	15	2.4	20
Horse	72	29	1.6	14
Compost (cattle)	75	17	2	26
Sheep	69	16	2.7	21
Swine	80	14	3.1	na*
Laying hens	69	6	8	6
Vegetables	87	19	2.7	6
Leaves	38	54	0.9	na*

*not available; after Rynk, 1992 and other sources.

Table 6. Working of compost and manure (after Melgers, 1993)

	composted straw manure	straw manure	fresh manure
C/N ratio	16-24	24-30	6-13
nutrient uptake	+	+	+++
working	-	+	+++
losses	++	+	--
disease control	+++	+	-+
water holding capacity	+++	+	-
humus formation	+++	+	-

projects in the Upper Midwest. The budgeter has been developed as an Excel spreadsheet. Budgeting can also be done by hand and this bulletin shows how to use the budgeter through examples of different crop rotations and manuring programs. Tables and worksheets are provided so readers can work out organic matter budgets for their individual rotations and farming situations (Appendix 1 and 2). Simple calculations can be done manually, or with a pocket calculator.

We recommend that farmers and advisors accompany the budgeting work with regular observations of crops and soils and with regular soil tests in order to recognize changes and to allow for timely adaptations whenever necessary.

The budgeting system's advantage is that it can be used to evaluate the impact of various crop rotations, animal manures and green manures, and thereby serve as a cost-saving, ecologically sound planning tool. If the active organic matter increases over a crop rotation cycle this probably indicates a sound crop rotation and increasing soil quality. A decline in the amount of active organic matter means that changes may be necessary to prevent a decline in soil quality.

Factors such as climatic conditions, soil type, and history of the land, crop rotation, and management practices like manuring and tillage determine the amount of active organic matter found in the soil (Fig. 11). After native soils were put into agricultural use in the Midwest there was a considerable decline in the amount of active organic matter. It is important to find out how to maintain or increase this active fraction of organic matter in a particular cropping system's soils. However, increasing the amount of soil organic matter is difficult and takes several years. Increases in the overall soil organic matter level are generally limited to about 30 percent under highly favorable conditions. However, if soil is put into extensively managed pasturage or high levels of manures and composts are applied, organic matter increases may surpass 30 percent.

In a farming system, several sources of organic material can serve to produce the active organic matter. Plant residues from roots and straw determine to a large extent the annual input. In a sustainable farming system, legumes grown as green manures or animal manures can contribute to the input. To do the budgeting we need to account for the crop rotation, the amount of residues produced by crops and the composition of these residues.

Within a rotation, fallow years or prolonged periods without soil cover will result in erosion and a loss of the active organic matter. A forage based system, with soils kept under grasses or grass-legume mixtures will result in general in an increasing active organic matter fraction. Soil tests are necessary to determine the active organic matter for a particular field.

Table 7 gives us an example of a crop table used in the budgeting system. The table summarizes the nitrogen release in the soil from corn residues and their contribution to the fraction of active organic matter depending on the yield level. In the budgeting we accounted for 2 years of nitrogen release (a minus sign indicates a nitrogen tie-up) from the residues following the harvest. During decomposition, residues are transformed partly into active organic matter. In the third year after crop harvest, residues will contribute to the active organic matter fraction. Straw or stover is a source for forming active organic matter if it is left in the field. In the table we distinguish between the two options "straw removed from the field" and "straw left in the field." Depending on the specific farming practices and markets, farmers keep their straw in the field, or remove it to use as bedding or to sell off the farm. If a crop is removed from the field for silage or haylage we use a table yield estimate for the crop based on what we think it would have yielded had we grown the crop out and harvested it for grain. Additional crop tables are provided for major crops in Appendices 3 to 8.

Legumes contribute to the active organic matter. They are essential in sustainable farming systems because they provide the main source of external nitrogen due to their capacity to fix atmospheric nitrogen in root nodules. If used as a cover crop, legumes may also limit soil losses by erosion and also limit the rapid organic matter turnover found in bare soil. Their contribution to the amount of available N and active organic matter is estimated in Appendices 9_a, 9_b and 10.

These tables are sufficient for estimating the contribution of forages during the establishment year and the first year of production. After that, the contribution of the perennial legumes is hard to estimate. While they are growing and are being harvested, large quantities of roots grow and decay and large

Fig. 11. It is important for farmers to hone their observational skills. These photos show two side-by-side topsoil profiles from a garden. The soil on the left received large quantities of leaf compost. This compost was left on the soil surface by the soils animals. The photograph on the right shows where equivalent amounts of sheep manure compost were applied to the soil. This compost was incorporated into the soil profile by the soil animals.

Table 7. Nitrogen release (lbs N/acre) and contribution to the active organic matter (lbs C/acre) of corn residues for different yield levels.

Grain yield. bu/acre*	stover removed: N release year 1	stover removed: N release year 2	stover removed: C to the active organic matter	stover left: N release year 1	stover left: N release year 2	stover left: C to the active organic matter
60	-10	2	250	-20	5	347
70	-11	3	291	-21	5	405
80	-12	3	333	-22	5	462
90	-12	4	374	-23	4	520
100	-13	4	416	-24	4	578
110	-13	5	458	-25	4	636
120	-14	5	499	-26	3	694
130	-15	6	541	-27	3	751
140	-15	6	582	-28	3	809
150	-16	7	624	-30	2	867
160	-17	7	666	-31	2	925
170	-17	8	707	-32	2	983
180	-18	8	749	-33	1	1040

*) 15.5% moisture for corn yield

quantities of leaves are lost from the hay and decompose in the soil. In fact several studies indicate that while alfalfa is being cropped, large quantities of roots, equal to the weight of roots in the spring, are turned over during the growing season. This makes it important to estimate how many roots alfalfa really has. Alfalfa tends to produce a maximum quantity of roots in its second or third year of growth. After that, many plants disappear from the stand due to disease, but the remaining plants grow larger roots to compensate. This compensation is not complete, and gradually, as the stand ages, the quantity of alfalfa roots in the soil declines. Grass roots grow slowly, but after several years of production, the quantity of grass roots may greatly exceed that of alfalfa, though the alfalfa may still produce many more tops than the grasses. Mature grass plants have a low top/root ratio and they can produce massive quantities of roots. These grass roots are excellent at building soil structure and packing organic matter into soil crumbs. The grass plants are more competitive than alfalfa at taking up nitrogen from decaying soil organic matter. They force the individual alfalfa plants to fix a greater percent of the nitrogen than they would if the alfalfa were growing alone.

Relationships between hay production and carbon turnover are also complex. Because of this, we have developed a computer submodel in our spreadsheet budgeter to estimate the C turnover and N released by the crop. It is important to know the yield of the alfalfa stand, the percent alfalfa in the hay, the age of the stand, and the percent protein in the hay. This can be easily done with the spreadsheet version of this organic matter budgeter, but it is more difficult to do accurately by hand. Therefore, we refer the reader to the spreadsheet in order to make these calculations.

Manures and compost are added to a cropping system to improve soil quality and to serve as a source of nutrients for crops. Their contribution to active organic matter can be considerable, depending on the composition and stage of decomposition. The manure table in Appendix 11 summarizes nitrogen release and contribution to active organic matter that might be expected from relatively fresh animal manures and their composts. These estimates are based on data from 28 different research trials. However, we expect that the right values will vary from farm to farm. Differences in manure quality will include variations in moisture and nutrient contents. The storage method, type of manure, and quantity of added straw have a large effect on the decomposition of the manure in the soil. We are aware that the nitrogen release from manure applications that we have predicted here is generally lower than common recommendations. However, we expect that some of the benefits to yields that are associated with manure applications are not due to nitrogen release, but rather to improved root health and root access to nutrients.

Table 8 summarizes the correlation between the total organic matter content of a soil and the amount of active organic matter for a Warsaw silt loam commonly found in southeastern Wisconsin. We determined this correlation by running the CENTURY simulation model (Parton et al., 1987) for a silt loam based on past land use. We will use these values for the active organic matter in our examples of the organic matter budgeting system. It should be realized, however, that the correlation could vary. Intensively cultivated soils are likely to have less active organic matter. Soils that have been in pasture for prolonged periods tend to have higher levels of active organic matter. Lighter soils have less active organic matter; heavier, clayey soils tend toward more active organic matter. Therefore, these values are only approximations. In our research work with farmers using this budgeter we are estimating the active organic matter by multiplying the particulate organic matter content (POM) times 2. Particulate organic matter is organic matter about the size of sand, and it appears to make up half of the active organic matter in the soils. (personal communication, 1998, Cynthia Cambardella, Soil Scientist, USDA, Soil Tilth Lab, Ames, Iowa).

Table 9. Amount of active organic matter lost each year under different crops.

Crop	Decomposition factor (-)
Corn	0.0469
Soybean	0.0353
Winter wheat	0.0469
Barley	0.0533
Oats	0.0554
Potatoes	0.0595
Sugar beets	0.0566
Red clover	0.0164
Alfalfa	0.0218
Sweet clover	0.0218

Loss of active organic matter is mainly determined by its rate of decomposition and by soil erosion. The type of crops, climatic factors and tillage practices all influence the rate of decomposition. Variation can occur due to local climatic conditions and specific farming system practices. Table 9 summarizes the fraction of active organic matter lost annually under different crops grown on a silt loam in southeastern Wisconsin. These losses take into account climatic conditions, general management practices for the area, and soil erosion. We have assumed flat land with a slope less than 2 percent, but on sloping land (>2 percent), or on soils under intensive tillage, losses

Table 8. Estimated size of the active organic matter fraction for a Warsaw silt loam

Organic matter %	Active organic matter*) (lbs C/acre)	Organic matter %	Active organic matter*) (lbs C/acre)
2.0	13819	3.6	24874
2.4	16582	4.0	27637
2.8	19346	4.4	30401
3.2	22110	4.8	33165

*) A bulk density of 1.45 g cm^{-3} was assumed

of the active organic matter may be considerably higher.

5b. Estimating the active fraction

In the following examples we will discuss organic matter budgets for a conventional corn-soybean rotation and a more diverse (sustainable) oats-alfalfa-corn-soybean crops rotation. The soil is a silt loam. Calculations are based on the amounts of carbon (C) per acre (a) since in regular soil tests organic carbon is determined more precisely than organic matter. To transform soil organic carbon to organic matter we may simply multiply the amount of organic carbon by a factor of 1.72.

Table 10 shows the organic matter budget for the more diverse rotation starting with the corn in 2000. The three years preceding this rotation were included in the budget to account for any residues from previous crops contributing to the active organic matter fraction in the course of the rotation.

The budgeting starts by summarizing the cropping year, crop name and crop yields in columns A, B, C_1 and C_2, respectively. Next, we turn to the crop tables, such as Table 7 for corn. In our example an average corn yield of 130 bu/acre was achieved in the past and entered in the budget for 2000. Corresponding to this yield level and taking into account the removal of straw from the field, we find a total contribution to the active organic matter of 751 lbs C/acre because the stover was returned to the soil. For each crop the contribution to the active organic matter is found in the corresponding crop tables of Appendices 3 through 10 and listed in column D_1 and D_2. In column E any contributions from manures may be entered based on manure application rates and corresponding contributions to active organic matter found in the manure table of Appendix 11.

In the next step we total the contribution from crop residues (D_1 and D_2) and manures (E) in column F, giving us the total annual input into the active organic matter. In the ***balance of the active organic matter*** we keep a running balance of the size of the organic matter fraction. Column F is transformed into Column G. This accounts for a 3-year period before fresh residues are transformed into organic material contributing to the active organic matter fraction (see arrows).

The initial size of the active fraction (Column H, year 2000) is determined from table 8 or from doubling the content of POM-C in the soil. Based on Table 8, for an organic matter content for this soil of 3.2 percent in 2000, we find a corresponding size of the active organic matter fraction of 22,110 lbs C/acre.

In columns I and J, the annual loss of active organic matter is calculated. This loss varies with the crops grown. Table 9 summarizes these decomposition factors for major crops. For corn in 2000 a decomposition factor of 0.0469 is found, which is entered in column I. Multiplication of the decomposition factor (I) with the initial size of the active organic matter fraction (H) gives us a total loss of active organic matter in 1994 of 1,037 lbs C/acre.

A new size of the pool of active organic matter (K) is calculated for the end of 2000. We account for gains (G) and subtract our losses (J) from the initial organic matter (H). This gives us the new size for the active organic matter in column K of 21,491 (22,110+751-1,037=21,491). The size calculated in column K for 2000 is our initial size for the following year (column H in 2001). These balancing steps are repeated for each year of rotations accounting for crop specific losses in columns I and J.

In making up the balance for the whole crop rotation, we compare the final size of the active fraction after 8 years (22,058 lbs C/acre)

Table 10. Organic matter budget for a small grain/forage/row crop rotation without manure.

		Yields of crops		**Residue contribution to active o.m.**				**Balance for active organic matter in the soil**				
Year	**Crop name**	Yield of grain in bu/acre	yield of forages (lbs/acre 15% moisture)	from grain or vegetable crops (lbs/acre)	from roots & leaves of perennial forages (lbs/acre)	from animal manures/ compost (lbs C/acre)	total (lbs C/a)	total gain (lbs C/acre)	active o.m. (lbs C/acre)	rate of loss	total loss (lbs C/acre)	new o.m. size (lbs C/acre)
A	**B**	**C1**	**C2**	**D1**	**D2**	**E**	**F=D+E**	**G**	**H**	**I**	**J=HxI**	**K=G+H-J**
1997	soybeans	45		418			418					
1998	oats/alfalfa	90	3000	304	348		652					
1999	alfalfa		8000		1425		1425					
2000	corn	130		751			751	418	22110	0.0469	1037	21491
2001	soybeans	45		418			418	652	21491	0.0353	759	21384
2002	oats/alfalfa	90	3000	304	348		652	1425	21384	0.0469	1003	21806
2003	alfalfa		8000		1425		1425	751	21806	0.0218	475	22082
2004	corn	130		751			751	418	22082	0.0469	1036	21464
2005	soybeans	45		418			418	652	21464	0.0353	758	21359
2006	oats/alfalfa	90	3000	304	348		652	1425	21359	0.0469	1002	21782
2007	alfalfa		8000		1425		1425	751	21782	0.0218	475	22058
											initial size	22110
											gain/loss	**-52**

Table 11. Organic matter budget for a small grain/forage/row crop rotation with 10 t/acre composted cattle manure.

		Yields of crops		**Residue contribution to active o.m.**				**Balance for active organic matter in the soil**				
Year	**Crop name**	Yield of grain in bu/acre	yield of forages (lbs/acre 15% moisture)	from grain or vegetable crops (lbs/acre)	from roots & leaves of perennial forages (lbs/acre)	from animal manures/ compost (lbs C/acre)	total (lbs C/a)	total gain (lbs C/acre)	active o.m. (lbs C/acre)	rate of loss	total loss (lbs C/acre)	new o.m. size (lbs C/acre)
A	**B**	**C1**	**C2**	**D1**	**D2**	**E**	**F=D+E**	**G**	**H**	**I**	**J=HxI**	**K=G+H-J**
1997	soybeans	45		418			418					
1998	oats/alfalfa	90	3000	304	348		652					
1999	alfalfa		8000		1425		1425					
2000	corn	150		867		1298	2165	418	22110	0.0469	1037	21491
2001	soybeans	45		418			418	652	21491	0.0353	759	21384
2002	oats/alfalfa	90	3000	304	348		652	1425	21384	0.0469	1003	21806
2003	alfalfa		8000		1425		1425	2165	21806	0.0218	475	23496
2004	corn	150		867		1298	2165	418	23496	0.0469	1102	22812
2005	soybeans	45		418			418	652	22812	0.0353	805	22659
2006	oats/alfalfa	90	3000	304	348		652	1425	22659	0.0469	1063	23021
2007	alfalfa		8000		1425		1425	2165	23021	0.0218	502	24684
											initial size	22110
											gain/loss	**2574**

with our initial size in 2000 (22,110 lbs C/acre). A net loss of 52 lbs C/acre was found for this rotation.

The budget shows that this crop rotation manages, more or less to maintain, but not increase the current level of active organic matter in the soil

An improvement of this rotation can be achieved by adding animal manures. Table 11 summarizes the budget for the same rotation with an addition of 10 tons/acre cow manure compost when the alfalfa is turned under. This results in a total gain of 2,574 lbs C/acre for active organic matter after 8 years. This gain looks promising in terms of soil health.

An organic matter budget for a conventional corn-corn-soybean rotation is presented in Table 12. In this system all residues are returned to the soil and N is applied as mineral fertilizer every time corn is grown. Under these conditions we predict a loss of 2,095 lbs of C/acre over the same 8 years. After many years this loss is likely to result in a new equilibrium, but the soil will show a bad structure and stability and increased soil erosion, and loss of soil fertility will be obvious. Leaving the straw in the field can improve the situation but does not result in an ecologically sound rotation. The corn stover is likely to tie up nitrogen, which will cause unstable yields if no additional artificial fertilizers are used

It can be useful to make an organic matter budget for your own farm. Readers are encouraged to use the form for the organic matter budget from Appendix 2 and all crop tables provided in Appendices 3 to 11.

5c. Estimating nitrogen availability

The important question remains as to whether enough nitrogen becomes available to grow each crop in the rotation. Since use of external nitrogen sources is limited in sustainable farming systems, crop growth will rely on decomposition of organic matter as the primary source of nitrogen. Leguminous types of forage are the most important sources of external nitrogen as they bring atmospheric nitrogen into the system and to crops grown in the rotation.

The budgeting system and calculations of the active organic matter fraction allow estimates of the amount of nitrogen coming available through mineralization in each year of the crop rotation. However, any estimates about nitrogen release should be considered premature and should be confirmed by soil tests. Nitrogen mineralization rates and availability in the soil may vary widely under local conditions.

Table 13 summarizes the nitrogen release and availability for the grain/forage/row crop rotation without manure additions. Cropping year, crop type and yields are summarized again in columns A, B, C_1 and C_2. The crop tables (Appendices 3 to 10) provide the nitrogen release from crop residues for 2 years following the growing year. This nitrogen release (or tie-up) is entered in Column D_1 for the first year and Column D_2 for the second year following the cropping year. For a corn yield of 130 Bu/acre in 2000 we find a nitrogen release (tie-up) of -15 lbs N/acre in the first year (2001, Column D_1) and 6 lbs N/acre for the second year (2002, Column D_2). For each crop grown in the rotation we enter this nitrogen release. Similar entries can be made in columns E_1 and E_2 for any manure additions.

An important source of nitrogen release stems from mineralization of nitrogen during the decomposition of active organic matter. To account for this nitrogen release, Column J from the organic matter budget (Table 10) is converted to Column F in Table 13. Nitrogen release from the active organic matter is now calculated in Column G by dividing Column F by a factor of 13 (for 2000: 1,037/13 = 80). This accounts for active organic matter having a C/N ratio of 13. Column H summarizes the total nitrogen release from different types of residue, manure and active organic matter.

Additional atmospheric nitrogen becomes fixed in the soil by free-living microbes and from deposition by rain (wet deposition) and dust particles (dry deposition). Although these nitrogen sources vary, we will use an average value of 40 lbs N/acre in our calculations (Column I).

The total quantity of available nitrogen, summarized in Column J, gives us information to help us predict whether we can grow a particular crop at a given yield level in the rotation. Total nitrogen availability (Column J) is compared with a calculation of the amount of nitrogen (Column K) that a crop needs to take up at that yield level.

Let us compare the calculations for available nitrogen with predicted crop uptake that are calculated using the data in Table 14. The N balance for corn in 2000 indicates that it is possible to grow corn without any additional nitrogen fertilizers. The nitrogen deficit found for soybeans and alfalfa can be made up by nitrogen fixation. We think the estimates are conservative because additional nitrogen that we have not accounted for may become available to crops from soil layers below the plowing depth. These deeper soil layers were not taken into consideration in the budgeting system. Deeper rooting crops like alfalfa profit far more from nitrogen from deeper soil layers than do shallow rooting crops. This means deeper rooting crops can bring up this nitrogen and prevent it from being lost from the system.

The budget in Table 15 shows that adding 10 tons/acre of manures compost increases the nitrogen that is available to the corn, thereby, assuring stable corn yields. Adding even larger quantities of manure may result in major losses of nitrogen into the groundwater.

For the corn-soybean rotation summarized in Table 16, soil cannot provide the quantities of nitrogen needed by the corn crop. This rotation is not a sustainable farming system since it requires high amounts of additional nitrogen inputs.

These rough estimates of the nitrogen available in each phase of the crop rotation tell us whether we have sufficient nitrogen cycling in the rotation and where and when shortages are likely to occur.

The numbers discussed cannot be considered as absolute values. This budgeter does not consider quantities of residual nitrogen that are available from the previous year in the form of nitrate and ammonium; however, our new spreadsheet based budgeter does allow inclusions of nitrate and ammonium data based on soil tests into the nitrogen budget. Refinements should be based on regular tests for soil nitrogen. Furthermore the budgeter does not consider true effects of extreme climatic conditions such as wet flooded conditions that cause denitrification, or drought and cold that limit the decomposition of organic matter. Whether nitrogen comes available at the right time of the season to grow crops is also a question this budgeter cannot answer. The mineralization of N from organic matter depends on the climatic and soil conditions and the time of year that the residues were turned under.

This system does not answer all environmental questions, such as how to determine potential nitrogen leaching losses. However, it can be concluded that with a balanced rotation and sufficient quantities of available manure, the demand for external nutrient inputs will be

Table 12. Organic matter budget for a row crop rotation without manure.

		Yields of crops		Residue contribution to active o.m.				Balance for active organic matter in the soil				
Year	**Crop name**	Yield of grain in bu/acre	yield of forages (lbs/acre 15% moisture)	from grain or vegetable crops (lbs/acre)	from roots & leaves of perennial forages (lbs/acre)	from animal manures/ compost (lbs C/acre)	total (lbs C/a)	total gain (lbs C/acre)	active o.m. (lbs C/acre)	rate of loss	total loss (lbs C/acre)	new o.m. size (lbs C/acre)
A	**B**	**C1**	**C2**	**D1**	**D2**	**E**	**F=D+E**	**G**	**H**	**I**	**J=HxI**	**K=G+H-J**
1997	corn	130		751			751					
1998	corn	130		751			751					
1999	soybeans	45		418			418					
2000	corn	130		751			751	751	22110	0.0469	1037	21824
2001	corn	130		751			751	751	21824	0.0469	1024	21551
2002	soybeans	45		418			418	418	21551	0.0353	761	21209
2003	corn	130		751			751	751	21209	0.0469	995	20965
2004	corn	130		751			751	751	20965	0.0469	983	20733
2005	soybeans	45		418			418	418	20733	0.0353	732	20419
2006	corn	130		751			751	751	20419	0.0469	958	20212
2007	corn	130		751			751	751	20212	0.0469	948	20015
											initial size	22110
											gain/loss	**-2095**

Table 13. Nitrogen availability in a small grain/forage/row crop rotation without manure.

		Crop Yields		N from grain crops		N from forages		From manure and/or fertilizer		From active o.m.		Balance for nitrogen in the soil					
Year	Crop name	Yield of grain in bu/acre	yield of forages (lbs/acre)	Year 1 (lbs/acre)	Year 2 (lbs/acre)	Year 1 (lbs/acre)	Year 2 (lbs/acre)	Year 1 (lbs/acre)	Year 2 (lbs/acre)	Loss C (lbs C/acre)	N release (lbs N/acre)	Total release (lbs N/acre)	N fixed & deposition (lbs N/acre)	Total available N (lbs/acre)	Removed by crops (N/acre)	Potential crop/soil N balance	Potential for N fixation to compensate deficit
A	B	C1	C2	D1	D2	D1	D2	E1	E2	F	G=F/13	H=D+E+G	I	J=H+I	K	L =J-K	
1997	soybeans	45															
1998	oats/alfalfa	90	3000	25													
1999	alfalfa		8000	-33	12	34											
2000	corn	130			3	129	15			1037	80	227	40	267	212	55	
2001	soybeans	45		-15			55			759	58	98	40	138	167	-28	yes
2002	oats/alfalfa	90	3000	25	6					1003	77	108	40	148	133	15	yes
2003	alfalfa		8000	-33	12	34				475	37	50	40	90	196	-106	yes
2004	corn	130			3	129	15			1036	80	227	40	267	212	55	
2005	soybeans	45		-15			55			758	58	98	40	138	167	-28	yes
2006	oats/alfalfa	90	3000	25	6					1002	77	108	40	148	133	15	
2007	alfalfa		8000	-33	12	34				475	37	50	40	90	196	-106	yes

minimal and the soil quality will most likely be maintained.

Table 14. Average nitrogen requirements for field crops

Crop	Coefficient
Grain crops	(lbs N/bu)
Corn	1.63
Soybean	3.70
Winter Wheat	1.41
Barley	0.94
Oats	0.66
Vegetables	lbs N/lb fresh produce
Potatoes	0.0033
Sugar Beets	0.0015
Hay	lbs N/lb @ 15% moisture
hay at 14% protein	0.0190
hay at 16% protein	0.0218
hay at 18% protein	0.0245
hay at 20% protein	0.0272

Table 15. Nitrogen availability in a small grain/forage/row crop rotation with manure.

		Crop Yields		N from grain crops		N from forages		From manure and/or fertilizer		From active o.m.		Balance for nitrogen in the soil					
Year	Crop name	Yield of grain in bu/acre	yield of forages (lbs/acre)	Year 1 (lbs/acre)	Year 2 (lbs/acre)	Year 1 (lbs/acre)	Year 2 (lbs/acre)	Year 1 (lbs/acre)	Year 2 (lbs/acre)	Loss C (lbs C/acre)	N release (lbs N/acre)	Total release (lbs N/acre)	N fixed & deposition (lbs N/acre)	Total available N (lbs/acre)	Removed by crops (N/acre)	Potential crop/soil N balance	Potential for N fixation to compensate deficit
A	B	C1	C2	D1	D2	D1	D2	E1	E2	F	G=F/13	H=D+E+G	I	J=H+I	K	L=J-K	
1997	soybeans	45															
1998	oats/alfalfa	90	3000	25													
1999	alfalfa		8000	-33	12	34											
2000	corn	150			3	129	15	20		1037	80	247	40	287	245	42	
2001	soybeans	45		-16			55		10	759	58	107	40	147	167	-19	yes
2002	oats/alfalfa	90	3000	25	7					1003	77	109	40	149	133	16	yes
2003	alfalfa		8000	-33	12	34				475	37	50	40	90	196	-106	yes
2004	corn	150			3	129	15	20		1102	85	252	40	292	245	47	
2005	soybeans	45		-16			55		10	805	62	111	40	151	167	-16	yes
2006	oats/alfalfa	90	3000	25	7					1063	82	114	40	154	133	21	
2007	alfalfa		8000	-33	12	34				502	39	52	40	92	196	-104	yes

Table 16. Nitrogen availability in a grain/row crop rotation without manure.

		Crop Yields		N from grain crops		N from forages		From manure and/or fertilizer		From active o.m.		Balance for nitrogen in the soil					
Year	Crop name	Yield of grain in bu/acre	yield of forages (lbs/acre)	Year 1 (lbs/acre)	Year 2 (lbs/acre)	Year 1 (lbs/acre)	Year 2 (lbs/acre)	Year 1 (lbs/acre)	Year 2 (lbs/acre)	Loss C (lbs C/acre)	N release (lbs N/acre)	Total release (lbs N/acre)	N fixed & deposition (lbs N/acre)	Total available N (lbs/acre)	Removed by crops (N/acre)	Potential crop/soil N balance	Potential for N fixation to compensate deficit
A	B	C1	C2	D1	D2	D1	D2	E1	E2	F	G=F/13	H=D+E+G	I	J=H+I	K	L=J-K	
1997	corn	130															
1998	corn	130		-33													
1999	soybeans	45		-33	3												
2000	corn	130		25	3			160		1037	80	268	40	308	212	96	
2001	corn	130		-33	12			160		1024	79	218	40	258	212	46	
2002	soybeans	45		-33	3					761	59	29	40	69	167	-98	yes
2003	corn	130		25	3			160		995	77	265	40	305	212	93	
2004	corn	130		-33	12			160		983	76	215	40	255	212	43	
2005	soybeans	45		-33	3					732	56	26	40	66	167	-100	yes
2006	corn	130		25	3			160		958	74	262	40	302	212	90	
2007	corn	130		-33	12			160		948	73	212	40	252	212	40	

6. Sources

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This budgeter is based on a review of numerous technical studies that analyzed the impact of crop residues, animal manures, and composts on nitrogen release and organic matter retention. A full list is not provided here for the sake of brevity but can be obtained from Walter Goldstein if desired.

Appendix 1. Steps to budget your organic matter and nitrogen availability.

The organic matter budgeting can be done using the blank forms and crop and manure tables provided in this part of the budgeter. Examples of the organic matter budgeting can be found in tables 10 though 12. The organic matter budgeting system consists of two steps. In the first step effects of the crop rotation and manure application on the active organic matter can be made. In a second step the nitrogen coming available in the soil can be estimated.

Calculate the changes in the active organic matter fraction by using Form I (Appendix 2) and go through the following steps:

i. Column A and B: Fill in the years and crops grown in the rotation, starting with 3 years preceding the crop rotation.

ii Columns C_1 and C_2: Enter for each crop average yields obtained on your farm in the last couple of years or use regional data for comparable soils.

iii. Columns $D_{1,}$ D_2 and E: Turn to the crop and manure tables of Appendix 3 to 10. Enter the appropriate quantity of active organic matter for your average yield levels and manure applications.

iv. Column F: Sum D_1, D_2 and E for the total contribution of residues to the active organic matter.

v. Column G: Account for three years before residues are transformed into the active organic matter.

vi. Column H: Determine the initial size of the active organic matter on your farm from Table 8 or by multiplying POM-C times 2. Enter this size fraction for the first year of the rotation.

vii. Column I: Determine from Table 9 the fraction of the active organic matter lost annually for each crop in your rotation.

viii Column J: Calculate the total annual loss of the active organic matters (J=HxI)

ix Column K: Calculate the size of the active organic matter for the end of the year (K=G+H-J).

x. Repeat steps vi through ix using the quantity of active organic matter in (K) as the size (H) for the following year.

Steps to estimate the nitrogen availability in your soil

i. Column A and B: Fill in the years and crops grown in the rotation, starting with 3 years preceding the crop rotation.

ii. Column C_1 and C_2: Enter for each crop average yields obtained on your farm in the last couple of years or use regional data for comparable soils.

iii. Column D_1 and D_2: Turn to the crop tables (Appendix 3 to 10) provided in this part. Enter for your yield levels the corresponding nitrogen release for the two years following the growth of a crop.

iv. Column E_1 and E_2: Turn to the manure tables in Appendix 2. Enter for your manure application rate the corresponding nitrogen release for the two years following your application.

v. Column F: Enter the loss of active organic matter from column J of your organic matter budgeting sheet (Form 1).

vi. Column G: Calculate the nitrogen release from G=F/15.

vii. Column H: The total nitrogen release is calculated as $H= D_1+D_2+E_1+E_2+G$.

viii Column I: Nitrogen fixation and deposition is site specific, assume about 40 lbs N/acre.

ix Column J: Calculate the total nitrogen availability from J=H+I.

x. Column K: The total nitrogen removed can be calculated by multiplying yields times the factors given in Table 14.

xi. Column L: The nitrogen balance is calculated from L=J-K.

Appendix 2. Forms for organic matter budgeting and estimation of the nitrogen availability in your soil.

FORM 1. Blank form to calculate changes in the active organic matte

		Yields of crops		Residue contribution to active o.m.				Balance for active organic matter in the soil				
Year	Crop name	Yield of grain in bu/acre	yield of forages (lbs/acre 15% moisture)	from grain or vegetable crops (lbs/acre)	from roots & leaves of perennial forages (lbs/acre)	from animal manures/ compost (lbs C/acre)	total (lbs C/a)	total gain (lbs C/acre)	active o.m. (lbs C/acre)	rate of loss	total loss (lbs C/acre)	new o.m. size (lbs C/acre)
A	**B**	**C1**	**C2**	**D1**	**D2**	**E**	**F=D+E**	**G**	**H**	**I**	**J=HxI**	**K=G+H-J**

- initial size ______

gain/loss ______

* bushels/acre for corn, soybeans and small grains
tons/acre for potatoes and sugar beets
lbs/acre for green manures and forages

FORM 2. Blank form to estimate nitrogen availability in a crop rotation

		Crop Yields		N from grain crops		N from forages		manure and/or fertilizer		From active o.m.		Balance for nitrogen in the soil					
Year	Crop name	Yield of grain in bu/acre	yield of forages (lbs/acre)	Year 1 (lbs/acre)	Year 2 (lbs/acre)	Year 1 (lbs/acre)	Year 2 (lbs/acre)	Year 1 (lbs/acre)	Year 2 (lbs/acre)	Loss C (lbs C/acre)	N release (lbs N/acre)	Total release (lbs N/acre)	N fixed & deposition (lbs N/acre)	Total available N (lbs/acre)	Removed by crops (N/acre)	Potential crop/soil N balance	Potential for N fixation to compensate deficit
A	B	C1	C2	D1	D1	D2	D2	E	E	F	G=F/13	H=D+E+G	I	J	K	L =J-K	

* bushels/acre for corn, soybeans and small grains
tons/acre for potatoes and sugar beets
lbs/acre for green manures and forages

Appendix 3. Nitrogen release (lbs N/acre) and contribution to the active organic matter (lbs C/acre) of corn residues for different yield levels.

Grain yield. bu/acre*	stover removed: N release year 1	stover removed: N release year 2	stover removed: C to the active organic matter	stover left: N release year 1	stover left: N release year 2	stover left: C to the active organic matter
60	-10	2	250	-20	5	347
70	-11	3	291	-21	5	405
80	-12	3	333	-22	5	462
90	-12	4	374	-23	4	520
100	-13	4	416	-24	4	578
110	-13	5	458	-25	4	636
120	-14	5	499	-26	3	694
130	-15	6	541	-27	3	751
140	-15	6	582	-28	3	809
150	-16	7	624	-30	2	867
160	-17	7	666	-31	2	925
170	-17	8	707	-32	2	983
180	-18	8	749	-33	1	1040

*) 15.5% moisture for corn yield

Appendix 4. Nitrogen release (lbs N/acre) and contribution to the active organic matter (lbs C/acre) of soybean residues for different yield levels.

Grain yield. bu/acre*	straw removed: N release year 1	straw removed: N release year 2	straw removed: C to the active organic matter	straw left: N release year 1	straw left: N release year 2	straw left: C to the active organic matter
30	12	4	152	17	8	279
35	14	4	177	19	9	325
40	16	5	203	22	10	372
45	18	6	228	25	12	418
50	21	6	254	28	13	465
55	23	7	279	31	14	511
60	25	7	304	34	16	557
65	27	8	330	36	17	604
70	29	9	355	39	18	650

*) 12% moisture for soybean yield

Appendix 5. Nitrogen release (lbs N/acre) and contribution to the active organic matter (lbs C/acre) of winter wheat residues for different yield levels.

	straw removed			straw left		
Grain yield.	N release		C to the active	N release		C to the active
bu/acre*	year 1	year 2	organic matter	year 1	year 2	organic matter
40	-5	2	254	-22	4	283
45	-7	3	285	-24	4	318
50	-8	3	317	-26	4	354
55	-10	4	349	-27	4	389
60	-11	5	380	-29	4	424
65	-13	5	412	-31	4	460
70	-14	6	444	-33	4	495
75	-16	6	476	-34	4	530
80	-17	7	507	-36	4	566
85	-19	8	539	-38	4	601
90	-20	8	571	-40	4	636
95	-21	9	602	-41	4	672
100	-23	9	634	-43	4	707

*) 12% moisture for wheat grain yield

Appendix 6. Nitrogen release (lbs N/acre) and contribution to the active organic matter (lbs C/acre) of spring barley residues for different yield levels.

	straw removed			straw left		
Grain yield.	N release		C to the active	N release		C to the active
bu/acre*	year 1	year 2	organic matter	year 1	year 2	organic matter
40	-6	8	135	-7	10	151
45	-9	9	152	-9	11	170
50	-11	10	169	-12	12	189
55	-14	11	186	-14	13	207
60	-17	12	203	-17	14	226
65	-19	12	220	-19	15	245
70	-22	13	237	-22	16	264
75	-25	14	254	-25	17	283
80	-27	15	270	-27	18	302

*) 12% moisture for barley grain yield

Appendix 7. Nitrogen release (lbs N/acre) and contribution to the active organic matter (lbs C/acre) of spring oats residues for different yield levels.

Grain yield. bu/acre*	straw removed: N release year 1	straw removed: N release year 2	straw removed: C to the active organic matter	straw left: N release year 1	straw left: N release year 2	straw left: C to the active organic matter
50	-12	6	169	-20	3	189
55	-15	6	186	-23	2	207
60	-18	5	203	-26	2	226
65	-20	5	220	-29	1	245
70	-23	4	237	-33	0	264
75	-26	4	254	-36	-1	283
80	-28	4	270	-39	-1	302
85	-31	3	287	-42	-2	320
90	-33	3	304	-46	-3	339
95	-36	3	321	-49	-4	358
100	-39	2	338	-52	-4	377
105	-41	2	355	-55	-5	396
110	-44	1	372	-59	-6	415

*) 12% moisture for oat grain yield

Appendix 8. Nitrogen release (lbs N/acre) and contribution to the active organic matter (lbs C/acre) for potato and sugar beet residues for different yield levels.

Yield tons/acre*	Potatoes: N release year 1	Potatoes: N release year 2	Potatoes: C to the active organic matter	Sugarbeets: N release year 1	Sugarbeets: N release year 2	Sugarbeets: C to the active organic matter
12.5	19	4	160			
15	23	4	192			
17.5	27	5	224	20	4	224
20	31	5	256	23	5	256
22.5	35	6	288	25	5	288
25	39	7	320	28	6	320
27.5	43	7	352	31	7	352
30	47	8	384	34	8	384
32.5				36	8	416
35				39	9	448
37.5				42	10	480
40				44	10	512

*) 12% moisture for oat grain yield

Appendix 9a. Nitrogen release (lbs N/acre) and contribution to the active organic matter (lbs C/acre) for alfalfa in the first year (establishment year). Different scenarios are given as to how the alfalfa is handled: 1) cut for hay and left for another year; 2) cut for hay and turned under in the fall; 3) not cut for hay but turned under in the fall.

	hay removed, crop left for another year			**hay removed, plants turned under**			**hay not removed, plants turned under in fall**		
Yield	N release		C to the active	N release		C to the active	N release		C to the active
tons/acre*	year 1	year 2	organic matter	year 1	year 2	organic matter	year 1	year 2	organic matter
1000	17	7	247	51	22	502	51	22	502
1500	22	9	282	59	25	564	59	25	564
2000	26	11	317	67	29	625	67	29	625
2500	30	13	350	74	32	684	74	32	684
3000	34	15	384	82	35	743	82	35	743
3500	39	17	416	89	38	799	89	38	799
4000	43	18	448	97	41	855	97	41	855

*) at 15% moisture.

Appendix 9b. Nitrogen release (lbs N/acre) and contribution to the active organic matter (lbs C/acre) for red clover and sweetclover used as green manure crops at different levels of top production in the establishment year. Neither were harvested for hay.

	red clover			sweetclover		
Yield	N release		C to the active	N release		C to the active
tons/acre*	year 1	year 2	organic matter	year 1	year 2	organic matter
1000	35	5	349	61	6	349
1500	50	8	523	93	8	523
2000	66	11	698	124	11	698
2500	82	14	872	156	14	872
3000	97	17	1046	188	17	1046
3500	113	20	1221	219	19	1221
4000	129	23	1395	251	22	1395

*) at 15% moisture.

Appendix 10. Nitrogen release (lbs N/acre) and contribution to the active organic matter (lbs C/acre) for alfalfa that is turned under at the end of its second year (first year of major production). Values are given for scenarios where all hay is harvested; where a third cut is turned under (25% of total tops); and where a fourth cut is turned under (15% of total tops).

potential production of hay	all hay removed			15% of all tops turned under			25% of all tops turned under		
	N release		C to the active	N release		C to the active	N release		C to the active
tons/acre	year 1	year 2	organic matter	year 1	year 2	organic matter	year 1	year 2	organic matter
3000	76	33	817	82	36	894	86	37	945
4000	87	37	947	95	41	1049	101	43	1117
5000	98	42	1074	108	46	1202	115	49	1287
6000	109	47	1195	122	52	1348	130	56	1450
7000	119	51	1312	134	57	1491	143	61	1610
8000	129	55	1425	146	62	1629	157	67	1765
9000	139	60	1533	158	68	1763	170	73	1916
10000	149	64	1636	170	73	1891	184	79	2061
11000	159	68	1736	182	78	2017	197	84	2204
12000	168	72	1830	193	83	2136	210	90	2340
13000	177	76	1921	204	88	2253	222	95	2474
14000	186	80	2006	215	93	2363	235	101	2601
15000	194	83	2088	225	96	2471	246	105	2726
16000	203	87	2164	237	101	2572	259	111	2844

Appendix 11. Nitrogen release (lbs N/acre) and contribution to the active organic matter (lbs C/acre) for fresh cow, pig, sheep, and chicken manures & composts made from them, and a vegetable compost.

	Fresh Cattle Manure			Cattle Man. Compost			Fresh Pig Manure			Pig Man. Compost		
Moist addition	N release		to active	N release		to active	N release		to active	N release		to active
tons/acre	year 1	year 2	o.m.	year 1	year 2	o.m.	year 1	year 2	o.m.	year 1	year 2	o.m.
4	6	3	308	8	4	519	20	10	443	9	4	508
6	9	5	540	12	6	779	30	15	665	13	7	763
8	13	6	720	16	8	1039	40	20	886	18	9	1017
10	16	8	900	20	10	1298	50	25	1108	22	11	1271
12	19	9	1081	25	12	1558	60	30	1330	27	13	1525
14	22	11	1261	29	14	1818	70	35	1551	31	15	1780
16	25	13	1441	33	16	2077	80	40	1773	35	18	2034
18	28	14	1621	37	18	2337	90	45	1994	40	20	2288
20	32	16	1801	41	20	2597	100	50	2216	44	22	2542
22	35	17	1981	45	23	2856	110	55	2438	49	24	2796
24	38	19	2161	49	25	3116	120	60	2659	53	27	3051
26	41	21	2341	53	27	3376	130	65	2881	58	29	3305
28	44	22	2521	57	29	3635	140	70	3103	62	31	3559
30	47	24	2701	61	31	3895	150	75	3324	66	33	3813

	Fresh Chicken Manure			Chicken Man. Compost			Fresh Sheep Manure			Vegetable/Soil compost		
Moist addition	N release		to active	N release		to active	N release		to active	N release		to active
tons/acre	year 1	year 2	o.m.	year 1	year 2	o.m.	year 1	year 2	o.m.	year 1	year 2	o.m.
4	37	18	333	11	5	393	35	17	846	1	1	340
6	55	28	499	16	8	589	52	26	1270	2	1	510
8	74	37	666	21	11	785	70	35	1693	2	1	680
10	92	46	832	27	13	982	87	44	2116	3	1	850
12	111	55	999	32	16	1178	105	52	2539	3	2	1019
14	129	65	1165	37	19	1374	122	61	2963	4	2	1189
16	148	74	1332	43	21	1571	140	70	3386	4	2	1359
18	166	83	1498	48	24	1767	157	79	3809	5	2	1529
20	185	92	1664	53	27	1963	175	87	4232	5	3	1699
22	203	102	1831	59	29	2160	192	96	4656	6	3	1869
24	222	111	1997	64	32	2356	210	105	5079	6	3	2039
26	240	120	2164	69	35	2552	227	113	5502	7	3	2209
28	259	129	2330	75	37	2749	244	122	5925	7	4	2379
30	277	138	2497	80	40	2945	262	131	6348	8	4	2549

Dry matter contents for fresh cattle, composted cattle, fresh pig, composted pig, fresh chicken, composted chicken fresh sheep, and vegetable/soil compost are 19.5, 24.6, 39.3, 34.3, 31, 31, 49.9, and 52.7%, respectively. You should adjust your values according to the dry matter content of your manure or composts.