Reviews

The Historical Roots of Living Mulch and Related Practices

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***Summary.* Since the domestication of the first crop species, farmers have dealt with the problem of soil depletion and declining crop yields. Fallowing of land was the first approach to restoring soil fertility, and is still the most commonly used method among indigenous farmers. Alternatives to fallow, such as crop rotation and green manures, developed in a number of areas. The earliest record of their use is in Chinese writings from ca. 500 B.C. Discussion of these practices is found in European agricultural publications dating from the 16th century. While these ancient techniques have proven value for soil conservation, their use in modern agriculture is quite limited. Renewed interest within the agriculture community in recent decades has resulted in a greater research effort in the areas of green manures, cover crops, and living-mulch cropping systems.**

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"Civilized man has marched across the face of the earth and left a desert in his footprints" (Carter and Dale, 1974).

Few people consider the importance of agriculture or soil conservation in the development of cultures. The rise ofcivilizations depends on the ability of a culture to produce not just enough food for survival, but a surplus of food. It is only with the production of surpluses and cash crops that population growth, trade, and the trappings of civilization can develop. Maintaining the productivity of the soil that feeds a population is essential to this process. Inevitably, as population increases, the pressure on the land to feed it increases. Historical records show that lands that sustained early civilizations, such as Mesopotamia, Greece, Egypt, and Rome, were depleted by intensive farming pressure and poor soil husbandry (Carter and Dale, 1974). This factor contributed significantly to the decline of these cultures. During the last decades of the Roman Empire, for example, yields of wheat and barley averaged 4 to 6 bushels per acre. Columella advised farmers to switch to grapes, "for none in Italy can remember when grain increased four-fold" (this would result in a "good" yield for that time, of 7 bushels/acre). By A.D. 395, farmers in Campania in southern Italy had abandoned 330,000 acres of land (Simkhovitch, 1937).

While the quotation that introduces this paper oversimplifies the story, the soil conservation record of past civilizations has not been good. How has western civilization managed its soils? Did our European ancestors learn anything from the mistakes of earlier cultures? And how do our current soil husbandry practices compare to those of past cultures?

Fallow and early European farming

The farmer has always had to deal with soil depletion. The first and most long-standing method of restoring soil productivity has been the simple fallowing of the land (Fussell, 1965). While the use of manures and green manures was known in very early times, fallowing has, until very recently, been the most common practice in dealing with declining soil productivity. Early European farmers followed the path of the Romans, growing mostly soil-depleting grain crops and depending on fallow to ameliorate the effects (Fussell, 1972). Europe was "saved" from agricultural decline by another, more-devastating disaster—the bubonic plague, which rose to epidemic proportions in Europe in the middle of the 14th century. The precipitous decline in population initiated long-term and ultimately beneficial changes in European agriculture.

It is estimated that Europe lost between one-eighth and one-third of its population to the plague between 1347 and 1351 (Goetz, 1990). This population decrease greatly lessened the pressure to produce grain for subsistence, and created a serious labor deficit as well. The large, communal fields of the open field system were divided among individual farmers. There was a shift toward less labor-intensive methods: pasturage and livestock production, and a concomitant increase in the application of manure to the land (Fussell, 1972). A result of these changes was the development of crop rotation theory. This practice and other conservation methods have served to sustain the productivity of Europe's soils.

Crop rotation

The development of crop rotation theory rested on an understanding that different crops vary in the amount of nutrients they take from the soil, and that some (notably legumes) serve to enhance the soil's ability to sustain subsequent crops. There was no accompanying understanding of plant nutrition, a science that was not to mature until the middle of the 19th century

Thomas Tusser's *Five Hundred Points of Good Husbandry,* published in 1580, was one of the earliest widely distributed volumes on agriculture. The following excerpt (with interpretation in parentheses) reflects 16th century understanding of soil conservation and crop rotation:

Otes, rie or else barlie, and wheat that is gray
brings land out of comfort, and soon to decay.
One after another, no comfort betweene,
is crop upon crop, as will quickly be seen
(Oats, rye, barley and wheat deplete the soil)

Still crop upon crop many fermers do take.
and reape little profit for greediness sake.
Though breadcorne and drinkcorn such croppers do stand:
Count peason or brank, as a comfort to land.
(Some greedy farmers sow crop after crop of wheat or barley, but receive diminishing returns. Peas or buckwheat help to restore soil fertility.)

Some useth at first a good fallow to make.
To sowe thereon barlie, the better to take.
Next that to sowe pease, and of that to sowe wheat,
Then fallow againe, or lie lay for thy neat.
(In this verse, Tusser sets out a rotation that calls for fallow, barley, peas, wheat, then fallow again or pasture. The term "neat" refers to cattle.)

(Tusser, 1580, p. 19-20, in Rasmussen, 1975)

Numerous crop rotation schemes were developed involving the major crops of the period: wheat, barley, clover, peas, and pasture grasses (Whiting, 1971). All systems included fallow seasons, and many involved green manure crops for the first time.

Tillage

"The finer Land is made by Tillage, the richer will it become, and the more Plants it will maintain" (Tull, 1731).

With these words, Jethro Tull started what became a revolution in the practice of agriculture. Born in 1674, Tull was an organist and gentleman farmer (Fussell, 1973). He approached farming scientifically, conducting comparative experiments on his Oxfordshire, England, estate. Here, Tull explored the role of tillage in making land more productive. Nothing in the agricultural system of the 18th century was conducive to the use of tillage. Farm implements were simple and crude. A farmer's entire array of machinery often consisted of a plow and a harrow (Fussell, 1965). The draft animals used to power these implements did not have the benefit of breeding for size and strength. Only the top few inches of soil were ever disturbed. Seed was broadcast by hand in the spring and maintenance of the field during the cropping season was minimal.

Thus, Tull was forced to invent the equipment he needed—the seed drill and the cultivator, which he is said to have constructed from pipe organ parts. The seed drill allowed for the planting of seed in distinct rows, so that cultivation between rows during the growing season was made possible. The benefits derived from this approach included reduction of seed waste and reduction in weed pressure on the crop. Using this system, Tull's yields far outstripped those of his neighbors, even without the regular addition of manure. He recorded his observations of this phenomenon in a book entitled *Horse Hoeing Husbandrie: An Essay on the Principles of Vegetation and Tillage* (Tull, 1731). Like Tusser, Tull worked without the benefit of an understanding of plant nutrition. While the value of manure and compost for increasing yields were well-known, the mechanism by which this occurred was not understood. Thus, Tull came to the conclusion through his observations that, whatever affect manure had on the soil, its effects could be simulated with tillage. His reasoning was as follows:

"Tillage is breaking and dividing the Ground by Spade, Plough, Hoe or other Instruments, which divide by a fort of Attrition (or Contusion) as Dung does by Fermentation" (Tull, 1731).

Furthermore, he was quick to point out the other advantage of his system—tillage not only killed sprouting weeds in the field, but, by reducing the amount of manure used, one could cut down the amount of weed seed introduced into the field in the first place. Thus, tillage served to:

". . . force open her (the land's) Magazines with the Hoe, which will thence procure (for) them at all times Provision in abundance, and also free them from Intruders; I mean, their spurious Kindred, the Weeds, that robbed them of their too scanty Allowance" (Tull, 1731).

While Tull's theories did not have an immediate impact on farming in Europe, their long-term effect on agriculture has been great. In the decades since Tull introduced the concept of tillage, it has become an integral part of western agriculture. Today tillage, with its attendant drawbacks, can be an obstacle to sustainability. Goals of green manure and cover crop advocates in recent years have been the amelioration of the negative effects of tillage.

Soil fertility theory after Tull

There were many other researchers working in the 18th century to unlock the secrets of the soil and plant nutrition. Several important concepts were derived from this work, such as the knowledge that humus resulted from the decomposition of plants and provided water-holding capacity as well as sustenance for crops. Humus imparts a dark color to soil, and the degree of darkness was held to reflect the richness of the soil. The culmination of this research was the "Humus Theory," which was developed in the last decades of the 18th century (Fussell, 1971). The Humus Theory went beyond the above-mentioned observations (which were substantially true) and held, wrongly, that all necessary substances for plant growth came from the humus, or organic matter, in the soil. The Humus Theory's main proponent was Albrecht Daniel Thaer of Germany. Thaer's great influence in the scientific community caused this theory, incomplete as it was, to dominate scientific thought for many years.

Finally, in the 1830s, a number of workers accumulated scientific evidence for proposing a mineral basis for plant nutrition. Research from this period provided the basis for our knowledge today. The scientist who is given credit for these theories is Justus van Liebig, a German chemist. In 1840, he published a work that set out the following facts about plant nutrition:

1) The carbon that the plant uses is derived from carbon dioxide.

2) The hydrogen and oxygen it uses comes from water.

3) Plants absorb other necessary elements from the soil.

4) Growth is proportional to the amount of mineral substances available to the plant (Fussell, 1971).

Liebig is best known for his "Law of the Minimum," which states that plant growth is restricted by that nutrient that is in lowest supply in proportion to the plant's requirement for that nutrient.

Liebig and his colleagues ushered in the modern era in crop nutrition and soil fertility study. Once an understanding of how plants derive needed nutrients from the soil was gained, research efforts branched out to encompass a wide range ofapproaches to maintaining soil fertility. It was now known that the value of manure was not only in its organic matter content but in its mineral content as well. Manure remained the main type of soil amendment used. However, much attention was turned to green manures, which act in much the same way. In this era of scientific investigation, researchers began comparing these soil amendments and investigating their chemical and physical effects on crop growth and on the soil.

Green manures and cover crops

The term "green manure" encompasses a wide range of practices. As defined by the Soil Science Society, a green manure is a "plant material incorporated with the soil while green, or soon after maturity, for improving the soil" (Soil Science Society, 1973). In practice, green manuring takes on many variations on this theme and includes both cover crops and living mulches. Adrien Pieters, in his 1927 book entitled *Green Manuring Principles and Practice,* presents four general categories, based on how they tit into the farmer's crop rotation. They are :

1) Main Crop, which is a green manure crop grown during the regular growing season, in place of any other crop. This is done only in cases of very poor soil that will grow no other crop because there is an expenditure of money and effort with no return.

2) Catch Crop, which is a green manure planted after the main crop has been harvested.

3) Winter Cover Crop, which often serves purposes other than as green manure. Planted in the fall, this planting serves to cover the soil in winter, thus protecting it from erosion. It may be allowed to mature and be harvested for grain, in the case of winter wheat or rye, or for hay, in the case of many legumes and grasses.

4) Companion Crop. This was Pieters' name for what we are calling today a "living mulch"; a species planted at the same time as the main crop or with the final cultivation and allowed to grow up during the growing season between crop rows as well as after the crop is harvested. At the time this method was used primarily in grain production and in orchards.

The plant species used as green manures, cover crops, and living mulches are many and varied. Green manures species are most often legumes or fast-growing forbs and grasses. The earliest recorded use of green manures comes from China. In 500 B.C. the writer Chia Szu Hsieh advised "For manuring the field, lu tou *(Phaseolus mungo* L. var. *radiatus)* is best, and siao tou *(P. mungo* L.) and sesame rank second. They are broadcast in the 5th or 6th month and plowed under in the 7th or 8th month . . . Their fertilizing value is as good as silk worm excrement and well-rotted manure." (Pieters, 1927).

Unlike the agriculture of the Orient, western agriculture, until recently, has never involved large-scale growing of legumes, either as a food source or as a green manure. In addition, the persistence of the feudal open field system ofagriculture throughout much of Europe's history further discouraged the use of green manures or cover crops by greatly limiting the individual farmer's options (Fussell, 1965). Finally, the rise of the concept of tillage and the view that a "clean-tilled" field was a sign of good husbandry further impeded the adoption of these practices. It was not until the 19th century that green manures and cover crops were used to any great extent in Europe.

In North America, the acceptance of green manures has been even more minimal than in Europe. The abundance of cheap, fertile land on this continent discouraged most practice of soil conservation; many farmers simply moved west when the fertility of their land declined. Among those who continued to farm in the Eastern states, however, the 19th century saw a trend toward the use of fertility-enhancing practices. Agricultural scientist Richard Allen observed that, by 1846, "this system (green manuring) has, within a few years been extensively adopted in some of the older, settled portions of the United States" (Allen, 1852).

Beginnings of the soil conservation movement

As agricultural science grew in prominence during the 1800s, there was an increasing awareness of the factors involved in soil productivity. Soil depletion gradually became a concern within the agricultural community. During the latter half of the 19th century, several long-term research projects were initiated in England and in the United States, in efforts to document the effects of various soil husbandry systems (continuous cultivation vs. various rotations, manures, and green manures as well as comparison to natural grasslands). Now-famous studies were begun at the Univ. of Illinois and at experiment stations in Pennsylvania, Ohio, and Missouri, as well as at Rothhamsted in England (White et al., 1945; Williams, 1926). There remained a strong belief that organic matter was a major factor in soil fertility and, even as the first large-scale productions ofartificial fertilizers was beginning, research was focused on maintenance of organic matter levels and the effect of crop production on their depletion. Many of these studies are ongoing today, and continue to document the long-term effects of our crop production systems.

In 1917, Adrian Pieters published a review of green manure research conducted at American agricultural experiment stations. Pieters cited nearly 200 studies, conducted in the 30 years since the establishment of the experiment station system in 1887. It is apparent that many of these early practitioners of soil science were concerned about the depletion of soils. Their research indicates that green manures and cover crops were considered to be valuable tools in the soil conservation effort.

The concern within the scientific community manifested itself in a number of ways in the early decades of the 20th century. In 1925, the American Society of Agronomy hosted a symposium on "soil deterioration," which explored the causes and effects of soil depletion (Haskcll, 1926). This symposium focused on how various agricultural practices contribute to soil deterioration and the role that public policy plays in this process. One participant reviewed the results of the long-term studies on crop rotation and soil fertility at Rothhamsted and at American experiment stations, some of which had been in progress at that time for over 70 years. Conclusions drawn from these studies were that crop rotation alone, even when legumes are included, was not able to maintain soil productivity over the long term. Additionally, research showed that "though three times as much plant food has been applied in continuous culture as in rotation farming, it has not produced as large a gross return" (Williams, 1926).

Conservation tillage

Another major problem facing American farmers was soil erosion. A 1926 headline in the USDA weekly *Official Record* stated that erosion was costing the American farmer $200,000,000 each year. While public awareness of erosion and the adoption of soil conservation techniques has been slow overall, several events in the 20th century forced changes to be made in some areas. A prolonged drought in the Great Plains states in the 1930s was the first such event. Many dryland farmers in what came to be known as the Dust Bowl were forced to either adopt soil conservation practices or risk major crop losses (Hurt, 1981). To lessen the impact of wind and drought conditions, farmers were encouraged to reduce tillage and to make use of cover crops and mulches. Research continues today on living mulch/cover crop systems for wind protection in sugar beets and other crops grown in the west (Lauer and Fornstrom, 1988).

Outside the Dust Bowl, there was little general adoption of these conservation methods. Before the introduction of herbicides, farmers were dependent on tillage for weed control. As tractors became more widely available in the 1920s and 1930s, the use of tillage increased in most areas.

A milestone on the road toward greater acceptance of limited tillage systems was the publication in 1943 of *Plowman's Folly* by Edward Faulkner. This work directly called into question the necessity for and the value of tillage. The suggestion that plowing—which had come to be considered fundamental to crop husbandry—was unnecessary, perhaps even wrong, was quite revolutionary. In his book, Faulkner, a farmer and county agriculture agent in Ohio, maintained that "no one has ever advanced a scientific reason for plowing" (Faulkner, 1943).

Faulkner's theories were based on the premise that the soil should be disturbed as little as possible in the process of raising crops and that, in this way, it will more closely simulate a natural ecosystem. Crop residue was to be left at the soil surface, not incorporated, thus providing erosion protection, moisture conservation, and a slow-release source of nutrients. His theories were derived from knowledge gained from the long-term soil management studies mentioned previously. While the thrust of Faulkner's book was reduction of tillage-not the use of cover crops and green manures—the acceptance of his ideas opened the door for a whole range of limited-tillage options. The efforts of conservation tillage advocates were greatly facilitated by the development of herbicides in the late 1940s. Now, with cultivation no longer required for weed control, the concept of reducing tillage gained greater acceptance. Some agronomists of this period predicted that herbicides would make tillage obsolete.

A number of minimum tillage systems were devised and equipment was designed to perform these new tillage operations. These systems included plow-planting, in which narrow strips were plowed and planted in a single pass over the field, and stubble mulch farming, which involved shallow cultivation with crop residue left on the soil surface (Shear, 1985).

The idea of a living mulch

Another approach to reducing tillage was sod-planting. It was found that, when cultivation is reduced, soil aeration and nitrification also decrease and soil crusting and erosion often increase. Sod-planting, in which row crops are planted into sod killed with herbicides, was developed to address these problems (Shear, 1985). Work in this area led directly to the development of the living mulch concept.

An outgrowth of this research was that the herbicides used in sod planting, when applied at reduced rates, could regulate growth of the sod without killing it. A 1965 article entitled "The Sleeping Sod" describes the concept of producing crops in a grass sod that has been "put to sleep" with a selective herbicide for the duration of the growing season. The author, J. Paul Lilly, discusses the practice in light of the productivity goals of that period; living mulches (or sleeping sods) were seen as a way to 1) put highly erodible and otherwise untillable hillsides into production and 2) produce two crops: a summer row crop and spring and fall pasturage in the same field in the space of year.

The goal of increased productivity during the 1950s and 1960s was met largely, however, through increased inputs of agricultural chemicals and fossil fuels. The emphasis was on the use of technology in food production. Conservation and soil husbandry often were looked upon as an unnecessary hindrance to the efficient operation of the farm. As this approach became established, some of its drawbacks were brought to light. The problems that faced agriculture in the early part of the century had not been addressed and actually had been exacerbated by much of the new technology. A growing group of agriculturists and environmentalists began again to look for alternatives to the poor crop husbandry practices that have characterized American agriculture (Shear, 1985).

In the 1960s, many of those concerned about these developments joined the growing Organic Movement. There was a call for returning to traditional farming practices, involving reduced inputs and an emphasis on use of "natural" fertilizers, such as manures and legumes. Living mulches and green manures had a place in this scheme as a nonchemical means of weed control and as organic soil conditions.

In the 1970s, the concerns of organic farmers became concerns for all farmers. The 1973 Arab Oil Embargo drove the costs of fuel and petroleum-based farm chemicals up steeply and sent shock waves through the agricultural community. Reduced tillage systems were put forth as a solution to the energy crisis and, by necessity, the concept of conservation tillage became more widely accepted (Triplett and VanDoren, 1977). Although the main thrust of this movement was based on simply allowing crop residues to remain at the soil surface, the living mulch idea was again looked into and more research was done, mainly with agronomic crops.

The direction of living mulch research

Toward the end of the 1970s, Robert Sweet began research at Cornell Univ. that applied the concept of companion crops/living mulches for the first time to vegetable production. It was he who invented the name "living mulch" to differentiate this practice from the many other manifestations of the green manure idea (Hughes and Sweet, 1979). Many horticulturists believe that it is in vegetable production and other small-scale, intensively managed cropping systems that living mulches can be used most effectively. Much of the recent research has been done in the area of vegetable production.

The Cornell Vegetable Crops Dept. gradually developed a fairly large and ongoing research program in the years since Sweet's first study was published in 1979. Meanwhile, Ray William and his colleagues at Oregon State Univ. began another, complementary research program on living mulch systems, focusing mainly on wind erosion control and on woody crops-tree fruits, Christmas trees, and nursery stock (R. Sweet, personal correspondence). These two programs laid a foundation upon which many other horticulturists have built.

In Apr. 1982, a group of living mulch researchers gathered at Oregon State Univ. for a workshop entitled "Crop Production using Cover Crops and Sods as Living Mulches." Sweet was an invited speaker, along with others from California, Oregon, Washington, and British Columbia. In addition to sharing results from their respective programs, the participants made plans for future work and discussed how best to design studies of these complex systems (Miller and Bell, 1982).

One of the top priorities highlighted in this workshop was the screening ofpotential mulch species for qualities important in an intercrop system. These characteristics are summarized in William's 1987 Oregon State Univ. Extension Circular on living mulches and include:

1) Rapid establishment to suppress weeds and provide early trafficability and erosion control.

2) Adequate wear tolerance and persistence.

3) Tolerance of drought and low fertility.

4) Reduction of costs associated with mowing intervals, fertilizer needs, thatch removal or chemical mowing.

5) Enhancement of crop yield and quality (William, 1987).

Two major screening studies conducted in the mid-1980s tested a combined total of 139 grass and legume species for these qualities. From each of these trials, several promising living mulches were chosen for further study. The more expansive of the two was conducted at Cornell Univ. by Nicholson and Wien (1983). They grew intercrops of five grasses and three white clover species with either sweet corn or cabbage. They characterized an inverse linear relationship between mulch dry weight and crop yield.

The second study, conducted at the Univ. of Connecticut by DeGregorio and Ashley (1985), differed from the Cornell study in that it compared mulch competition with weed competition rather than with a bare ground control. Mulches were all grassy species; no legumes were included. This study points out one of the underlying ideas behind living mulch systems—that an intentional, regulated ground cover may be preferable to the uncertainties of weed competition.

Controlling competition is the key to the successful use of living mulches and has been a persistent obstacle to widespread acceptance of this practice. In his 1911 book entitled *Field Notes on Apple Culture,* Liberty Hyde Bailey suggested that management of cover crops in orchards should involve increasing manure application and suppressing the sod through grazing of hogs or sheep.

A 1952 study, conducted by Univ. of Illinois agronomists, showed that the crucial nutrients in the competition picture are nitrogen and water (Kurtz et al., 1957). Competition can be reduced by regulating the intercrop's use of these nutrients or by choosing mulch species that are drought-tolerant or nitrogen-fixing. Screening work on new species, particularly legumes such asvetches and dwarf clovers, continues (Lanini et al., 1989).

Mulch suppression can be accomplished in several ways. By far the most successful to date has been with use of reduced dosages of herbicides—the sleeping sod approach. A large amount of this work has been done by agronomists using suppressed grass sods mainly in field corn production (Lewis and Martin, 1967; Loughran and Hartwig, 1987). In horticultural crops, researchers have examined several approaches to mulch suppression. A representative work is a 1982 study by Vrabel, Minotti, and Sweet at Cornell. In this study, researchers compared five herbicides, plus mowing, for suppression of white clover mulch in sweet corn. Their results indicate that both methods can suppress mulch growth effectively, and acceptable yields can be maintained with either method.

A recent development in the suppression of living mulches is the use of rototilling in legume mulches (Grubinger and Minotti, 1990). Yield of sweet corn was compared in mowed vs. rototilled white clover living mulch. The rototilled treatments compare favorably, not only with mowed plots, but with clean-cultivated check plots as well. This response is very likely due the contribution of fixed nitrogen made available by the rototilling of the legume, and the more effective suppression achieved by this method.

In spite of these successes, overall research results present a mixed picture of the benefits and risks associated with living mulch systems. The possibility of crop damage when herbicides are used to suppress the mulch has been noted (Lindgren and Ashley, 1986) and, while some researchers have been able to control competition (Grubinger and Minotti, 1990; Lanini et al., 1989), studies on a variety of crops show yield reductions even with suppression of the mulch (Neilsen and Anderson, 1989; Wiles et al., 1989).

Living mulch systems can be more difficult to manage than conventional cropping systems and often require specialized equipment or changes in scheduling. Changes in the soil environment can occur as a result of both the reduction of tillage and the presence of a living ground cover in the field (Haynes, 1980; Thomas and Frye, 1984). Living mulch often alters soil temperature and moisture levels and can affect seed germination and disease incidence. Insect and vertebrate pest problems sometimes increase under living mulch systems (deCalesta, 1982; Norris, 1986), although they have been found to support beneficial insects as well, in some cases (Andow et al., 1986; William, 1981).

Overall, a living mulch system is more complex than conventional, clean-tilled systems, and for this reason living mulches, like other no-till systems, are not suited to all situations. There are many instances, however, in which living mulches can be used effectively. In recent years, the study of this practice has been incorporated into complex studies that take a systems approach to crop production. Ideally, these studies involve a multidisciplinary team, including horticulturists, entomologists, plant pathologists, ecologists, agronomists, and agricultural economists. Living mulches, cover crops, and green manures integrate well into many cropping systems and, as such, are being studied increasingly in many research programs.

The future

"It is seen how my earnest wish is that the surface of the ground should at all times, winter and summer, be well covered, whenever it possibly can be accomplished." Richard Parkinson, 1807

Crop husbandry, in all of its manifestations over the centuries, always has involved an appreciation of the value of the soil as a natural resource and of the importance of protecting that resource. Regardless of what terms we use to describe them, our goals have remained basically the same. Today, we have defined our objectives in terms of sustainability in agriculture. Sustainable agriculture has been defined as "profitable and efficient production with emphasis on improved farm management and conservation of soil, water, energy and biological resources" (National Research Council, 1989). A healthy, sustainable agroecosystem must resemble, to some extent, a natural ecosystem. In a natural ecosystem, energy and nutrient flow is relatively stable and self-regulating. Living mulches, green manures, and cover crops act to increase the amount of biomass that remains in place and thus contribute to sustaining the system over the long term (Allison, 1973; Kononova, 1961). Their value lies in their role in maintaining and conserving the soil and, as such, these practices will remain, as they have been in past eras, a useful tool for solving the problems that face agriculture today.

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