Despite the positive effect on root development of mulch combined with minimum tillage, this practice cannot always replace conventional tillage. On Alfisols in Nigeria, the initial root development of maize and soybean was slowed down by minimal tillage with mulch. Nevertheless, after 3 to 4 weeks this difference was made up by the accelerated root growth resulting from greater soil porosity on the zero tillage plots.

Legumes such as cowpea and pigeonpea show more vigorous root growth and clearly respond well to zero tillage sowing with mulch (MAURYA and LAL 1981). Particularly on introducing this technique it is advisable to choose a rotation using deep-rooting plants such as pigeonpea.

Root growth is also facilitated by the tunnels left in the soil by earthworms and when the roots of the previous crop decay. In times of drought, roots can spread quickly through these tunnels, following them down to the sinking groundwater table (GRAFF and MAKESCHIN 1979).

5.3.6 Soil chemical properties

Mulch protects or even increases soil humus. Thus it also brings about an increase in the cation exchange capacity (CEC), i.e. the soil's capacity to store nutrients.

Mulch stimulates the activity of soil organisms and through these the breakdown of organic substances. Furthermore, organic matter is protected and enhanced, the end effect being an equilibrium at a relatively high level (higher than with conventional tillage).

An Alfisol at Ibadan was found to have a C-content of 2.3% (AYANABA and OKIGBO 1975). Two years after clearing this had fallen to 1.7% on plowed plots, but on plots with minimum tillage mulched only with maize residues, the C-content was still 2.3%. After 3 years it came to 1.4% and 1.8%.

As SINGH et al. (1979) reported, decomposition under the oxidative conditions on the surface of the litter cover (mulch) is relatively rapid and more complete than under semi-aerobic conditions. However, lignin, wax and fat-like compounds remain behind as stable humus (AYANABA and OKIGBO 1975).

Table 5.9 presents the results obtained by these scientists at IITA in Nigeria. Here the humus status and the cation exchange capacity (CEC) were maintained with residue mulch, whereas these fell markedly when residues were removed.

Table 5.9. Effect of residue management on the C-content and cation exchange capacity of a site in Nigeria (IITA, Ibadan, 1972-73)

Harvest residues	Returned amount (t/ha)	Organic matter (C) (%)	CEC (meq./100 g of soil)
Remaining on the field	16.4	1.63	6.82
Removed	-	1.04	4.64

Source: AYANABA and OKIGBO (1975)

Using banana-leaf mulch on coffee (20 kg/tree), SANDERS (1953) was able to substantially improve the C-content of soils. However, he was not able to do so with elephant grass, which has a closer C/N ratio. In contrast, MUTEA et al. (1980), also using elephant grass in Kenya, improved the C-content of the soil under coffee from 3.8 to 4.4%. The moisture content of the soil at depths of 0-120 cm was almost always 2% to 5% higher with mulch.

In the humid savanna climate of Ibadan, Nigeria, mulching with leaves and branches from *Leucaena* (about 4-5 t DM/ha/year), which had been planted in alleys, increased the C-content of the soils over 4 years to 1.47%, compared with 0.98% for the control (IITA 1981). Using a groundnut shell mulch (around 5 t/ha/year) in the dry savanna climate of Samaru, Nigeria, the C-content of a sandy loam (Alfisol) was improved from 0.45% to 0.67% in 9 years. A level of 0.75% was achieved with a light application of fertilizer (10 kg P, 26 kg N), which had shown no humus effect without mulch. This increase, small in absolute terms but nonetheless significant (66%) had, according to JONES (1971), a considerable impact on the buffering capacity and nutrient content of the soil at this site, improving the cation exchange capacity by about a third, from 2.2 m.e. to 3.3 m.e./100 g of soil. The gain in humus from the organic matter was 20.5% higher with a groundnut shell mulch (C/N ratio of 55:1) than with a corresponding amount of farmyard manure (C/N ratio of 25:1).

The protective effect of mulch on humus, which is more significant than its humus-building benefit when materials with close C/N ratios are used, is primarily due to its regulatory influence on temperature and moisture. Alternate drying and wetting - especially when the drying is accompanied by a strong increase in soil temperature - accelerate the breakdown of humus and result in high N mineralization (JAGNOW 1967).

These changes in conditions are less pronounced under mulch; humus breakdown is decreased in degree and speed. MUTEA et al. (1980) regard mulching as one way of reducing the "N flush" that occurs after a dry period, thereby making the nitrogen available to the crops over a longer period. According to JAGNOW (1967), the supply of N under mulch is more steady than without mulch, especially in the dry season. However, in the rainy season, greater losses of nitrogen through leaching may occur because the rain - and the nitrate with it - can penetrate deeper and more rapidly into the soil. In times when high rainfall is certain it therefore makes sense to use ground cover plants rather than mulch whenever possible. These plants reduce losses caused by leaching and can be cut at the beginning of the dry season.

Mulch materials with a disparate C/N ratio have the advantage of covering the ground longer, but immobilize nitrogen in the upper soil layers so that a temporary shortage of N must be expected, especially when mulching is first introduced. This short-term nitrogen deficit (HAGIHARA 1975 and others) can be offset by applying mulch with legumes, some additional manure or supplementary mineral fertilizer (best applied in strips along the row).

When the soil life and a new humus level with a normal C/N ratio have been built up (after 1 to 3 years), this "hunger" effect disappears or is even reversed because of the higher humus turnover (LAL 1975; GRIFFITH 1951, cited in AYANABA and OKIGBO 1975; TANAKA 1974).

Table 5.10. Nutrients removed via the harvesting of some field crops in smallholdings

Crop	Yield (kg/ha)	Nutrients removed (kg/ha) N	P	K	Ca	Mg
Maize (grains only)	1100	17.1	3.0	3.0	0.2	0.2
Rice (paddy only)	1100	13.6	3.15	3.9	0.9	1.5
Groundnut (nuts)	550	28.5	2.4	3.0	0.3	1.0
(shells)	220	2.2	0.2	1.8	0.7	-
total	770	30.7	2.6	5.3	1.0	1.0
Cassava (fresh tubers)	11000	25.0	3.0	66.0	5.9	-
Yam (fresh tubers)	11000	38.6	3.0	39.9	0.7	-
Banana (fruit)	11000	30.7	4.5	63.2	0.7	-
Cocoa (beans)	550	13.6	3.2	11.4	-	-
(husks)	550	11.4	1.2	25.0	-	-
total	1100	25.0	4.4	36.4	-	-

According to NYE and GREENLAND (1960), the rainfall alone in West Africa delivers up to 18 kg N, 18 kg K, 13 kg Ca and 13 kg Mg per ha per year. BLUM (1980) reports that rainfall is responsible for 5-35 kg N, 0.2-7.3 kg P, 2.3-38 kg S, 0.2-17 kg K, 0.2-30 kg Ca, and 0.1-26 kg Mg per ha per year, depending on location.

Source: OKIGBO (1980)

Significant amounts of nutrients are added or returned to the soil with crop residues and especially with mulch brought to the field from elsewhere. As can be seen in Table 5.10, the amount of nutrients removed from the soil with the harvest itself is relatively low on most smallholdings. Provided nutrients were not removed in other ways, returning crop residues to the soil would be enough to render the system virtually self-sustaining with regard to most nutrients (see Table 5.11).

Approximate values of the mean nutrient contents of some plant residues are listed in Table 5.12. According to this table, the application of 10 t/ha of sorghum straw adds 58 kg N, 10 kg P, 151 kg K, 21 kg Ca, 13 kg Mg and 10 kg S to the site. Ten tonnes of elephant grass per ha represents about 190 kg N, 12 kg P and 300 kg K (TOLHURST and KILAVUKA 1975).

Table 5.11. Proportion of nutrients in the residues of some crops (% of above-ground biomass)

	N	P	K	Ca	Mg	S
Millet	53	62	92	97	90	75
Sorghum	49	58	93	95	75	64
Maize	31	32	82	95	57	43
Wheat	24	21	90	80	51	-
Rice	32	24	86	77	48	-
Groundnut	40	41	80	95	77	55
Cowpea	50	43	82	98	82	-
Cotton	43	40	81	99	93	-
Mean	40	40	86	92	72	59

Source: BALASUBRAMANIAN and NNADI (1980)

If crop residues are removed or burned, however, the losses are considerable. Burning incurs the loss of C, N and S. According to CHARREAU (1974, cited in BALASUBRAMANIAN and NNADI 1980) 20-40 kg of N and 5 kg of S per hectare are lost every year in this way. Burning is the main reason for the savannas' overall deficits of C, N and S.

Table 5.12. Average nutrient content of some crop residues (% of dry weight)

Crop/part of plant	N	P	K	Ca	Mg	S
Millet stems	0.65	0.09	1.82	0.35	0.23	0.15
Sorghum stems	0.58	0.10	1.51	0.21	0.13	0.10
Maize stover	0.70	0.14	1.43	0.36	0.11	0.12
Wheat straw	0.62	0.12	1.72	0.27	0.15	0.12
Rice straw	0.58	0.13	1.33	0.20	0.11	-
Groundnut leaves	2.56	0.17	2.11	1.98	0.68	-
Groundnut stems	1.17	0.14	2.20	0.92	0.50	-
Groundnut shells	1.00	0.06	0.90	0.25	0.10	0.10
Cowpea leaves	1.99	0.19	2.20	3.16	0.46	-
Cowpea stems	1.07	0.14	2.54	0.69	0.25	-
Cotton leaves and twigs	1.33	0.27	2.35	1.27	0.25	-

Source: Compiled by BALASUBRAMANIAN and NNADI (1980)

For tea cultivation in Rwanda, DE PRINS and DE VUYST (1975) urge that all residue cuttings from tea plants should remain in the plantation to be used as mulch, as these would fully balance the loss of P and K. The N balance too was almost even. However, because an N loss of at least 30% must be expected as a result of decomposition, the use of a legume mulch cut from shade trees such as *Albizia* sp. and *Leucaena* sp. is also advisable (FRANKE 1980).

In trials by IITA in Nigeria, the N status of the soil was fully maintained through mulching with *Leucaena*, with an annual maize yield from alley cropping of 3.6 t/ha (IITA 1981).

Indirect effects of mulch on the nutrient balance are apparent in humus formation and the increase in soil organisms (see Section 2.3.3). The availability of P, K and Mg was often improved significantly through mulching (FRANKE 1980, BOUHARMONT 1979).

Table 5.13. Nutrient balance on two tea plantations in Rwanda

Site	Returned elements via lopping (leaves and branches)			Removal via picking		
	---------- kg/ha -----------					
	N	P	K	N	P	K
Marais (Histosol)	204.1	19.6	31.8	174	5	48
Collin (Ferralsol)	71.0	21.7	69.7	87	9	32

Source: DE PRINS and DE VUYST (1975)

The accelerated fall in pH value observed under zero tillage in temperate climates may also be expected in the tropics. This development can and must be countered through heavy applications of mulch. Deep-rooting plants can be rotated or grown in strips to bring up calcium from the deeper soil strata before being used as mulch. Earthworms that excrete their casts on the soil surface play an important role in restoring Ca. On acidic soils their activity can be encouraged through a light addition of Ca to the mulch.

Of special interest is the question of how mulching and minimum tillage influence the effectiveness of phosphorus applications. This nutrient is often deficient in tropical soils. Research findings from temperate areas suggest that the efficiency of mineral P fertilizer can be significantly improved through mulching and/or minimal tillage in the tropics too.

HAYNES 1980 observed that orchards undersown with grass showed a markedly higher level of available P than did those with bare soil. It was found that grasses can take up a large "luxury" amount of P and K in a short time. P fertilizers can thus be rapidly transformed into organic P forms. While these are unavailable to plants in the short term, once mineralized they are of great importance to the agro-ecosystem. BOULD et al. (1954, cited in HAYNES 1980) showed that the P uptake of fruit

trees in orchards with undersown grass, which was mulched after mowing, was up to 37% higher than if the fertilizer had been applied to bare soil. It may be assumed that, because of its rapid conversion into organic form, the phosphorus found its way into the natural circulation of materials, rather than becoming fixed in the soil in the form of apatites. In this form, through decomposition and mineralization via mulch and soil organisms, it was more effectively taken up by the trees.

Studies in the USA on minimum tillage and mulching showed a higher P fertilizer efficiency with mulch tillage compared with conventional cultivation techniques (PHILLIPS et al. 1980). Two main reasons are given:

* The uptake of P fertilizers applied to the surface is especially good under mulch because the soil moisture on the surface is higher than it would otherwise be. This improves the diffusion rate of P into the plentiful fine roots (and the mycorrhizae hyphae) which permeate the lower mulch layers.
* The application of fertilizer only to the surface minimizes its contact with the mineral soil. In this way fixation is largely avoided. The result is that more phosphorus remains soluble and hence available to plants.

Minimizing the contact of the fertilizer with the mineral soil is of far greater importance in tropical locations, with their iron-rich soils, than in temperate regions. The greater efficiency of P fertilizers when combined with mulch is likely to be enhanced in the tropics. By applying P fertilizer over mulch, WILLSON (1972) achieved a 40% improvement in the uptake of P by tea plants.

Reducing erosion also has an impact on the nutrient status of a site. In Chinchina, Colombia, on fallows which succeeded 2 years of maize cropping, a loss of 440 kg/ha of N, P, K, Ca and Mg was measured with the first year of erosion (SUAREZ de CASTRO and RODRIGUEZ-GRANDES 1962, cited in LAMPRECHT 1973).

ROOSE (1981) reports that 90 t of soil erosion on a maize field in Adiopodoué, Côte d'Ivoire, meant an annual loss of 143 kg N, 29 kg P, 47 kg Ca, 20 kg Mg, and 43 kg K. Surface runoff was responsible for an additional loss of 39, 3.4, 23, 15 and 10 kg/ha respectively (9 years of measurement).

Finally, mulch offers an almost perfect means of protecting and improving the soil without the competition for growth factors which is unavoidable with live plants.

5.3.7 Soil life

There is no doubt that mulch has a positive effect on soil life. Mulch provides nutrients and energy to soil organisms, which develop extremely well under aerobic surface conditions that resemble those of the tropical rain forest.

The more stable temperatures under mulch help foster life in the soil, as do the relatively moist conditions and shade. These affect both the microfauna (fungi, bacteria, etc) and the mesofauna (beetles, earthworms, etc). PEREIRA and JONES (1954) saw the increased activity of soil organisms as welcome "tillage" assistance, promoting good tilth, porosity and building materials for plants.[97]

Table 5.14. Effect of mulch on earthworm activity in a maize field

Treatment	Casts/m²*	Equivalent weight (t/ha)
Total mulch cover	568	127
Mulch between the rows	264	59
No mulch	56	13

* 8 weeks after mulching
Source: LAL (1975)

[97] The use of pesticides can damage soil life (IITA 1981). Pesticides must therefore be selected with care, or else not used at all (FUKUOKA 1978).

In the forest and moist savanna zones, earthworms benefit considerably from mulch. Under mulch with minimum tillage, ROCKWOOD and LAL (1974) observed earthworm activity that approached that of a natural bush fallow. With 2400 renal casts per square meter, the activity under mulch was 24 times higher than on plowed land without mulch. Table 5.14. shows the influence of mulch on earthworm activity in western Nigeria.

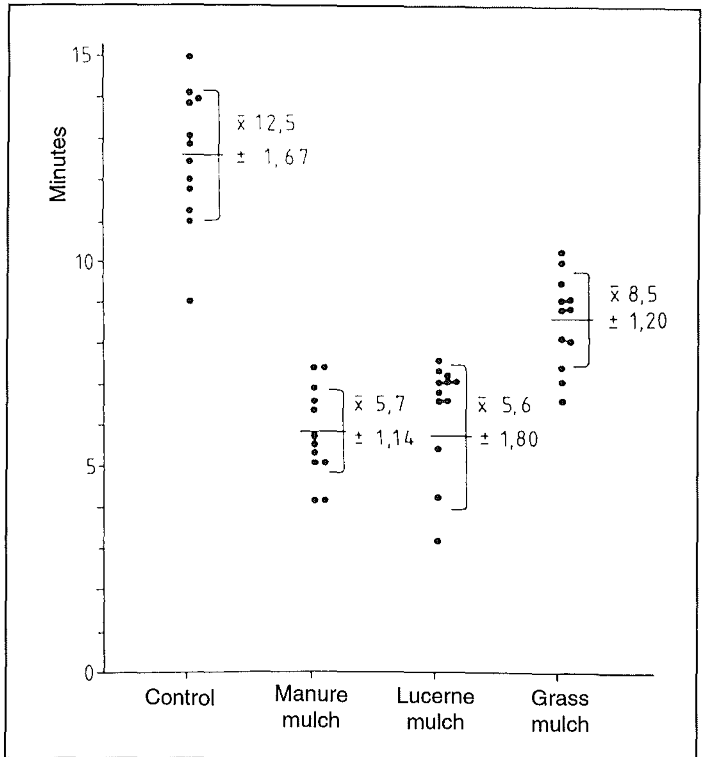
GRAFF and MAKESCHIN (1979) provide a good overview of the activity and importance of soil organisms and call attention to the value of soil life with regard to the energy and nutrient dynamics of ecosystems.

Through the uptake of compounds rich in nutrients and energy into the metabolism of soil organisms, many materials that would otherwise be swiftly broken down and mineralized are reclaimed, reused, structured, conserved and passed on to other organisms, so that their mineralization is more gradual. This interaction of life cycles, which slows down the turnover of energy and nutrients in the ecosystem, is also known as "recuperation" and is a vital function of soil organisms. It is especially important in the tropics, where the conversion and release of nutrients is particularly rapid. Without this recuperation mechanism, the through-flow of energy and nutrients is swift and losses (e.g. through leaching) are high.

In semi-arid regions too, mulching can considerably stimulate soil organisms. In northern Iran, earthworm activity in fruit plantations was increased by two to four times through the use of mulch, bringing a marked improvement in the ability of the soil to absorb the water from the infrequent but violent downpours (Figure 5.12).

In the savanna, termites especially are encouraged by mulching. They too help to improve soil structure. In addition, they bring K-rich material from the soil substrata up to the surface, thereby ensuring good tilth and nutrient balance. Termite hills are richer in C, Ca, Mg and K, but the nutrients are fixed, often becoming available again only 80 years later (GRAFF and MAKESCHIN 1979, WEBSTER and WILSON 1980, IITA 1981).

Figure 5.12. Influence of mulching on the infiltration time of water on a fruit plantation in northern Iran



* 3 liters water in a pipe 20 cm in diameter

Source: FALLAHI (1978), cited in GRAFF and MAKESCHIN (1979)

Despite these important benefits, termite hills are often burned with the crop residues at the end of the dry season to prevent their too rapid increase near human settlements (BALASUBRAMANIAN and NNADI 1980).

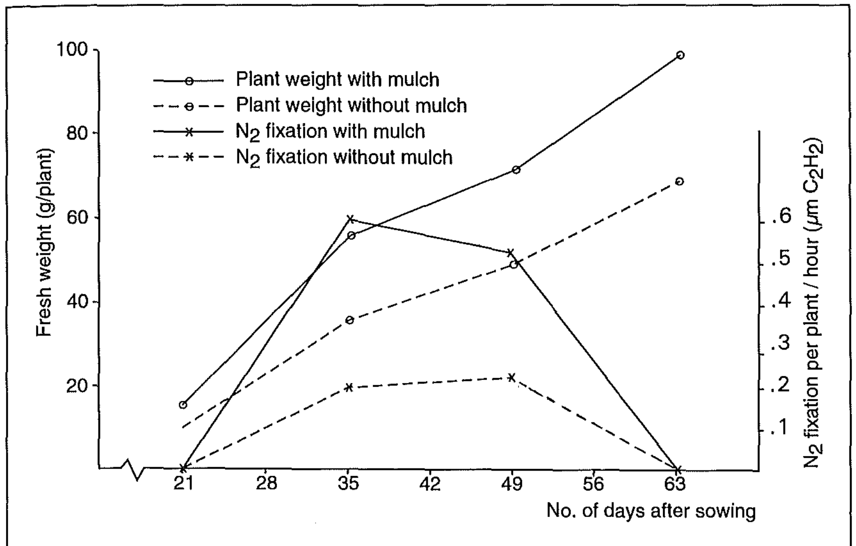
The stimulation of soil life also affects rhizobia. Numerous experiments (REYNOLDS 1975, AYANABA and OKIGBO 1975, GRAHAM 1981) in the tropics have shown that mulching improves yields of legumes such as phaseolus beans through increased

nitrogen fixation. The stabilizing effects of mulch on soil temperature and moisture appear to be the main factors at work here.

Applying 4 cm of rice husk mulch to phaseolus beans, WATERS et al. (1980) achieved a marked increase in N_2 fixation and the fresh weight of bean plants in Cali, Colombia (Figure 5.13).

Free-living N_2-fixing bacteria can also be stimulated by mulching. Rice straw mulch (10 t/ha) rotted by flooding for 50 days before the new rice crop was planted increased nitrogen fixation by 32% (RAMASWAMI 1979). (See Chapter 8 for further information on the promotion of natural symbionts.)

Figure 5.13. Effect of rice husk mulch on the fresh weight of beans and on N_2 fixation through rhizobia, Cali, Colombia*



* 1000 m elevation, 1100 mm rainfall, 24°C annual mean.

Source: WATERS et al. (1980)

5.3.8 Weed control

It is generally known that mulch can suppress or at least check weed growth (LAL 1975, WEBSTER and WILSON 1980). In addition to blocking light, mulch increases the biological activity to which the weed seeds are exposed. Moreover, with no intensive mixing and turning of the soil (minimum tillage with mulch), fewer seeds are stimulated to germinate. Table 5.15 shows that the effect of mulch is considerable. However, it also makes it clear that total weed control cannot be expected.

Table 5.15. Effects of mulch on weed control in maize, moist savanna region, Nigeria

Treatment	Weed growth (kg/200 m²)	
	1st season, after 4 weeks	2nd season, after 8 weeks
Rice straw mulch	0.5	15.0
Forest litter mulch	0.5	13.0
Control (no mulch)	20	46.0
LSD (0.05)		9.0
Source: LAL (1975)		

PEREIRA and JONES (1954) point out that mechanical weeding is often difficult when partially decayed mulch is present. For this reason they suggest a combined application of mulch and herbicides. This approach was quite widely taken up in the 1960s and '70s, leading to the well-known "mulch-tillage" method in which weeds are killed by spraying (usually with 2.5 liters Paraquat/ha) and if necessary cut for mulch 2-3 days before the crop is sown. According to ROCKWOOD and LAL (1974), given sufficient coverage by mulch, hoeing 2-3 weeks after sowing is quite enough to control weed growth.

Research by WIJEWARDENE and WEERAKOON (1982) in Sri Lanka confirmed that combining herbicides with minimum tillage and mulch provides more effective weed control and better soil protection than conventional cultivation, with or without herbicide use. Moreover, it has no negative impact on yields (rather the reverse). Nevertheless, this method should be regarded with strong reservations. It is expensive for smallholders (LAL 1975), and it leads to increased dependence for developing countries on external inputs (WIJEWARDENE and WEERAKOON 1982). More importantly, the long-term environmental effects of most herbicides must be regarded with mistrust. WEGMANN (1977) reported that Paraquat, for instance, accumulates in the soil, blocking sorption bodies. Hence it must be considered a danger to our ecosystem, for its toxicity is extremely high.

Developing mulching techniques so that weed control can be achieved without the use of herbicides thus appears imperative. Table 5.16 presents findings on weed control from Sri Lanka.

Table 5.16. Effect of mulching with rice straw on the yield of *Vigna unguiculata* and on weed growth, Sri Lanka

Treatment	Cowpea yields (kg/ha)	Weeds (DM) (g/m)
No mulch	362	14.3
Mulch 4 t/ha	491	11.1
Mulch 8 t/ha	625	8.5
LSD (p = 0.05)	65	5.4
Source: WIJEWARDENE and WEERAKOON (1982)		

Applying a mulch of 4 cm of either grass, groundnut shells or maize stalks, QUINN (1975) was able to reduce the labor expended on weed control in tomato by 31%, 37% and 14% respectively. Maize stalks were least effective because they are bulky, impeding weeding with a hoe, so that it was sometimes necessary to pull weeds by hand.

In Tanzania, THOMAS (1975) managed to reduce the labor required for weed control significantly by using various mulches. With a 5 cm cover of sawdust, only two light weeding operations were necessary over a 10-month period; with 5 cm coconut leaves (which were stripped of the heaviest stems to make weeding easier), three weedings were needed, while five were necessary on the control plot.

These examples demonstrate that mulch can have a considerable effect on weed infestation. But there is also evidence to the contrary. Ten tonnes of maize straw mulch per hectare made little appreciable difference, according to IITA (1981). Where not enough material is available for reasonably complete ground coverage, it may be better to mulch every second row, so that weeds are effectively suppressed in one row and hoeing is not hindered in the row without mulch.

NOGUEIRA et al. (1973) advise that mulch materials brought from elsewhere should be as free as possible from weed seeds. In areas with sufficient rainfall, the use of ground cover plants (live mulch) rather than mulch may be more suitable under some conditions.

Table 5.17. shows the effects on weed growth of alley cropping with *Leucaena*, which was used as a mulch for maize and cowpea.

5.3.9 Effects of mulch on diseases and pests

There is no cultivation method of which we can say absolutely that it prevents or encourages destructive agents. This is because both effects appear side-by-side, and the reduction of one disease or pest is sooner or later linked to the promotion of another. The question, then, is not whether mulch constitutes a means of combating pests, but rather what effect it has on what pests and crops under what conditions?

The first step in answering this question is to review the effects of mulching on site conditions. The second is to consider how modified site conditions are likely to affect the incidence of specific pests and diseases.

Table 5.17. Dry weight of weeds in maize and cowpea under alley cropping and open field cropping

	Weight of weeds (g/m^2)	
Treatment	Maize	Cowpea
Open field cropping (without mulch)	96 (579)*	123 (499)*
Alley cropping (*Leucaena* rows 2 m apart)	19 (728)*	17 (424)*
Weed suppression (%)	80	86

* Figures in parentheses are the yields (kg/ha) of maize and cowpea. Their relatively low values reflect an extremely dry growing period.

Source: WIJEWARDENE and WEERAKOON (1982)

The effects of mulch on site conditions include modifying soil temperature, maintaining a moist soil surface, preventing plant leaves from contacting the soil, protecting against splash impact on wet soil, improving water relations, influencing the microclimate of the soil, and altering the color of the surface.

If soil life is diverse and active, numerous interactions take place between the soil organisms. These keep each other under control through competition and antibiosis. The chances of mass outbreaks by one particular soil-borne disease agent are thus far smaller.

Disease forms that can survive long periods of adverse conditions, such as sclerotium from *Phymatotrichum* (root rot in cotton), can be induced to germinate in the absence of a host through the presence of organic matter - after which they die. In biologically active soil, pests are subject to increased attack by other organisms during their dormant periods, thus diminishing their survival rate. Finally, mulch favors the development of soil organic matter which, with few exceptions, promotes plant health (ALLISON 1973).

A few specific consequences of mulching with harvest residues are known. Government regulations prescribing the removal of cotton stalks are perhaps the best-known example of pest control by means of destroying crop residues. Such regulations are usually made with extensive monoculture or permanent single-crop plantations in mind (FRANKE 1980). These farming systems are highly susceptible to mass infestation by pests and diseases and should be avoided.

However, stem borers in maize, sugar cane, or sorghum (*Chilo* sp., *Ostrinia* sp., *Diatrea* sp., etc) are also a problem on small farms. They pupate in the stems of the host plant and can easily infest new stands when crop residues remain on the fields as coarse mulch cover (KRANZ et al. 1979).

Plowing in, grazing down, composting or fine chopping residues can significantly reduce infestation. Burning should always be avoided if possible, so as to maintain fertility by returning organic matter to the soil.

Whether major infestations of insects can be countered in the long term through the use of mulch to increase the population of parasites and predators greatly depends on the type of cropping system, the other plant protection measures used, and other influences. In trials in Mexico, mulch on maize induced neither an increase nor a decrease in pests (VIOLIC et al. 1982). A successful example of the use of crop residues for this purpose is the two-step crop succession from Japan. By alternating rice and rye straw mulch on rye and rice crops, FUKUOKA (1978) was able to create a stable agro-ecosystem and control the incidence of major diseases (e.g. *Pyricularia orizae*) and pests (e.g. cicadas).

In southern Brazil, mulch from rice husks and grass triggered an increase in pest activity. In combination with plant protection measures, however, yields were significantly higher than without mulch (NOGUEIRA et al. 1973). In contrast, the occurrence of cicadas (*Empoasca* sp.) in Puerto Rico was reduced through the use of mulch with silver sheeting and sugar cane straw. Mulching with sugar cane straw produced yields that equalled those obtained with "clean-weeding" plus insecticides (CRUZ 1981).

Variable effects on coffee plantations have been noted. In Kenya, infestation by leaf miner moths (*Leucoptera meyrinckii* and *Leucoptera coffeina*) increased following the introduction of mulching techniques. The authors attributed this to the fact that warm dry soil, where larvae can dry out, is absent when mulch is used (LEE and WOOD 1971, cited in TÜRKE 1976).

LE PELLEY (1968, cited in TÜRKE 1976) confirmed this finding, but also found that the damage from *Diarthrothrips coffeae* is reduced through the use of mulch and the cool moist conditions it provides. ACKLAND (1971, cited in VAN RIJN 1982) points out that coffee plants suffer less moisture stress under mulch and are therefore less susceptible to pests and diseases. The same author also reports that banana leaf mulch used on banana trees deters attack by the banana root borer *Cosmopolites sordidus*.

Mulching with *Eupatorium odoratum* on pepper plants (20 t fresh weight/ha), LITZENBERGER and HO (1961), working in Cambodia, had good results in combating nematodes (*Heterodera marioni*) and their attendant infections (e.g. *Phytium complectans*).

Another trial, with *Eupatorium* in Nigeria (IITA 1982), substantiates these findings. The nematicidal effect of mulch materials also seems to have made a considerable contribution here: the banana yield after four growing periods with mulch (40 t fresh weight/ha) was four times higher than without mulch (see Table 5.20).

In parts of Asia, as well as in other regions, mulch can aggravate infestation by rats and mice because it provides them with a nesting place. This problem is addressed by BHARDWAJ (1981), and by BALASUBRAMANIAN and NNADI (1980).

Mulching is sometimes rejected by farmers in the subhumid regions of Africa because it can cause a drastic increase in termites, which are then likely to shift their attack to other crops, including coffee plants. In addition, snails can multiply rapidly under mulch. Farmers can either experiment with different forms of mulch or else stop using mulch altogether and fight the problem by other means (e.g. snail predators).

Mulching is a traditional practice when growing certain vegetables. In East Kalimantan, for example, mulches are used on maize, stringbean, Chinese mustard, pumpkin and squash, but not on aubergines, red peppers and cassava (SCHUBERT et al. 1982).

In Samaru, Nigeria, the yield of marketable tomatoes (bush type) was improved by using around 4 cm of grass or maize mulch (see Table 5.22), which contributed to a decline in the incidence of *Sclerotium rolfsii* and other diseases (QUINN 1975). ODEBUMNI (1979), on the other hand, discovered an increase in fungal disease following the application of mulch.

By applying mulch to garden beans (especially with coconut palm fronds; 2-4 cm cover), REYNOLDS (1975), working in Western Samoa, was able to decrease the incidence of *Sclerotium rolfsii* during the rainy period, achieving up to 365% higher yields. This disease occurred less frequently in the dry season and was no longer the most decisive factor affecting yields. However, during this season yields were still higher when mulch was used, since the lower soil temperature stimulated improved germination and rhizobium activity.

In Malawi, mulching aggravated outbreaks of collar rot disease (caused by *Fusarium stilboides*) in arabica coffee (SIDDIQUI and CORBET 1965, cited by TÜRKE 1976). The authors recommended that mulch should not be spread right up to the stem: an area round the stem should be left bare to discourage the disease.

In contrast, FEAKIN (1972, cited in TÜRKE 1976) found that attacks of Panama disease (*Fusarium oxysporum*) in bananas could be reduced by mulching with sugar cane trash. Because of the mulch, extreme fluctuations in moisture conditions, which favor the disease, were avoided. In nursery beds for cocoa plants, URQUART (1955, cited in TÜRKE 1976) found that mulch was effective in controlling the incidence of *Colletotrichum*, because it prevented spores on the ground from being splashed up onto the leaves.

Interesting results were obtained by WEINKE (1962) in mulch trials with beans *(Phaseolus vulgaris)*. Through mulching with grain straw, sawdust and other materials

rich in carbon, nitrogen was immobilized in the hypocotyl region of the bean stems. When concentrated in the hypocotyl area, nitrogen encourages infection by *Fusarium solani*. Nitrogen in the deeper soil layers had no influence on the course of the disease. In other words, the disease can be countered by mulching with materials having a relatively high C/N ratio.

In summary, the innovative use of mulch, despite its manifold benefits, can be attended by failures as well as success. Traditional reservations regarding its use should therefore always be treated seriously and investigated. Observing the following principles can help to avoid trouble:

* Studying the biology and population dynamics of pests usually provides good indications of the effect that mulching might have on their incidence.

* Mulch materials should be checked for commercially relevant pests and diseases in order to avoid spreading these to new stands.

* Depending on the length of the rainy period, mulch materials can have widely different effects, for example on the occurrence of fungal diseases.

* Success or failure can depend critically on the choice of material. For this reason, several materials should be tried.

* The way mulch is applied can be decisive (in, and/or between the rows).

* Each site is different. For instance, in hot areas, germination is encouraged by mulch, decreasing the risk of diseases. In cooler mountainous regions, on the other hand, mulch may delay warming in the morning hours, producing the reverse effect.

Finally, in considering the relationship between mulch and the incidence of pests and diseases, it is not enough simply to count disease symptoms or pests. Since mulching improves soil physical and chemical properties, it also strengthens the crop plant and thus enhances its resistance to or tolerance of pathogens. It is quite possible for crops to produce higher yields despite higher pest infestation. In other words, the positive effects of mulching can more than compensate for increased attacks by pests or diseases.

5.3.10 Effects on yields

In general, mulch has a positive effect on yields. However, negative effects are reported from areas with cooler seasons or times of the day (e.g. the higher Andes, southern Brazil, monsoon Asia), due to delayed ground warming.
Higher yields cannot always be expected from mulching when this is combined with minimum tillage because, after plant species or variety, the soil has a profound influence on yield. Hence the good results achieved by SANCHEZ and SALINAS (1981) with this practice in Africa were not always reproducible in South America because there yields are limited more by soil chemical than by soil physical factors.

This section summarizes a number of experiments, providing an overview of the extent to which mulch can be expected to influence yields.

The most dramatic effect on yields demonstrated so far is on coffee. In trials by PEREIRA and JONES (1954) in Kenya, coffee yields were doubled - in the dry year of 1950 as well as in the wet year of 1951 - through the application of a total mulch cover consisting of 10 cm of elephant grass. Mulching every second row produced a yield increase of some 50% (see Table 5.18).

FRANKE (1980) cites results from COSTE (1965) in Kenya, who reported yield increases of three to six times over the control, depending on variety. In trials by BOUHARMONT (1979) in Cameroon, mulch was grown in situ between the rows of coffee plants. This produced an average increase in yield of 14% in the 3 years after it was planted (50% in dry years). SANDERS (1953), in 10 years of trials, improved coffee yields by 50% by mulching with banana leaves (1 ha per ha coffee).

Table 5.18. Coffee yields (kg/ha) in response to grass mulch (10 cm), Kenya

Year	Rainfall (mm/yr)	Control (no mulch)	Mulch before rainy season: every row	Mulch before rainy season: every second row	Mulch after rainy season (total)
1950	610	95.4	190.8	136.8	89.1
1951	1372	854.9	1516.5	1328.2	1232.8

Source: PEREIRA and JONES (1954)

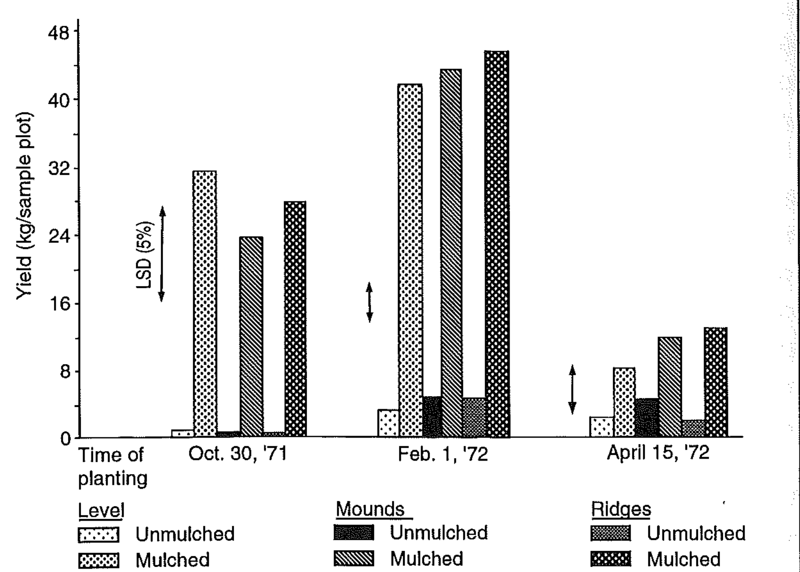
Most of the data on mulch use and annual crops pertain to maize. For example, LAL (1978) achieved 38, 10 and 22% higher yields in 3 consecutive years for maize under mulch. In other trials (LAL 1975) the increase was 20%.

In more recent experiments by MAURYA and LAL (1980), minimum tillage with mulch produced only slightly higher yields than conventional cultivation in normal years with sufficient rainfall. However, in dry years, considerably higher yields were achieved with mulch. These findings confirm those of ROCKWOOD and LAL (1974), in which mulch and zero tillage produced maize yields that at least equalled those obtained with conventional cultivation. The same was true for cowpea and pigeonpea. Soybean responded poorly to mulch and zero tillage.

With groundnuts on a semi-arid site in Senegal, CHOPART et al. (1979) increased yields by 24% using mulch. However, these results were obtained only when thorough weeding was carried out. Phaseolus beans also appear to respond well to mulch in the tropics. NOGUEIRA et al. (1973) increased bean yields in southern Brazil during the hot season using a mulch of grass and rice husks. In the cool, wet season, mulching had no significant effect. WATERS et al. (1980) confirmed the positive effect of mulch on beans. In trials at CIAT (Colombia), the vegetative mass (roots and shoots) in the mulched treatment (4 cm rice husks) was 50% greater than in the control. Owing to the onset of a dry period, there was no difference in final yields, however. REYNOLDS (1975), applying 2.5 cm of coconut leaf mulch, increased the yield of garden beans by 73-300%.

A positive response to mulching has also been found for tomato. In the dry savanna of Nigeria (700 mm/year; Luvisol; sandy-clayey loam) tomato responded to grass mulch with an increase in marketable yield of 20-40% (see Table 5.22).

Figure 5.14. Effects of bed preparation and mulching on the tuber yield of yams (*Dioscorea* sp.)



Source: LAL (1975)

Few findings are available on root and tuber crops. In India, TAMBURAJ et al. (1980, cited in VAN RIJN 1982) achieved a marked improvement in cassava yield with minimum tillage and mulch compared with conventional methods. LAL (1975) found that yams could be planted earlier with mulch and that very good yields were

then achieved, compared with an almost total crop failure without mulch. Yields with mulch were also significantly better when the crop was planted at the normal time (see Figure 5.14).

On an Ultisol in Yurimaguas, Peru, WADE (1978, cited in SANCHEZ and SALINAS 1981) mulched five crops with *Panicum maximum*. He obtained yields 64% of those obtained with optimal mineral fertilization. By mulching with *Pueraria phaseoloides* (kudzu), levels of 80% were achieved (see Table 5.19).

Table 5.19. Effects on five successive crops of mulching or incorporating green manure compared with yields from fertilized plots given in percent of crop yield under optimal mineral fertilization (= 100)

	1st crop (soybean)	2nd crop (cowpea)	3rd crop (maize)	4th crop (ground-nut)	5th crop (rice)	Average
Bare soil	9	59	33	55	64	44
Grass mulch	14	103	57	52	94	64
Grass, plowed in	33	90	70	69	94	71
Pueraria mulch	-	97	72	63	90	80
Pueraria, plowed in	109	77	88	79	99	90

Yields with optimal mineral fertilization were (kg/ha): soybean 1100, cowpea 740, maize 4170, groundnut 2880, rice 2740. All other treatments did not receive any mineral fertilizer.

Source: WADE, cited in SANCHEZ and SALINAS (1981)

As these numerous findings show, mulching has, with a few exceptions, a highly positive influence on crop yields. The findings also demonstrate the contribution of mulching to long-term yield stability, especially when combined with minimum tillage.

The system of banana cultivation (see above) described by BERTONI (1926) clearly demonstrates this long-term effect on yield stability. NYE and GREENLAND (1960) obtained similar results in Africa. While yields in a maize/cassava rotation with mineral fertilizer began to fall sharply after 8 years, they were maintained in mulched fields.

In trials carried out by IITA (1982), plantain groves that had received mineral fertilizer were unprofitable after 4 years. In contrast, when they were mulched with 40 t of fresh *Chromolaena odorata*, yield levels gradually increased. Yields from mulched areas were four times higher in the fourth trial year than those from areas with mineral fertilizer (see Table 5.20). Much of this increase may be attributed to the nematocidic properties of *C. odorata*.

Table 5.20. Effects of mulch (leaves and stems) from *Chromalaena odorata** or of mineral fertilizer on plantains (measured in fourth trial year)

	Mulch (40 t/ha/year)	Mineral fertilizer**
Yield (t/ha)	22.8	4.8
Bunch weight (kg)	11.8	8.1
Harvested plants (% of original stand)	116.0	36.0
Length of harvest (months)	10.0	6.0

* Formerly *Eupatorium odoratum*
** 300 kg N, 250 kg P_2O, 550 kg K_2O/ha/year

Source: IITA (1982)

Finally, FUKUOKA (1978) stressed that the effect of mulch can also depend on the variety of crop plant. Trials by MENEZES SOBRINHO et al. (1974) confirm this. In

experiments with garlic they found that two out of three varieties, "Amaranthe" and "Barbado", responded well to mulch, whereas the variety "Branco" showed no response. The effect of mulch on "Barbado" was superior to that of mineral fertilizer (see Table 5.21).

Table 5.21. Response of garlic varieties (*Allium sativum* L.) to mulch and to nitrogen fertilizer in Sete Lagoas (Minas Gerais), Brazil.*

		Yield of garlic in kg/ha	
Variety	N fertilizer (kg/ha)	With mulch	Without mulch
Branco	0	5980	5520
	500	6160	6320
Barbado	0	5710	2910
	500	6270	4140

* All treatments received a basic dressing

Source: MENEZES SOBRINHO et al. (1974)

5.4 Economics of mulching

Evaluating mulch for its cost-effectiveness is difficult because of the lack of data. It is useful first to define four different situations:

* The mulch material is produced in areas specially set aside for the purpose.
* Crop residues are utilized as mulch.
* The mulch material is a byproduct of or waste material from processing.
* The mulch material is grown with the crop in the same field without detracting from its yield (in situ mulch).

Growing mulch material on fields designated for this purpose means that these areas are not available for growing other crops. The opportunity costs depend on the crops that might have been grown instead.

As shown in Table 5.18, coffee yields can be virtually doubled by using mulch. In this case the decision in favor of mulch is simple, because it requires considerably less work and capital to grow a hectare of grass than to plant another hectare of coffee without mulch. The decision is more difficult when yields increase sharply with mulch but are not quite doubled. CLAYTON (1968, cited in TÜRKE 1976) describes such a case in Kenya. Here the gross income from mulched coffee was around US $ 4500, compared with only US $ 2540 from non-mulched coffee fields, a difference of US $ 1960. The cost of growing and applying the mulch was far less than US $ 1960, so that mulching would still appear to be highly cost-effective. However, if labor costs are ignored, coffee without mulch could be grown on the grassland instead of mulch.

In deciding whether to mulch or not, the farmer must now compare the opportunity costs of not growing 1 ha of unmulched coffee (that is, US $ 2540) with the additional profit obtained from 1 ha of coffee with mulch (US $ 1960). In this case, if there are no other constraints, the farmer must decide in favor of planting a second hectare of unmulched coffee.

LAL (1975) concludes that the production of mulch materials in specially designated areas is uneconomic for many annual crops, at least if benefits and costs are calculated in the short term, for a single growing season only. For crops that produce high marketable yields or where plenty of land is available, the lost alternative use of mulch-producing fields is not so important. Thus, applying mulch to tomato in Nigeria proved economically viable (QUINN 1975), whereas tying the tomato plants to support stakes, though it increased yields, required too much costly labor and was therefore uneconomical.

Even small mulch applications of some 4 cm produced a yield increase of over 40% (Table 5.22). The 31% decrease in the labor required for weed control is not included in this calculation.

Table 5.22. Yield of marketable tomatoes in response to mulching and staking in Samaru, Nigeria*

Grass mulch (4 cm)	Tied to stakes	Marketable yield (t/ha) (ave. 1968-70)	Additional labor required (person-days/ha)
-	-	23.02	0
Yes	-	33.62	160
-	Yes	33.92	247*
Yes	Yes	41.31	407*

* Fertilized experiment, fungicide used.

Source: QUINN (1975)

In Brazil, mulch on beans was also shown to be unprofitable when applied in years of poor rainfall (NOGUEIRA et al. 1973). Even in years with good rainfall distribution, the additional labor required for mulching was not cost-effective. In contrast, the use of *Eupatorium* mulch on plantains, described in Section 5.3.10 (Table 5.20), proved to be highly profitable under local conditions.

The economics look quite different when crop residues are used for mulching. In this situation the cost of the mulch material no longer includes the opportunity cost of extra mulch-growing land. Mulch use becomes economically viable if the additional benefit it brings is greater than the costs of transporting and spreading it, and if the benefit from using the residues as mulch is greater than alternative uses, such as livestock feed, fuel, or raw materials.

TÜRKE (1976) refers to trials carried out by KAMAARA and KIMEU (1973) in Kenya (Table 5.23). By mulching with maize straw, which is plentifully available in coffee-growing regions, they were able to increase coffee yields by 170 kg/ha at almost no extra cost. This considerably improved the profitability of growing maize.

Table 5.23. Returns to maize production (grain and mulch), Kenya

Inputs	Costs (US $)	Yields	Value (US $)
84 kg/ha P 135 kg/ha N	14.7	1. 45 sacks of maize each 1 US $	45.0
Seed	1.4	2. 170 kg of coffee each 0.17 US $	29.1
Soil cultivation	1.4		
Weed control	4.9		
Harvesting, handling, storage, transport	4.1		
Total	26.5		74.1

Source: KABAARA and KIMEU (1973), cited in TÜRKE (1976)

On a Fluvisol (pH 8.1) in India, returns to the use of rice straw mulch on wetland rice were high (RAMASWAMI 1979, see Table 5.24).

The mulch-tillage methods being developed for the tropics in Nigeria and Sri Lanka can be classed as mulching techniques with crop residues. In combination with herbicides, these methods reduced the costs of maize production by 50% over conventional plowing (WIJEWARDENE and WEERAKOON 1982). These results were confirmed in trials by the Centro Internacional de Mejoramiento de Maís y Trigo (CIMMYT) (VIOLIC et al. 1982). Combining mulching with herbicide use is unsatisfactory from an environmental viewpoint, however. Such methods should be replaced with ones that eliminate herbicides altogether, and these should then be assessed for their economic viability.

Table 5.24. Economic viability and effect of straw mulch on the yield of organic matter, grain and straw, and on biological nitrogen fixation in wetland rice

Treatment	A	B	C	D	E	F	G
Control	1.55	17.4	4194	7083	-	-	281
N, P_2O_5, K_2O 180-90-90	1.58	12.3	4520	8500	1530	2.95	271
10 t/ha mulch	1.59	12.3	4600	7500	600	7.67	373
10 t/ha mulch + 90 kg superphosphate	1.47	11.4	4667	7200	1191	3.92	370
15 t/ha mulch	1.53	12.0	4495	6466	900	4.99	326
15 t/ha mulch + 90 kg superphosphate	1.55	11.9	4733	8533	1491	3.18	380

A Organic C (%)
B C/N ratio
C Yield (kg/ha)
D Straw yield in (kg/ha)
E Cost of straw and mineral fertilizer (rupees), 1977
F Yield in kg per rupee spent
G Nitrogen fixation (kg/ha)

Source: RAMASWAMI (1979)

A fundamental prerequisite for mulching with crop residues is high biomass production in the field. The choice of rotation, variety and crop mixture must be made with this in mind. Where this is not possible, it may still be feasible to obtain mulch material from local processing operations (e.g. sugar cane residues, rice husks, cottonseed or oil cake, groundnut shells, etc). Since these products are refuse by nature, their use incurs only the minor cost of spreading them on the fields, and transport costs, depending on distance.

Finally there is the option of growing mulch material on the same field together with the crop itself. Provided there is no reduction in main crop yields, this method is most attractive, for it requires far less labor than does bringing mulch material from elsewhere. In experiments by BOUHARMONT (1979), the savings in labor were 20-

40%, just for spreading mulch on the field. WALLIS 1964 (cited in TÜRKE 1976) reports even more attractive savings from Kenya, where carting in the mulch comprised about 60% of the cost of mulching coffee.

On coffee plantations in Cameroon (1100 m a.s.l.; ca. 1650 mm/yr, 3-4 arid months), BOUHARMONT (1979) grew mulch between the rows of coffee plants, while at the same time suppressing weed growth using *Flemingia congesta*, a legume which uses relatively little water and is drought resistant. The coffee yield did not suffer.

Table 5.25 compares the labor requirement for different methods of growing coffee with mulch. *Mimosa*, *Pueraria* and *Stylosanthes* were not suited to this location because of their high water requirement and poor weed suppression. Mulching with *Flemingia congesta* grown "in situ", though demanding 30-40% more labor in the first year, required about 40% less labor in the second and third years, compared with the control, in which coffee was grown with no ground cover[98].

Since soil tillage was omitted (which is appropriate for young plants anyway), the labor required for the *Flemingia* method was only marginally higher and produced a yield increase of more than 14% during the early growth stage of the coffee plant.

In the above calculations, only short-term and immediate effects were considered as these are easy to assess. The other effects of mulching, such as nutrient breakdown or nitrogen fixation by legumes, were not taken into account. Soil protection and erosion control are also difficult to assess in monetary terms, although they are of vital importance, and they too were omitted from the calculations.

ROOSE (1981) points out that the capital often invested in anti-erosion structures and terracing in areas with slopes of up to 20-25% could in many cases be saved by applying mulching techniques. EDWARDS (1979), in Kenya, calculated that the costs of losing 1 ha of fertile soil equal those of bringing 4 ha of moderately fertile land under cultivation (if such land still exists).

[98] In the former method, *Flemingia* is lopped and mulched several times a year; the fields without ground cover and mulch are lightly tilled once a year.

Stable yields and the long-term maintenance of soil productivity are effects of mulch use that are seldom taken into account in cost-benefit analyses.

Table 5.25. Labor requirement (person-hours) for different coffee-growing methods (with mulch-producing ground cover plants, with mulch brought in from elsewhere, and with no ground cover) during the first 3 years in Cameroon*

Treatment[1]	*Pueraria* GC/ mulch	*Mimosa* GC/ mulch	*Stylo.* GC/ mulch	*Flemingia* GC/ mulch	Mulch from other areas	Control without mulch
1st year sowing[2]	9	9	9	28	-	-
Tending	36	36	36	66	30	30
Lopping and mulching	8	18	18	14	20[3]	-
Tilling	-	-	-	-	50	50[4]
Total	53	63	63	108	100[3]	80
2nd + 3rd year sowing	-	9	-	-	-	-
Tending	36	36	40	13	33	40
Lopping and mulching	12	12	12	40	23[3]	-
Tilling	-	-	-	-	50	50[4]
Total	48	57	52	53	106	90

* Ca. 1650 mm/yr, 3-4 arid months, 1100 m a.s.l.
1) GC/mulch means that the ground cover crop is sown under the coffee and is then cut and spread within the rows.
2) Not counting the work of preparing the seedbed.
3) Not counting the labor of transporting the mulch from its source to the field.
4) Some tilling of the soil is usually necessary in the early growth stages of the coffee plants.

Source: BOUHARMONT (1979)

In conclusion, no economic assessment of mulching is of general validity. Cost-effectiveness can only be judged case by case, for it depends on the mulching method used and on local cost ratios. Low production costs, low transport costs and well organized operations are the most important points to be observed if mulching techniques are to be profitable. Methods with high labor costs are, as a rule, only viable for the intensive cultivation of market crops.

5.5 Use of mulch in a zonal context

In the **permanently humid tropical forest regions** - and to some extent also in the semi-evergreen zones - using ground-cover plants (live mulch) may be more suitable than applying mulch.

AYANABA and OKIGBO (1975), however, stress that excellent results have often been achieved using mulch in just such climates, because mulch cushions the impact of the irregular dry spells that are especially detrimental to yields when they occur during critical periods of plant growth.

LINDE (1982) found in Yurimaguas, Peru (on an Ultisol) that live mulch had a negative effect on soil moisture availability for growing crops.

Grasses are very suitable as mulch material in these zones as they are available all year round. However, as the work of many authors shows, excellent results can also be achieved with other plants, such as *Pueraria phaseoloides* or *Eupatorium odoratum*, or with mulch materials from trees, such as *Leucaena*. It has also been shown that mulching with pineapple or maize residues decreases erosion.

Dominant in these zones are soils with stable structure, rich in clay and having a relatively high organic matter content. On such soils, good results can be expected from using mulch in combination with minimum tillage. Occasionally, on poorly drained soils, negative effects have resulted from the use of mulch, due to waterlogging. Findings by THOMAS (1975) show that if rainfall is abundant it may be better to use a mulch material that lies somewhat loosely, so as to allow gas exchange.

Using mulch to cover and shade the soil stabilizes soil conditions so that these closely resemble conditions under natural forest. Its beneficial effect on soil life in general and on the micro-organisms which we know of today, such as rhizobia and mycorrhizae, has been demonstrated many times (see Chapter 8).

Most of the experimental results on mulch focus on its use in **subhumid savanna climates**. Here it is only in very rare cases (where the water-holding capacity of the soil is high or at higher elevations where evaporation is less) that live ground-cover plants are appropriate as a means of protecting the soil and maintaining its fertility.

Ground-cover plants reduce yields by competing with the main crop for water. Although this effect can be offset to some extent by cutting and mulching the vegetative matter, methods using live ground-cover plants or undersowing are still risky in the savanna.

In contrast, integrating trees or shrubs such as *Leucaena* and *Tephrosia* with the cropping system appears a better option as these do not compete so strongly with annual crop plants, and mulch from their leaves often has a positive influence on yields, as experiments by IITA and others have demonstrated.

Humus decomposition, which is accelerated by the alternation between wet and dry conditions in subhumid climates (JAGNOW 1967), can be slowed down through the use of mulch. Overheating of the upper soil can also be avoided with mulch, as can rapid injury to and compaction of the soil structure near the surface, caused by the first heavy rains falling on recently plowed, unprotected fields.

In areas with bimodal rainfall, mulch is especially helpful in the short rains, which are often unreliable. In the longer rainy season, yields with and without mulch are often similar, but mulch still affords much needed protection against erosion during this season.

On soils that are already severely degraded and compacted, mulch cannot realize its full potential benefit, especially if the soil is not tilled. Such soils should be prepared for use by first placing them under 1 to 3 years of bush fallow or other vegetation. Soil physical properties and biological activity can be improved rapidly in this way.

It is important that mulch be applied at the beginning (not at the end) of the rainy season in this zone, as soil organisms are at their most active during the rains.

In the semi-arid regions and dry savannas, water becomes the main factor limiting yields. The soils in these zones, usually very poor in carbon and with a high content of poor clay and fine sand, are at high risk from erosion. Under such conditions, it is especially important to a) improve the infiltration of rainwater, and b) minimize unproductive water loss. Mulching contributes towards both these aims and is an appropriate means of improving water use efficiency.

Whether tillage can be dispensed with or not is still very much disputed. Maintaining soil structure by means of mulching alone may be very difficult, however. This is because "plowing" in a mulch zero-tillage system is carried out primarily by soil organisms, which, in the dry savanna regions, are active for a relatively short time.

On tilled soils, mulch can help maintain the structure of a plowed furrow, which otherwise may be destroyed by early rainfall. Independent of the method of cultivation, mulching in dry savanna areas helps improve the water economy and the structure of the soil, because it reduces surface runoff, the erosion of fine particles and the unproductive evaporation of soil water.

Whether it is possible to obtain enough mulch material depends on local conditions and the cropping system. If crop residues are fed to livestock or are used in some other way, the alternative of mulching with this material will not be very attractive. However, residues and natural vegetation should not be burned.

The use of mulch in **mountainous regions** is especially appropriate because of its efficacy in reducing erosion. Only in areas near the upper limits for cropping may it be better to avoid mulching, so as not to interfere with the warming of the soil that must take place each day. The color of the mulch material can play a role here: dark materials warm up more quickly. According to WIJEWARDENE (no date), working in Sri Lanka, *Robenia* proved a useful tree crop for the production of mulch material at tropical altitudes of 1000-3000 m.

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