5. Mulch and its application

5.1 Definition

"Mulching" is a crop husbandry practice in which organic (or inorganic) material is spread over the soil surface to influence the physical, chemical and biological properties of the soil and its micro-climate with the aim of improving the productivity of a site.

The following discussion is based on this definition and purposely avoids using the term "mulch" in any broader sense, as this often leads to confusion. A clear distinction should be made between mulch as defined above, and "live mulch", which is the sowing of soil-covering plants under another crop. For this, terms such as "undersowing", "cover cropping" or "mixed cropping with ground-cover plants" are more appropriate.

The "turning under" or incorporation of green plant matter or crop residues is also often called mulching, although "surface, shallow or deep incorporation" would more accurately describe what is meant. This practice should really be called straw manuring or green manuring, depending on the age of the plant materials being incorporated. Green manuring is described in Chapter 4.

5.2 Principles of mulching

5.2.1 Mulch materials

The choice of mulching materials is usually determined to some extent by local availability, as transporting materials from elsewhere is generally not practicable, except perhaps for intensive cultivation or in the vicinity of markets (see LAL 1975). Crop residues and weeds are the most economic sources of mulch material. Other sources include hedges, trees, anti-erosion belts, fallows, non-arable land, and waste from mills, local factories and canneries. Use of residues from the latter even make it possible to return "exported" nutrients to the land.

If enough land is available, it may be worthwhile to grow mulch material on areas especially set aside for this purpose. For example, mulch crops for coffee include Guinea grass (*Panicum maximum*), Guatemala grass (*Tripsacum laxum*) and elephant grass (*Pennisetum purpureum*).

Organic materials are preferable to other mulches such as plastic sheeting, because they not only encourage soil life but are also a long-term source of energy and nutrients.

The color of mulch material can influence the behavior of pests (IRRI 1974, KRANZ et al. 1979, CRUZ 1981), but its greatest effect is on soil temperature. Dark materials warm up faster than light ones. The latter act better as an insulator, reflecting radiation, which may pass upwards onto the leaves of the crop plants.

The C/N ratio of mulch materials (see also Table 6.1 in Chapter 6, on compost) has an effect on the rate of decomposition. Materials with a low C/N ratio decay relatively quickly. Thus a layer of green grass cuttings may be fully decayed in 2 to 3 months, while straw-like materials and banana-leaf mulch will provide good soil cover for up to 6 months (SANDERS 1953, etc).

JAGNOW (1967) therefore recommends that, for the most part, materials having a high C/N ratio should used in the humid tropics. However, a thicker layer or repeated applications (if technically possible) can also ensure permanent ground cover. If the materials decay more slowly than is desirable, leguminous litter or dung can be applied to promote fermentation and N-exchange and thereby hasten decomposition. FUKUOKA (1978) describes this practice in a farming system with rice straw mulch (see below). Experiments in Rwanda showed that mulch breaks down more rapidly on open fields than on partially shaded land (NEUMANN, personal communication).

The physical structure of the materials essentially determines their effect. Whether loose, bulky materials or fine, dense ones are more appropriate depends on the

objective: controlling erosion, stabilizing soil temperature, promoting infiltration, reducing evaporation, etc).

Under very humid conditions and on soils with poor aeration, the use of relatively loose materials is generally preferable to ensure adequate ventilation. In Africa, mulch experiments on seed-plots for coconut plantations showed that a 5 cm covering of sawdust worked better than a comparable layer of coconut leaf mulch under conditions of 1300 mm annual rainfall. In India, on the other hand, under 3000 mm annual rainfall, the coconut leaf mulch proved more successful. It allowed better air access, while the less effective protection against evaporation afforded by this mulch was of less importance here (THOMAS 1975).

Very bulky materials should either be hacked to pieces first or else not used at all. The thick lamina from coconut leaves, tough maize stalks and large branches can obstruct subsequent farming operations such as plowing, weeding or planting (QUINN 1975, REYNOLDS 1975). Very light mulch materials such as groundnut shells may be washed off sloping fields or from raised beds by heavy rains (QUINN 1975). When they become dry, large leaves such as banana leaves can easily be blown away by the wind (LINDE 1982).

Whenever possible, mulch material grown on non-arable land or fallows should first be shaken vigorously or threshed so as not to carry more weed seed than necessary onto the cropland (NOGUEIRA et al. 1973).[81] LINDE (1982), in his investigations in lowland Peru, found that sawdust and bark mulch sometimes contain phytotoxic substances. Some weeds are also known to have phytotoxic effects. EUSSEN and SLAMET (1973) mention guaco (*Micania micrantha* Knuth.) in this connection.

Other weeds, however, have highly positive mulching characteristics, such as for example *Eupatorium odoratum*[82] (IITA 1982, LITZENBERGER and HO 1961).

---

[81] In practice, this is difficult if large areas are involved.

[82] Extreme caution must be observed with this Composite in regions where *Eupatorium* does not occur naturally, as it can rapidly spread out of control.

Familiar with local conditions, farmers are usually well aware of the advantages and disadvantages of different weed plants. Algae and aquatic weeds may also be useful as a mulch. For example, they are widely used on the island of Chiloe in Chile (SARPI and ETSCHEVERS 1975).

5.2.2 Minimum depth of mulch cover

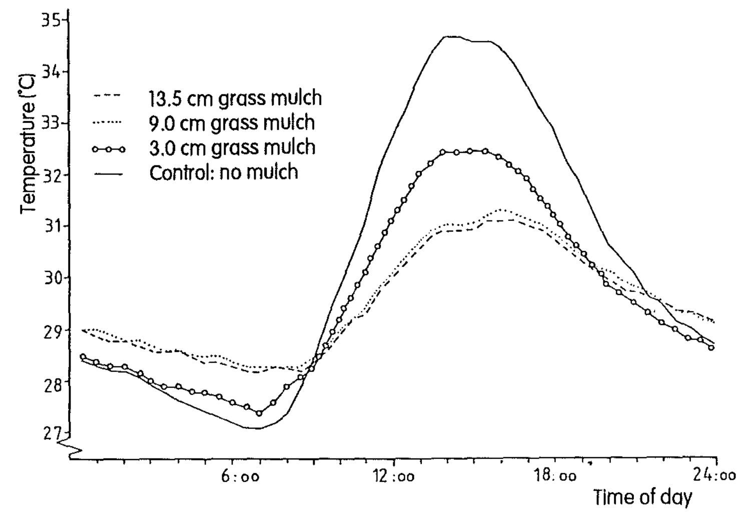
The rule is: the finer the mulch material, the less of it is required (MINNICH and HUNT 1979). As Figure 5.1 indicates, a minimum of 9 cm of grass mulch was necessary on a site in Yurimaguas, Peru, to prevent the surface soil from heating beyond the critical germination temperature of 30°C during the hot afternoon hours.

Increasing the depth of the mulch layer to 13.5 cm did not increase its effectiveness. Furthermore, as Figure 5.2 shows, the stabilizing effect on soil temperature of 9 cm of grass mulch can be achieved with thinner layers of other materials, sawdust giving the best results.

Similar results were obtained for soil moisture (see Section 5.3).

According to PEREIRA and JONES (1954), an optimal effect on water relations for coffee is achieved with a minimum layer of between 12.5 and 18 cm (depending on material).

Figure 5.1. Soil temperatures 5 cm below the surface during a 24-hour period under various depths of grass mulch (air dried)*

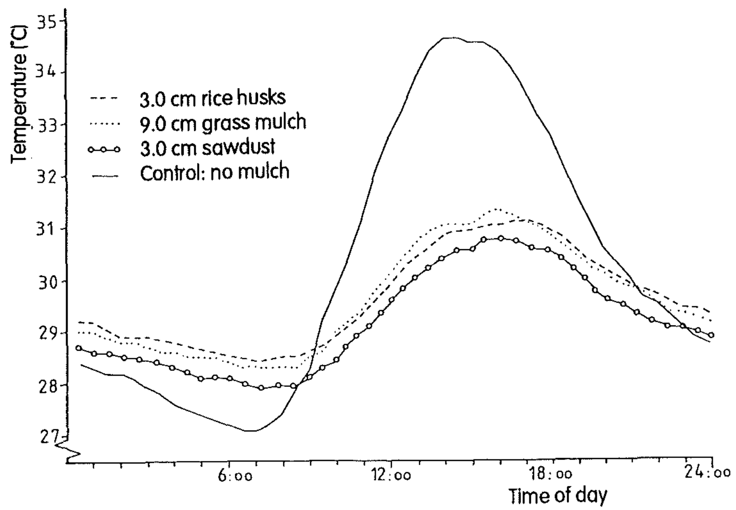


* 4.5 cm thick, 9.0 cm thick and 13.5 cm thick (average of 20 days, measured every half hour)

Source: LINDE (1982)

In controlling erosion, even relatively small quantities of mulch have produced good results. On a loamy sand with a 3% slope in Ibadan, Nigeria, mulching with maize residues reduced the surface runoff on a contour-plowed maize field by 17% and soil erosion by 50% (BABALOLA and CHHEDA 1975).

Figure 5.2. Soil temperature 5 cm beneath the surface during a 24-hour period under different mulch materials*



* Average of 20 days, measured every half hour. Mulch layer: 3.0 cm sawdust and rice husks, 9.0 cm dried grass

Source: LINDE (1982)

Studies by ROOSE (1981) indicate that a 2 cm-deep layer of straw (representing approximately 6 t of mulch per hectare) is as effective in decreasing the erosive action of rain as a stand of trees 30 m high. These results were confirmed by LAL (1975), as shown in Table 5.4.

It is difficult if not impossible to obtain quantitative data on the amounts of mulch needed for controlling weeds or for other purposes, as the effectiveness of any mulch is determined largely by its relationship with the soil and other site-specific factors. This question will be discussed in more detail in Section 5.3. As a general rule

however, it should be noted that a layer of mulch that is too thin, combined with minimal tillage, may turn the advantages of mulching into disadvantages. According to LAL and ROCKWOOD (1974), the latter include compaction, weed invasion and erosion.

To plan mulching operations and make recommendations to farmers, quantitative data are needed. Expressing the amount of mulch to be applied in cm layer depth is usually more practicable than t/ha. The variable use of both these measurements in recommendations and experimental results make it difficult to compare practices across locations and almost impossible to judge their feasibility.

It is a good idea, therefore, to collect local data in tables that relate the different descriptions of quantity to each other and that indicate the types and amounts of crop residues or other vegetation that can be expected from the various kinds of land (cropland, grassland, fallow, etc). On small test plots (10 m^2), a spring scale and meter-stick can be used to determine the quantitative relationships between the amount of young growth, the amount of mulch applied and the depth of the mulch layer. Table 5.1 is an example of how such a table might be constructed.

Table 5.1. Example of a table for relating amount of mulch to mulch layer depth

Crop plant / yield level (vegetation)		Crop residues/ amount of mulch t/ha dry/fresh matter	Corresponding depth of mulch (cm) dry/fresh	Other data, observations, remarks *
	high			
	average			
	low			

* For example: Rate of decay, nutrient contents, C/N ratio, price, nematicide effects, phytotoxic effects; directions for use, etc.

5.2.3 When mulches should be applied

Whenever possible, mulches should be applied before or at the beginning of the first heavy rains. Numerous experiments in various climatic zones have demonstrated that mulches are considerably more effective when applied at this time (LAL 1975, ROOSE 1981, etc).

According to studies by PEREIRA (1953), for example, mulch is far more effective at promoting infiltration than it is at reducing evaporation. In experiments in a semi-arid region of India, ALI and PRASSAD (1975) also found that the effect was practically nil when mulch was applied to prevent evaporation in the dry period. The layer applied earlier, during the monsoon season, resulted in better barley yields. Soil organisms also benefit far more if mulch is applied in the rainy season (see below).

In climates where crop germination is hindered by seasonally low temperatures, it may be better to spread mulch in the rows only after tillering has begun, or else to cover the soil only very thinly at first and to increase the mulch layer between the rows after the seedlings have emerged through the cover (WHYTE et al. 1959). The same goes for the use of bulky or thick materials that might impede young plants from establishing evenly.

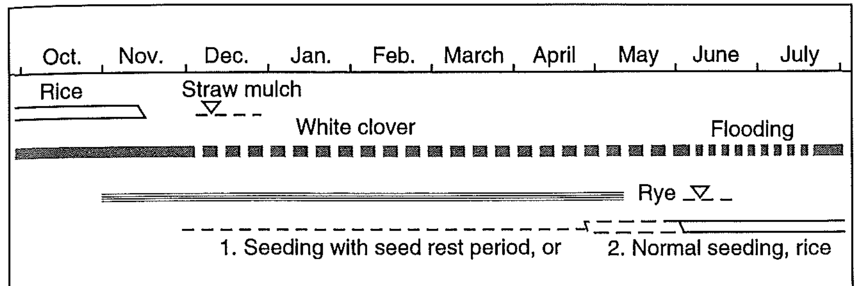
On vegetable plots it is best to mulch heavily only when young plants have become somewhat hardier. Young plants can be harmed by the products of decomposition from decaying fresh mulch materials. PAIN and PAIN (1977), who used semi-rotted mulch rich in lignin, removed the mulch temporarily for planting and covered the soil again completely once the plants were well established.

In the long term, soil coverage should be as permanent as possible, since only then are the beneficial effects of mulch fully expressed.

5.2.4 Techniques of application

In Japan, FUKUOKA (1978) developed a sustainable system of rice cultivation based on the use of mulch. This system involves sowing white clover (*Trifolium repens*; 2 to 3 kg/ha) amongst the maturing rice about 1 month before it is harvested (see Figure 5.3). Shortly thereafter, the "winter" crop of rye (40 - 60 kg/ha) is sown. The rice harvest follows 2 to 3 weeks later. After threshing, the rice straw is brought back to the field where it is loosely mulched (without being chopped short).

Figure 5.3. Temporal sequence of crops in a mulch cultivation system



Source: FUKUOKA (1978)

The rye and the white clover spring up through the mulch and the field is not worked again until shortly before the rye is harvested, when rice is sown again in the standing rye crop.[83] To speed the straw mulch decomposition, FUKUOKA adds small quantities of chicken manure, which is sprinkled over the mulch. The field is then flooded for a maximum of 2-3 weeks in June, to stimulate rice germination, weaken the white clover and suppress weeds. The cycle is then repeated from the beginning.

If the white clover or weeds develop too strongly the field may be briefly flooded a second time, provided sufficient water is available. According to FUKUOKA, 20 years of experience have shown that all other operations are superfluous or even counter productive.

[83] Alternating the grain crop in this way is essential for preventing disease.

The yield for this site is about 4-5 t/ha of paddy rice, comparable with other yields for the region. The four principles of this system according to FUKUOKA (1978) are:

* No plowing
* No mineral fertilizers
* No mechanical or chemical weed control
* No pesticides.

In addition to having proved itself over many years, this system, according to its author, offered a good combination of varieties and was strictly tailored to the limitations of the site. He believed that with some modifications it could be applied in other locations.

A completely different system, also based on the use of mulch, was described by BERTONI (1926) for growing bananas. Again, with a few adjustments, it should be applicable to other tall, fast-growing crops. The decline of soil fertility under banana plantations is very rapid, despite the use of mineral fertilizers (IITA 1982, FRANKE 1980). Growers are often obliged to shift to newly cleared land after only 5 to 6 years.

In Alto Paraná, Paraguay, however, BERTONI came across banana plantations that had been established in the early 17th century. Their continuing productivity was, he discovered, due to intensive mulching. In 20 years of trials of his own he developed a sustainable cropping system that was superior, in terms of both production and returns, to all other methods known at the time.

The first step is to clear an area of forest without burning or removing any organic matter. All undergrowth is cut with a machete and left to lie as soil cover. Holes are then drilled and the bananas planted (5 x 5 m). Only then are the trees felled, and in such a way that their crowns cover the ground evenly, i.e. their trunks do not cross over one another. The trees are debranched where necessary, this material also being mulched. The plantation is then finished.

In the first year selective weed control must be carried out two to three times to clear taller new growth. Weeds that cover the ground are allowed to remain, with the exception of grasses, composites, and a few particularly aggressive weeds. After 18 months, the mulch has decomposed to a degree that allows the farmer to walk round the plantation without being obstructed. Marketable timber may, in some cases, be removed at this point. Over the next few months only the banana fruit should be harvested, all natural regrowth serving either as ground cover or, if cut, as mulch.

The system can be enhanced by planting 15 to 20 trees per hectare and a few undercrops (legumes, roots and tubers are especially suitable) without incurring any fail in banana yield. For further information, see BERTONI (1926).

The procedure developed by IITA for using mulch in combination with herbicides will not be discussed in detail here. On this topic see LAL (1975), ROCKWOOD and LAL (1974), IITA (1981) and (1982), WIJEWARDENE and WAIDYANATHA (1984).

Usually mulch is spread out over the entire field and seed (or plants) are then sown in it.[84] If it is necessary to bring in the mulch, carts, wagons, or carrier frames can be used, as described in Chapter 6 on compost.

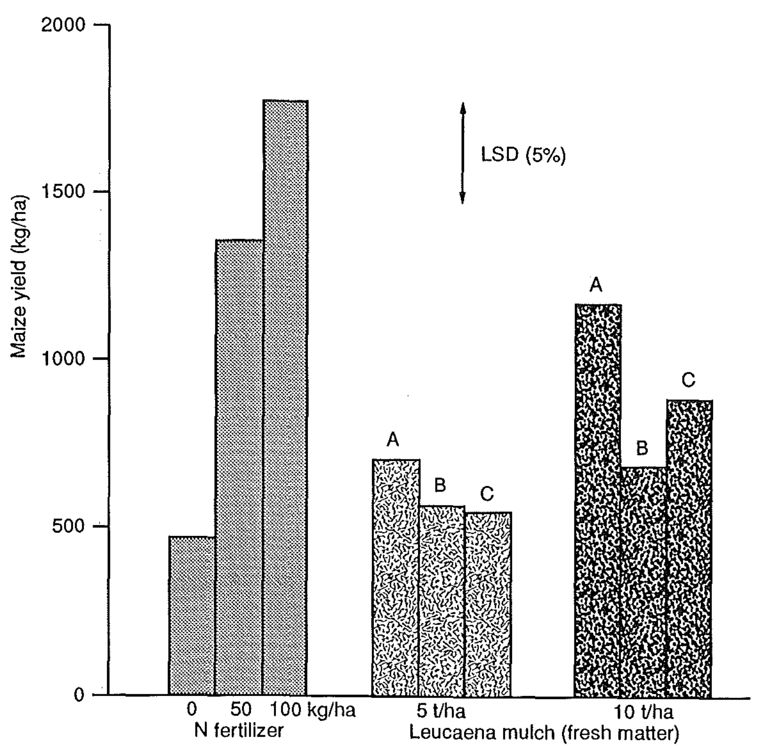
For many crops (especially vegetables), mulch is added after planting. The first application is best made on freshly tilled soil. The mulch can be applied between the rows, in them, or as a general cover. The effect on yield of these various application techniques has received little study as yet.

Some experiments used a mulch of chopped *Leucaena* shoots harvested from a *Leucaena* fallow (5,000-10,000 kg/ha fresh matter) on maize (IITA 1981). As Figure 5.4 shows, mulch applied in a 25 cm-wide strip along the rows of maize (A) proved more effective than applications 50 cm wide (B) or complete coverage (C). Clearly

[84] In Nigeria, IITA developed a manually operated "rolling injection planter". Like the "punch planter", it is especially suitable for use on smallholdings where mulch is used (IITA 1981, 1982, WIJEWARDENE and WAIDYANATHA 1984).

how mulch is applied can influence its effectiveness, as well as other factors such as site conditions, crop and season.

Figure 5.4. Effect on maize yield of different quantities of N fertilizer and *Leucaena* mulch and of various application techniques on a sandy Ustorthent in Nigeria*



* Strip application at widths of 25 cm (A), 50 cm (B) and total ground coverage (C)

Source: IITA (1981)

This is also demonstrated in another experiment with mulch which, like the one above, was carried out at Ibadan, Nigeria, over a period of 3 years. The maize was sown in rows 75 cm apart. Various mulching techniques were tried, including:

* A total coverage of mulch
* Mulch between the rows (55 cm wide strip)
* Mulch in the rows (20 cm wide along the seed rows)
* No mulch (control).

The total coverage produced yield increases of 38, 10 and 22% over the control for 1973, 1974 and 1975 respectively. The corresponding values for mulch applied between the rows were 19, 8 and 18%. Mulch in the row only proved ineffective. As a rule, the most complete mulch covering possible was shown to be most advantageous. The question of the best application strategy therefore only arises when too little mulch is available to cover the entire area.

Labor requirements are an important consideration, both for the task of mulching itself and as regards the effect of mulching on subsequent operations. MÜLLER (1982), for example, observed that farmers in Colombia applied mulch only to every second row of beans. If they had spread it on every row, the covering would have been too thin to suppress the weeds, and hoeing, impeded by the mulch, would have been necessary in every row. By mulching every other row, weed growth was effectively checked in the mulched rows and the amount of weeding was reduced by half.

5.2.5 Options for producing mulch

Providing they are not marketable, crop residues are the cheapest source of mulch. Depending on the crop, these may provide a great deal of mulch (sugar cane, pineapple, banana), or virtually none (yam, groundnut, beans).

By choosing suitable crop varieties, rotations and mixtures, the farmer can significantly increase biomass production and hence the availability of mulch material.

ROOSE (1981) strongly recommends the increased cultivation of plants that produce greater vegetative mass and that protect the soil with denser root systems.

JANSSENS et al. (1984) describe such systems as essential to ecologically oriented agriculture. Often portrayed as outdated farming methods in need of improvement, they are in fact far better suited to the conditions of smallholder agriculture in most parts of most developing countries than are the intensive systems of the Green Revolution.

As Table 5.2 shows, trials in West Africa indicated that the mulching of crop residues helps to prevent a decline in soil fertility. However, this table also shows that mulching the residues alone is not enough.[85]

Anti-erosion belts of grass or protective hedgerows (e.g. of *Cassia* sp. or *Cajanus cajan*) can supply additional mulch material. Uncultivated land and fallows can be another inexpensive and useful source of mulch. For instance, EAVIS and CUMBERBATCH (1977) improved saline alkaline soil in Barbados using mulch from the ample supply of *Andropogon intermedius* growing on nearby wasteland.

Cutting mulching material on such unused land can reduce the risk of bush fires as well as concentrating useful organic matter containing N and S. Nevertheless, this removal of nutrients contributes to the further impoverishment of the land. Excessive mulch removal should therefore be avoided. Alternatively, some means of replacing nutrients must be undertaken, with a view to using the land again in the longer term.

[85] The N or C content may be maintained but soil compaction and other signs of degeneration appeared under maize mulch. However, the authors attribute these to the harmful effect on soil life of the heavy use of pesticides in these trials.

Table 5.2. Characteristics of the upper soil layer (0-15 cm) on a site newly cleared from secondary forest (oxic paleustalf) after 8 years of continuous cropping and after fallow

Treatment	pH (H_2O)	Total N(%)	Effective CEC (m.e./100g)	Exchangeable cations (m.e./100 g) Ca	Mg	K	Bulk density (fine soil) g/cm^3 (1-5 cm)
Continuous cropping with minimum tillage							
Maize, residues mulched	5.0	0.18	3.23	2.19	0.41	0.35	1.20
Maize, residues removed	4.7	0.11	1.81	1.13	0.24	0.11	1.31
Maize/ cassava	5.6	0.15	3.40	2.04	0.42	0.32	1.25
Soybean, residues removed	5.0	0.11	3.05	1.65	0.42	0.32	1.32
Natural and sown bush fallow							
Natural growth	6.5	0.19	5.14	3.53	0.91	0.41	0.88
Guinea grass	6.7	0.26	7.69	4.75	1.28	0.91	1.01

Source: IITA (1981)

On extensively grazed land, over-mature fodder refused by the animals is often left standing. Cutting such growth and using it as mulch nourishes crops and at the same time improves the quality of the grazing land (WEIZENBERG 1962).

The more scarce such "free" areas are - that is, the more intensively a region is cultivated - the more attention should be paid to measures that increase their productivity. Thus DUNCAN (1975) suggests that wasteland should not simply be left fallow, but instead should be planted with suitable grasses and tended to produce good mulch material. The productivity of natural grasslands can be increased by sowing legumes (in narrow strips, e.g. *Desmodium ovalifolium* or *Pueraria phaseoloides*) that become established and spread within the natural grass stand (CIAT 1982).

It has been the practice in Kenya for many years to use special areas planted with elephant grass to mulch the coffee plantations. The size of the grass area required to produce enough mulch for a particular stand of coffee greatly depends on the fertility of the soil, the amount of fertilizer, and the species and variety of grasses used. For example, TOLHURST and KILAVUKA (1975) were able to grow 5-20 t DM/ha on the same soil using various strains of *Pennisetum purpureum*.

According to PEREIRA and JONES (1954), about 2 ha of mulch-growing area was needed in Kenya in the 1950s to mulch every hectare of coffee. The nutrients added to the coffee-growing area amounted to 90-200 kg N, 60-150 kg P_2O_5 and 250-500 kg K_2O per hectare for elephant grass. This quantity of nutrients exceeds the requirements of the coffee crop (FRANKE 1980). It would thus make more sense to fertilize the mulch fields than the coffee. In this way, not only would overcropping of the mulch-producing areas be avoided, but their higher productivity would mean that their size could be reduced. According to MUTEA et al. (1980), intensive mulch production of this kind means that just half a hectare of elephant grass would be sufficient to mulch a hectare of coffee. On this scale, the use of land to produce mulch (e.g. as contour strips) has a better chance of being accepted by farmers.

This approach has another advantage. Grasses are better able to utilize mineral fertilizers than are annual crops, with their relatively meager root systems (SANCHEZ and SALINAS 1981). The dense network of grass roots permeating the upper soil enables soluble mineral fertilizers to be taken up more quickly and effectively, minimizing the risk of fixation or leaching. The nutrients are then delivered to the crop field as mulch where, like the natural crop litter, they enter the nutrient cycle of the agrarian ecosystem. In some cases this results in a better utilization of fertilizer, especially in the case of phosphorus (PHILLIPS et al. 1980, HAYNES 1980; see also Section 5.3.6).

A way of producing mulch "in situ" was pursued by BOUHARMONT (1979) in an experimental program lasting several years. In the densely settled coffee-growing region of northwest Cameroon (sandy Arenosol, 1600 mm/year), it is all but impossible to increase the cultivation of coffee using mulch from areas outside the coffee fields because of the scarcity of land. In the search for a means of growing mulch directly on the coffee plantation, various undersown crops were tested.

As experiments by RODRIGUEZ (1958, cited in BOUHARMONT) in Colombia had already demonstrated, this method frequently met with failure because the undersown crops competed too strongly with the coffee for water. This was also the conclusion of BOUHARMONT's (1979) experiments with *Pueraria phaseoloides* and *Mimosa invisa*. *Flemingia congesta*, on the other hand, showed very good results and was superior to the control. Water and nutrient regimes were improved. *Flemingia* is sown when the coffee is planted and requires rather a lot of care in the first 3 months (see Table 5.25). At the beginning of the first dry season (and three to four times each subsequent year) it is cut and mulched into the rows.

Mixed cropping in strips or "alley cropping" offers another way of intensifying biomass production in annual cropping systems (WIJEWARDENE and WEERAKOON 1982) (see also Chapter 3 on agroforestry). Planted in rows 2-6 m wide, fast-growing shrubs that tolerate lopping (e.g. *Leucaena leucocephala* or *Glyricidia sepium)* are well suited to mulch production. In addition they provide wood and nitrogen and have a positive influence on nutrient recycling and weed control. With regard to maintaining soil fertility, the performance of such systems resembles that of bush fallows (IITA 1981).

The shrubs are cut back to 1 or 2 m in height at the beginning of the crop planting season. Leaves and fine twigs are applied between the crop rows as mulch. Heavier branches are used or sold as firewood, industrial timber or stakes for tomato or yam. The annual crops are sown in the mulch. They are mulched again as they grow, since the shrubs must be pruned to prevent them casting too much shade during the growing period.

A considerable amount of mulch can be produced in this way (see Table 5.3). There are no adverse effects on crop yields (because of the different depths of the root systems), provided that plant density and crop husbandry measures are appropriate to the site and crop. However, the loss of land to the hedgerows reduces the total production of the food grain crop to some extent.

Table 5.3. Yield of mulch (dry matter) and nutrients from *Leucaena* hedges planted between rows of maize and their effect on maize yield

Site	Mulch yield (kg/ha)	Nutrients in mulch (kg/ha)			Maize yield (kg/ha)	
		N	P_2O_5	K_2O	Without *Leucaena*	With *Leuceana*
Ibadan, Nigeria*	3000	100	n.k.	n.k.	1000	1900
Maha Illupallama, Sri Lanka**	2800 leaf mulch + 3000 branchwood)	90	20.6	87.6	570	730
Baybay, Philippines***	3700 (3 cuttings)	28	14	29.3	2800	3200

* In this experiment, the control plot was also planted with *Leucaena*; the cuttings were either removed (without *Leucaena*) or left (with *Leucaena*). Only the non-fertilized version is given here. The yield level in fertilized plots was higher.
** Planting distance: 2 m. The yields from this experiment were severely reduced by extreme drought - only half of the average rainfall was received. The trial plot was not fertilized. Control: pure maize stand with double planting density.
*** Planting distance: 1.5 m. *Leucaena*'s poor N fixation was due to the highly acidic soil conditions. Maize received a fertilizer application of 30 kg N/ha. Control: pure maize stand with double planting density.
n.k. = not known.

Sources: Ibadan, IITA (1981); Maha Illupallama, WIJEWARDENE and WEERAKOON (1982); Baybay, ROSA et al. (1980).

ROSA et al. (1980) obtained similar results in their experiments in the humid tropics of the Philippines. They planted *L. leucocephala* in rows parallel to the slope's contour lines with 10, 15 and 20 plants per meter (rows 1.5 m apart, 30% gradient). *Leucaena* was sown 90 days before the maize and thinned after 3 weeks. The maize was sown 25 cm apart on small mounds between the hedges (26.667 plants per hectare, as opposed to 53.333 in the control plot without *Leucaena*). Sowing the

maize directly helped outweigh the higher labor costs of planting and tending the *Leucaena* (IITA 1981, POUND et al. 1980). Twenty-five days after the germination of the maize, the *Leucaena* was lopped to just 25 cm above the ground and mulched.[86] In the first growing period, *Leucaena* produced a respectable yield at a density of 15 plants per meter (no significant improvement was obtained at 20 plants/m). The nutrients from the mulch were used by the maize, yields being over 100% higher with alley cropping than without it. This higher yield more than compensated for the smaller area planted with maize. Moreover, erosion was reduced and infiltration improved. Table 5.3 compares the results from different locations.

IITA has also carried out trials on more than 30 species of trees and shrubs to test their suitability for various climates. These include *Cajanus cajan, Acioa barterii, Alchornea cordifolia, Tephrosia candida, Cordia alliodora, Albizia falcata, Treculia africana* and *Parkia clappertonia*, to name a few.[87]

5.3 Effects of mulch

Figure 5.5 summarizes the various effects of mulch, some of which are discussed in this section.

5.3.1 Reducing erosion

Minimum tillage combined with the application of mulch is practised in temperate regions (e.g. the USA) primarily because of its effectiveness in reducing wind and water erosion. According to LAL and ROCKWOOD (1974), the greatest advantage of such practices, in tropical as in temperate regions, is the assured and inexpensive reduction of erosion. LAL's (1975) experimental results, given in Table 5.4., provide

[86] This differs significantly from the IITA practice of cutting back to 1-2 m. A different type of *Leucaena* was used: the Hawaii type grows short and bushy while the Salvador and Peru types grow high and tree-like.

[87] *Tephrosia* is susceptible to nematodes (*Heterodera radicola*) (SCHOOREL, cited in VAN RIJN 1982).

impressive evidence of the effectiveness of mulching in this respect. At a mulching rate of only 2 t/ha, surface runoff was decreased by 60% and soil erosion by an average of 90%. A triple application (6 t/ha or 600 g/m^2) reduced surface runoff by 90% and soil erosion to practically zero.

ELLISON (1952) had already shown that the chief cause of erosion is the kinetic energy of rain. He also found that rainfall of 75 mm an hour exerts the same amount of energy on the soil as would plowing it 29 times. The erosion process can be described as follows: the impact of raindrops ("splash erosion") destroys the soil aggregate or the crumb structure of the soil surface. The tiny particles thus created clog the fine pores of the soil and inhibit the infiltration of rainwater. If infiltration is hindered or prevented by heavy surface silting or mud, as is particularly liable to happen on very dry or already saturated soils, then a film of water forms on the soil surface. Small waves caused by the impact of falling raindrops keep this film in constant agitation, washing out more soil particles and further destabilizing the soil aggregate.

This film of water, if set in motion, takes the soil particles with it, resulting in the removal of a layer of surface soil ("sheet erosion") or deeper washes ("gully erosion"). The faster the water flows, the longer the slope and the steeper its incline, the greater will be the erosive power of the water.

Mulch works to reduce erosion in two ways. First, it protects soil from the impact energy of raindrops (silting). Thus it ensures that soil pores remain open to take in rainwater. Secondly, mulch slows down the runoff speed of water, preventing it from carrying away too much soil.[88] As Table 5.4. shows, the latter effect can be achieved with very small amounts of mulch.

[88] Rain water generally arrives faster than it can enter the soil. This is especially apparent on silty and fine-sandy savanna soils (*sols ferrugineux* or *Luvisols*), which often have an infiltration rate of 10-20 mm/hour, while very ferrallitic soils may exhibit infiltration rates of between 60 and 800 (ROOSE 1981).

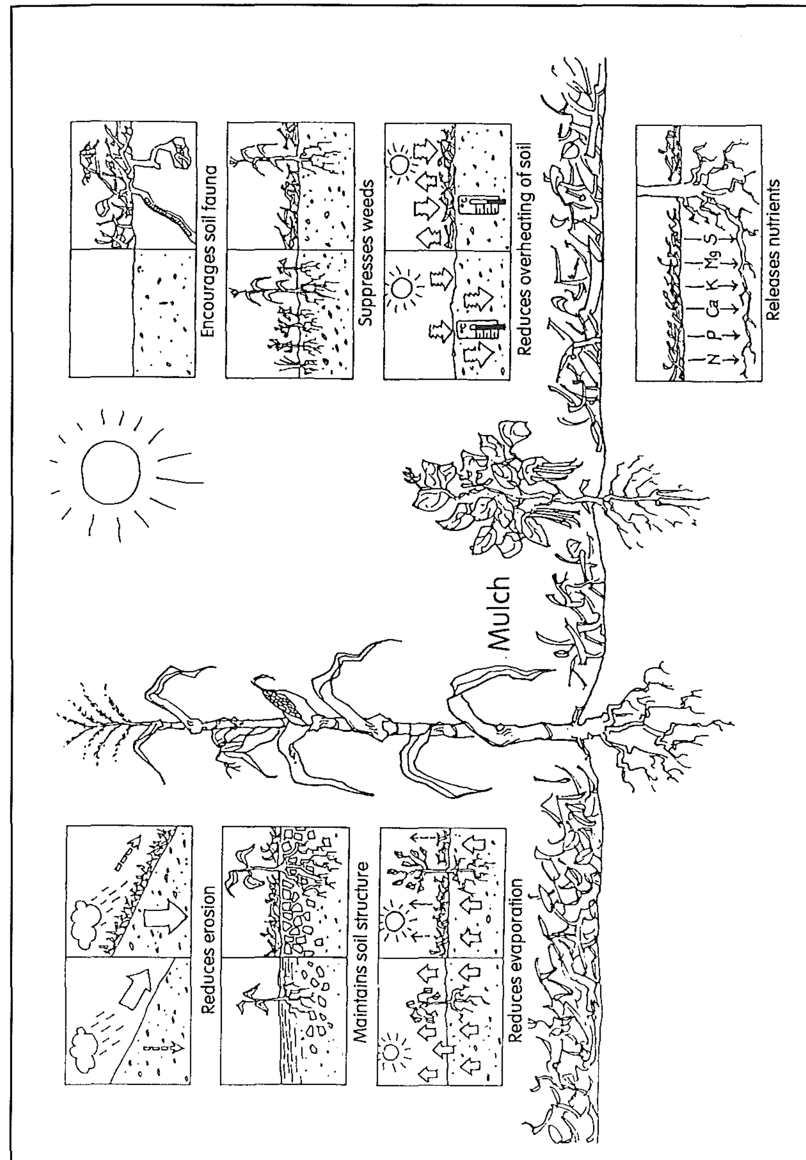


Figure 5.5. The effects of mulch

Table 5.4. Effect of various mulching rates on surface runoff and soil loss from a Paleustalf at Ibadan, Nigeria*

Mulching rate (t/ha maize straw)	Slope gradient (%) 1	5	10	15	Average
	Surface runoff (mm)				
0	12.0	14.8	10.4	14.8	13.0
2	1.3	6.2	6.0	5.7	4.8
4	0.4	1.5	3.6	3.3	2.2
6	0.0	0.7	1.9	1.8	1.1
	Soil loss (t/ha)				
0	0.48	12.19	27.06	12.25	13.00
2	0.01	3.49	0.82	0.64	1.24
4	0.00	0.67	0.11	0.31	0.27
6	0.00	0.16	0.03	0.08	0.07

* Total rainfall 1200 mm
Source: LAL (1975)

A soil with poor infiltration capacity is more at risk from erosion through intense rainfall. Erosion control measures are especially necessary for such soils.

In Africa, ROOSE (1981) found that rainfall intensities of over 100 mm/hour are no rarity in the humid tropics. Even in the dry savanna, near the limits for rainfed cropping, rainfall with an intensity of 60-70 mm/hour was likely to occur at least once a year on average. ROOSE also examined the aggressivity of rainfall - a term used to describe its duration and intensity - which can be expressed by means of an aggressivity index. He found that aggressivity is significantly less in the temperate latitudes (index values of only 20-120) than in the savannas (200-600), and the humid tropics (values as high as 500-1400).

The enormous implications of these differences become clear when it is realized that the degree of erosion is calculated as the product (not the sum) of the aggressivity of

rainfall (R) and the factors that influence erosion. WISHMEIER and SMITH (1978) developed the following formula for calculating erosion: A = R x K x L x S x C x P, where A is the annual soil loss in t/acre, R are the natural rainfall characteristics, K are soil properties, S is the gradient of slope, C is the type of land use and P are the soil protection measures being applied. The formula is known as the Universal Soil Loss Equation (USLE).

In this equation mulching significantly reduces the soil protection factor P (ground cover). Whereas for unprotected soil this factor is 1 (meaning that the rain and the other factors can express their erosion potential to the full), a straw mulch layer of only 2 cm (about 6 t DM/ha) reduces it to 0.01-0.001. According to ROOSE's (1981) calculations, the control thus provided is comparable to that of a 30 m high rainforest (factor 0.001).

Table 5.5. presents further experimental results that illustrate this relationship. Here too, erosion was almost completely controlled by the use of mulch alone.

Table 5.5. Effect of slope (%) and use of pineapple harvest residues on erosion (t/ha), Adiopodoumé, Côte d'Ivoire*

		Uncultiv. tilled soil	Pineapple harvest residues: Burned	Incor-porated	Mulched	Average per gradient of slope
Gradient of slope	4%	45	1.2	0.7	0.1	11.8
	7%	136	4.1	0.8	0	35.2
	20%	410	69	33.2	1	128.3
Average		197	24.8	11.5	0.4	58.8

* Sol ferralitique on sand, rainfall (in 16 months): 3336 mm

Source: ROOSE (1981)

ROOSE (1981) also found that, on slopes of less than 15%, the impact energy of rain is the only significant cause of erosion. This means that surface runoff becomes the leading cause of erosion only when the gradient exceeds 15%.

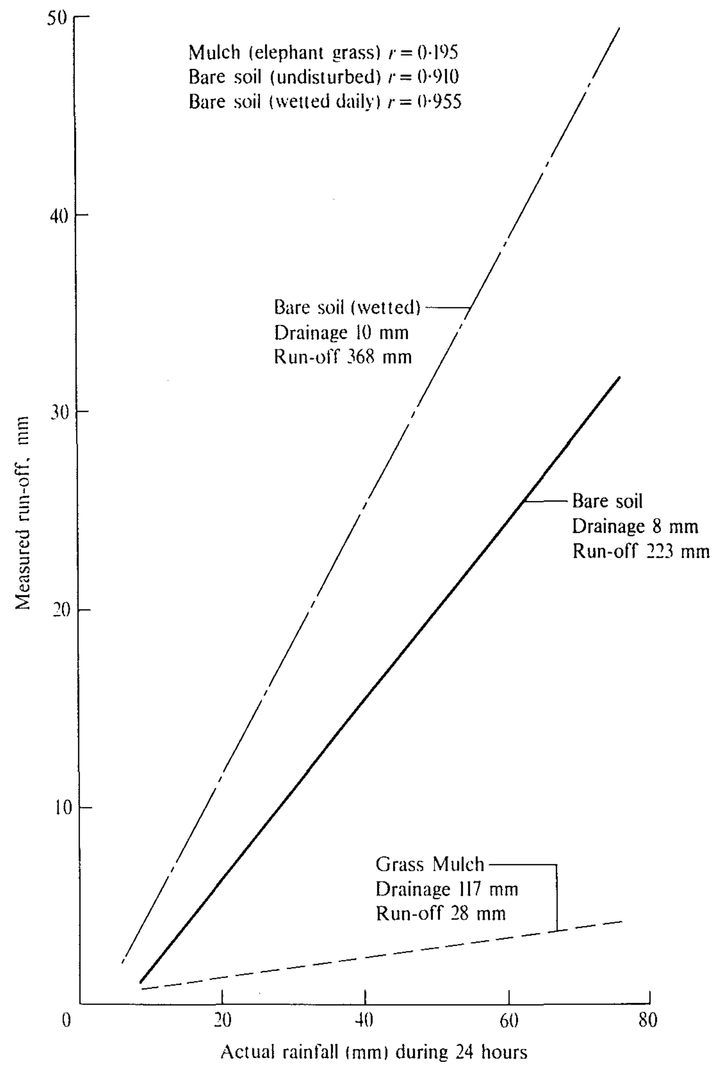
On these steeper slopes mulching is indirectly effective, since it raises the threshold at which surface runoff starts to occur by promoting infiltration (see Figure 5.6). And even where runoff does occur, mulching slows it down, thus vastly reducing its erosive effect.

5.3.2 Maintaining soil structure

According to SANCHEZ and SALINAS (1981), the case for applying mulch in Africa rests primarily on its contribution to maintaining good physical soil conditions. This benefit is especially important with regard to Alfisols (Luvisols), which are found widely in Africa.

It is true that good soil structure can be produced with the plow, which loosens and aerates the soil, creating pores for water to infiltrate and reducing the capillary action of rising groundwater (this is important, especially in semi-arid regions). But plowing also has many disadvantages. It has high energy requirements. Turning the soil stimulates the germination of new weed seed and accelerates the oxidation of soil humus (VAN RIJN 1982). The most positive effects of plowing on soil structure are usually of short duration. ROOSE (1981) found that the loosening effect was lost after about 1 month unless the soil was quickly protected by a layer of ground-cover plants. After 120 mm of rainfall, the positive effects had disappeared on all trial plots, and often had even been reversed.

Figure 5.6. Relationship between rainfall intensity and surface runoff with and without mulch on a slope with a 2% gradient in Namulonge, Uganda



Source: FARBROTHER and MANNING (1952), cited in WEBSTER and WILSON (1980)

Mulching arrests this trend. Studies by LAL (1978) on an Alfisol (oxic Palaeustalf) in Ibadan, Nigeria, showed that soil density was reduced under mulch. Under a complete mulch cover it was 1.40 (0 to 10 cm) and 1.42 (10 to 20 cm), as opposed to 1.54 and 1.70 with no mulch cover. The effect on penetration resistance (Table 5.6) was similar, with considerable effects on root-growth extension.[89]

Table 5.6. Influence of mulch on soil layer density and penetration resistance of an Alfisol under maize, Ibadan, Nigeria

Treatment	Soil layer density (g/cm^3)		Penetration resistance (kg/cm^2) 20 and 40 days after sowing			
	0-10cm	10-20cm	20 days		40 days	
			0-10cm	10-20cm	0-10cm	10-20cm
Control	1.54	1.70	0.83	1.73	2.79	4.36
Mulch in the rows	1.45	1.58	0.73	2.01	1.75	3.72
Mulch between the rows	1.45	1.47	0.60	1.07	1.24	3.23
Complete mulch cover	1.40	1.42	0.36	1.27	1.15	3.13
LSD (0.05)	0.18	0.14	0.30	0.21	0.74	1.06

Source: LAL (1978)

The positive effects of mulching on soil structure are not merely the result of the protection it affords from sun and rain, but also of the increased biological activity that develops beneath the mulch cover. This is many times greater than for uncovered soil and contributes to loosening the soil and stabilizing the aggregate. PEREIRA and JONES (1954) state that a 2-year mulch can have as beneficial an influence on soil structure as 4 years of grass fallow. PEREIRA (cited in KEEN and DUTHIE 1953) describes mulching as "a good method of tillage". Clearly this is

[89] According to WIJEWARDENE (1981, cited in VAN RIJN 1982), at least 3-5 t of mulch/ha are necessary to prevent soil compaction under minimum tillage.

justified when it is considered that not only is the enormous energy of the rain deflected from the soil but also that earthworms, which are greatly encouraged by mulch cover, shift up to 50 t of soil or more per hectare, depositing their casts on the surface as stabile Ca-enriched aggregate. Earthworm casts are among the most stable of all soil aggregates (LAMOTTE 1975, GRAFF and MAKESCHIN 1979, ROOSE 1981).

The importance of the soil's porous texture decreases as the proportion of earthworm tunnels increases (KOCH 1966, cited in GRAFF and MAKESCHIN 1979). The macro-porosity of the soil is increased and its rooting permeability and water infiltration are improved. Through the coarse pores, air can escape and water enters the soil.

In drier regions the importance of earthworms is superseded by that of termites. Their activity, which is again aided by the presence of plant residues, also contributes towards improving soil structure. They bring fine, nutrient-rich soil up to the surface from deeper soil strata, helping to equalize soil textures. However, if this soil is subsequently carried away by erosion, the result is a more serious long-term loss of nutrients (ROOSE 1981) as the effects of erosion are selective.[90]

Tillage by soil organisms can be viewed as the most effective form of soil cultivation, because the energy stored in plant residues is converted directly in the field as it is processed by soil organisms, a fact that prompted LAL (1978) to remark that earthworms are "the best plows for tropical soils".

Mulch protects (JAGNOW 1967) and adds to (JONES 1971) the humus content, a further contribution to the stability of soil structure.

[90] In studies by BABALOLA & CHHEDA (1975), the proportion of clay in eroded soil was three times, the silt four times and the humus eleven times higher than in the original soil.

On highly compacted and dense soils, where minimum tillage is practised, a first mulch application may actually increase surface runoff under some circumstances, an effect also known in temperate regions (LARSON et al. 1971). On such soils, which may be regarded as totally degraded, LAL (1980) recommends that *Stylosanthes* or *Pueraria* be planted for 1 or 2 years to break up the soil before mulching begins.

5.3.3 Water economy

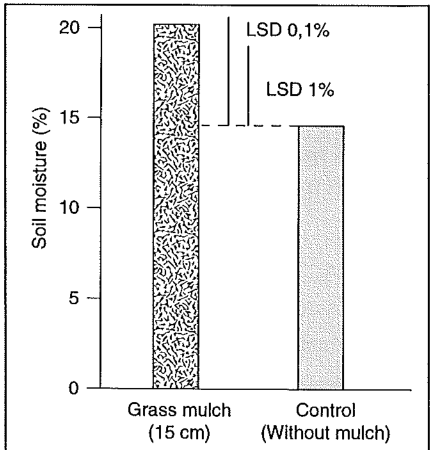
The water balance of a soil is essentially governed by the rainfall that enters it and the water lost through transpiration and evaporation. The more water a soil takes in and the less it evaporates unproductively, the more water remains for the productive transpiration of crop plants.

As mentioned in Section 5.3.1, mulch promotes infiltration, thereby contributing towards better water relations. Similarly positive effects on the water economy arise through the decrease in evaporation which may also be expected. Factors that promote groundwater evaporation include high air and topsoil temperature, low relative humidity of the air layer near the soil surface, and strong air movement at the soil surface.

On a Paleudult in the tropical rainforest of Peru, LINDE (1982) found that, after a 6-day dry period, soil moisture in the upper 20 cm of soil with no mulch cover had already fallen to 14.5%, whereas soil under mulch still retained a water content of 20.2%.

Measurements on another trial plot made just 1 day after a violent downpour of 73.5 mm (the soils had previously undergone a dry period) showed an even greater difference in the soil water balance (about 9%). The difference grew more marked as the depth of the mulch layer increased (Figure 5.7). In addition to decreased evaporation, better infiltration of rainfall seems also to have played an important role here.

Figure 5.7. Soil moisture content of an Ultisol after 6 dry days a) under grass mulch (15 cm) and b) without mulch (average from 10, 15 and 20 cm soil depth)

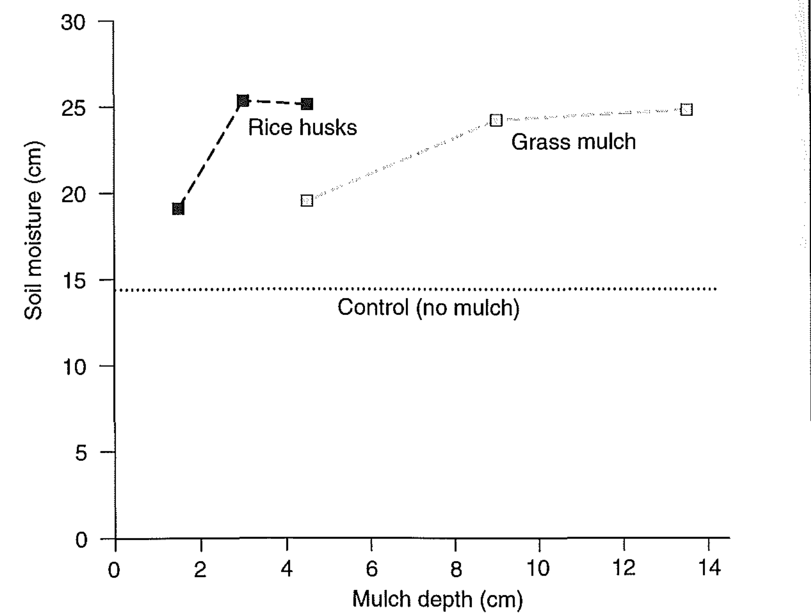


Source: LINDE (1982)

According to SANCHEZ and SALINAS (1981), the evaporation-reducing effect of mulch is especially observable during growing periods - i.e. at times with regular rainfall, more intense sunlight and higher soil temperatures.[91] On an Oxisol in the *cerrados* of Brazil a mulch cover of grass (10 cm *Melinis minutiflora*) reduced evaporation during short dry periods by more than 4 mm a day. FRYREAR and KOSHI (1974) were able to use mulch from cotton-gin trash to significantly improve the moisture content of crop soils.

[91] Evaporation is especially high from relatively water-saturated soils, which are able to quickly resupply large amounts of water to the surface. Mulch is highly effective in checking evaporation under such conditions. The water loss from soils that have already formed a dry upper layer is markedly less because the drier soil acts as a barrier for the diffusion of water vapor and upward capillary movement. The water loss in this case is more soil-related and less determined by outside factors such as the presence or absence of mulch (LEMOS 1956, cited in TÜRKE 1976).

Figure 5.8. Soil moisture content under different mulch materials of varying depth



Source: Adapted from LINDE (1982)

Good results were also obtained by EAVIS and CUMBERBATCH (1977) in experiments on a semi-arid site with saline alkaline soil (sandy clay and clay). A mulch application of 10 t of grass hay per ha improved the soil physical structure; during a 6-month period, the measured soil moisture of a sugar cane field was 4% higher with mulch than without. This clearly had an effect on nutrient uptake and hence on yield.

In experiments by LAL (1978), in which different mulching techniques were applied to maize (total cover, between the rows, and on the rows), the soil moisture content was directly linked to the degree of mulch cover, rising from 0.11 g water/g soil to 0.13 g water/g soil with total mulch cover.

By mulching with sawdust and wheat straw (10 t/ha), YADAV (1974) was able to markedly improve the moisture conditions of a semi-arid site in Rajasthan, India (45% clay) that had already been sown with maize. He achieved an average yield increase of 20%.

However, improvements in the water economy achieved with mulch are not always as clearcut. In trials by PEREIRA and JONES (1954), mulch improved the water economy of a coffee plantation only when it was applied during rainy periods. Applied at the beginning of the dry season, it had little or no effect.

To some extent these results confirm the investigations of LEMOS (1956) (see previous footnote), who showed that the evaporation-reducing effect of mulching was especially evident when mulching was carried out during periods of frequent rainfall.

MAURYA and LAL (1980) pursued the question of whether mulch, in combination with minimal tillage ("mulch tillage"), is better for the water economy than conventional tillage. Their experiments were carried out with different crops on an Alfisol. Minimum tillage combined with a mulch cover of maize residues and weeds proved better than plowed furrows. The soil water content on the mulch-tilled plots was almost always higher than on the plowed plots, though it must also be noted that this effect was more marked in pure maize stands (averaging 5% more soil moisture over the whole growing period) than in mixed crops. In maize and cassava mixtures there was little difference between the two methods. This may be attributable partly to the overall higher water consumption but primarily to the better ground cover provided by a mixed stand.

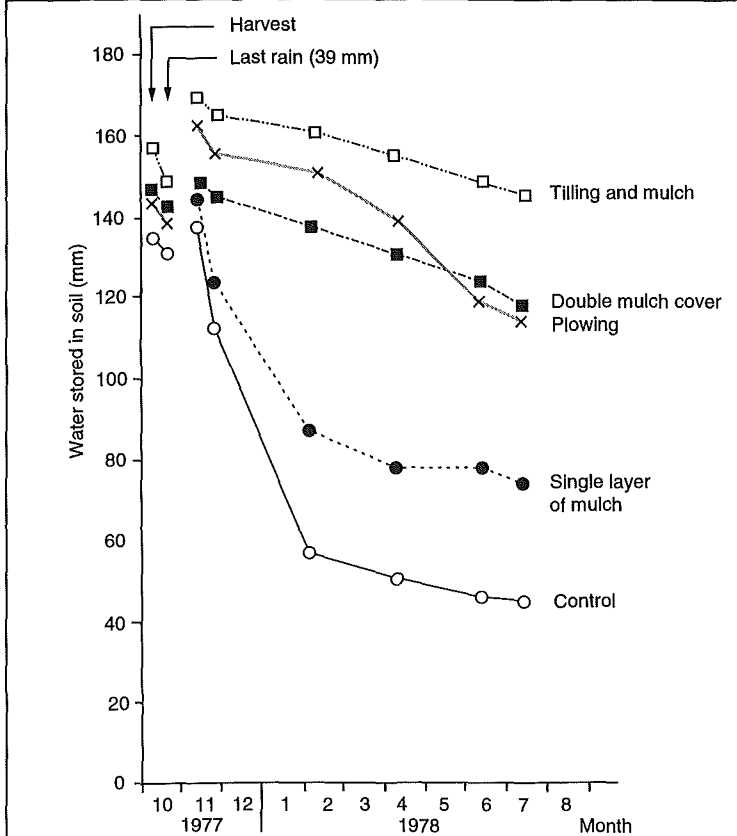
These authors thus confirmed the results of earlier experiments by LAL (1978), who also noted higher moisture reserves under mulch-tilled crops of maize, pigeonpea, and soybean than on plowed fields.[92]

CHOPART et al. (1979) investigated the same question. The results of their experiments on a cambic Arenosol (85-93% sand) in Bambey, Senegal (640 mm

[92] This applies chiefly to the upper 30 cm of soil; smaller differences below this level were not significant.

annual rainfall) are presented in Figure 5.9. On this site, simple plowing at the beginning of the dry period produced far better results than minimum tillage and mulching with harvest residues. However, this was without weed control. The optimal combination was plowing followed by the application of mulch, which would not be easy for farmers to carry out.

Figure 5.9. Effect of land management on the water economy of a cambic Arenosol in Bambey, Senegal (October 1977 to July 1978)



Source: CHOPART et al. (1979)

Here, on sand, the yield was not affected by the improved infiltration under mulch because the water was quickly drawn down to the deeper soil layers and stored where it was inaccessible to the groundnut crop.

Minimum tillage with a double cover of harvest residues (around 8 t/ha) achieved approximately the same level of soil moisture as plowing carried out in the previous growing period.[93] The control (mulched and plowed under) had by far the greatest water loss. These trials showed that, independent of the kind of tillage applied, mulching was always associated with decreased evaporation and improved soil water reserves.

The general conclusion is that, on the clay-rich binding soils of moister climates, mulch with minimum tillage is as good as or better than plowing for the soil water economy. Plowed furrows, on the other hand, usually produce better results in relatively dry regions with sandy and weakly structured soils. This was the case in experiments by SAHA et al. (1980), who conducted their experiments on a semi-arid site with alluvial, sandy loam over a clay-rich subsoil. One may surmise that the sandy, dry surface soil acted as its own mulch cover, such that any additional effect from mulching was minimal.

To sum up, with rare exceptions mulching is effective in increasing infiltration and reducing evaporation. As a rule, the water content of the soil is increased.

When extremely dry periods occur or rains fail altogether, then mulching cannot be expected to produce a miracle. However, mulching has a strong regulatory influence on moisture relations, and the 3-7% more soil moisture that is often found under mulch can cushion the yield-decreasing impact of drought stress.[94]

---

[93] The plow produced somewhat better results in 1976 than in 1977 because, after plowing in 1977, unexpected rainfall of 39 mm partially destroyed the clumpy, loose structure of the plowed ground. However, according to ROOSE (1981), such irregular rainfall events are not rare in this climate.

[94] At a soil density of 1.5, 1% in weight of water represents 1500 kg water per cm of soil per ha. As the effect of mulch usually extends down to a soil depth of about 20-30 cm, resulting in a moisture content 3-7% higher than on unmulched soils, this represents 90,000-210,000 litres of water/ha in 20 cm of soil, or in other words 9 - 21 litres/m^2 or rainfall in the top 30 cm of soil of 9-21 mm. Water reserves are 13.5-31.5 mm.

Thus, in trials by BOUHARMONT (1979), a conventionally tilled coffee crop suffered drought stress for 4 weeks,[95] in contrast to 1 week for the mulched plot. LAL (1975) made the same observation with regard to maize. Soil moisture conditions are important not only at the critical stages of a crop's growth (berry formation in coffee, flower formation in maize, etc) but also during sowing. RICKERT (1974) was able to increase the germination rate of *Panicum maximum* seed from 0.4% to 2-13% by applying a straw-mulch cover of 5 t/ha.

5.3.4 Soil temperature

The temperature of the soil influences plant growth both directly and indirectly, through root extension, soil moisture, soil life, nutrient uptake, and so on. If the soil temperature exceeds a certain level, or drops below a critical minimum, crop growth and productivity suffer. For most tropical crop plants the upper extreme begins at about 30-35°C and the lower at around 15-20°C.

The heat economy of soils (and thus the temperature in the root area of crop plants) is governed by the energy of incoming radiation, the heat capacity of the soil, its thermal conductivity, and the rate of evaporation (TÜRKE 1976). These factors can be influenced by mulch. For example, mulch can reflect sunlight if, like straw, it is lighter in color than the soil. It also absorbs some of the radiation energy, thus functioning as insulation. The soil under a mulch cover therefore receives less heat.

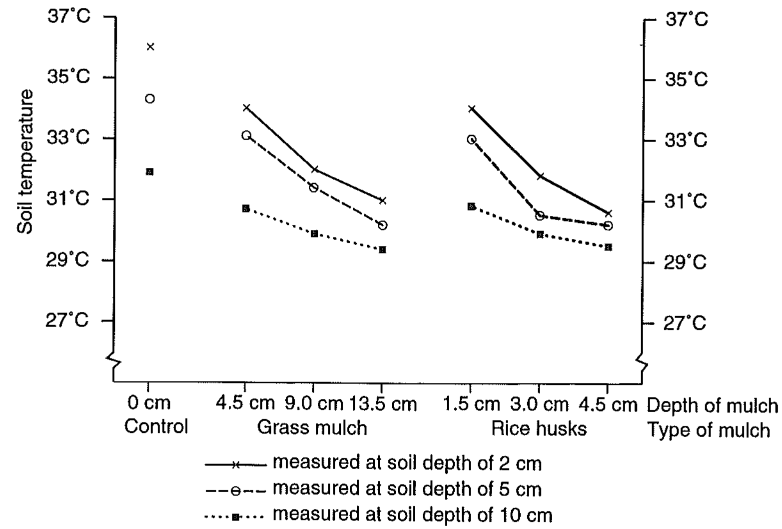
Less heat means less evaporation, and hence increased soil moisture (see Section 5.3.3). This in turn means that the soil's heat capacity and thermal conductivity are enhanced. The soil will therefore be cooler than a dry soil. In contrast, dry soils heat up faster and cool down again more quickly.[96]

[95] The soil moisture tension was > 10^4 cm H_2O.

[96] Special mulching materials such as sheet plastic or coal dust can be used to increase the heat supply to the soil and raise soil temperature. This practice is primarily important outside the tropics.

As already discussed in Section 5.2.2 (Figures 5.1 and 5.2), the temperature differences obtained through the use of mulch can easily reach 4°C or more at midday. The difference is greater, the closer to the soil surface the measurements are taken (Figure 5.10). The maximum soil temperature at 2 cm depth on an Ultisol with a 9-cm cover of grass mulch was only 30.5°C, whereas it was 36°C in soil without mulch.

Figure 5.10. Soil temperature under different types and depths of mulch at soil depths of 2, 5 and 10 cm.*



* Measured at 2:00 pm (average over 12 days) on a Paleudult in Peru

Source: LINDE (1982)

MAURYA and LAL (1980) carried out experiments on an Alfisol in Ibadan, Nigeria. Under stands of pure maize and of maize with cowpea, temperatures measured during the day at depths of 5 cm averaged 31-38°C from the first to sixth week without mulch. Under mulch, temperatures reached only 29-33°C. After harvesting, the difference between mulched and unmulched soils was still about 1-2°C. In another trial with maize, the average maximum soil temperature was 7°C higher without mulch during the first 1.5 months. After the harvest, the difference fell to 2-3° (LAL 1975).

Table 5.7, showing results obtained by ROCKWOOD and LAL (1974), illustrates the effect of mulching 2 weeks after sowing maize, pigeonpea, soybean and cowpea. The maximum temperatures at a soil depth of 5 cm were approximately 41°C without mulch, nearly 9° higher than on mulched fields and clearly exceeding the temperature range optimal for seed germination.

Table 5.7. Effect of cultivation techniques on the maximum soil temperature at a depth of 5 cm under different field crops, 2 weeks after sowing on an Alfisol, Ibadan, Nigeria

Treatment	Maximum soil temperature (°C)			
	Maize	Pigeonpea	Soybean	Cowpea
Plowed only	41.4	40.0	41.4	41.8
Zero tillage (with mulch)	31.6	32.4	32.4	33.4
Difference	9.8	7.6	9.0	8.4

Source: ROCKWOOD and LAL (1974)

LAL (1978) made a closer examination of these factors as they relate to maize. He found that during the first 4 weeks of growth, soil temperatures lay above the optimum for about 3-6 hours a day.

Thus the essential advantage of mulch application lies in buffering fluctuations in the temperature curve: maximum temperatures are reduced and minimum ones raised (see Figures 5.1 and 5.2). In experiments by LINDE (1982), the temperature at a soil depth of 5 cm ranged over only 3°C under a sawdust mulch, whereas without mulch it fluctuated over 7°C in 24 hours. The average temperature with mulch was about

1°C lower. In the case of a banana mulch on coffee in Tanzania, the daily temperature at a depth of 5 cm fluctuated by 2-3°C, whereas the fluctuation without mulch was 12°C (JAGNOW 1967). Depending on the soil, this effect can be detected down to a soil depth of 20-30 cm (LINDE 1982).

Mulch thus helps create temperature conditions in the soil that come very close to those under leaf litter from natural vegetation (AYANABA and OKIGBO 1975).

Crop yields can be increased by minimizing high soil temperatures, although the impact of temperature alone, independent of other influences, is difficult to prove in field trials. Vegetable crops, frequently grown under suboptimal, hot conditions, are particularly affected by soil temperature. In West Samoa, REYNOLDS (1975) found that, of all the examined factors influencing yield, soil temperature had the largest impact on the performance of garden beans (*Phaseolus vulgaris*). Under a coconut mulch, the average temperature in the upper 5 cm of soil during the first 2 weeks after sowing was only 28.6°C, while that of the control, with no ground cover, was 37.6°C. Mulching brought a marked improvement in the germination of the bean seed. Yield was highly significant ($r = 0.89$, $P = 0.01$) correlated with low soil temperatures under mulch, which were associated with an improvement of 73%.

5.3.5 Root development

European experience with regard to root growth following mulch application is not necessarily applicable in the tropics. The tendency for plant development to suffer through delayed soil-warming under mulch in temperate climates is generally reversed in the tropics.

In trials by REYNOLDS (1975), mulch used on garden beans in West Samoa improved root development (chiefly because of lower soil temperature). WATERS et al. (1980) at CIAT, applying 4 cm of rice husk mulch to *Phaseolus* beans, reported a 38% gain in root weight. EAVIS and CUMBERBATCH (1977) also observed a markedly larger volume of root-permeated soil after mulch application on sugar cane.

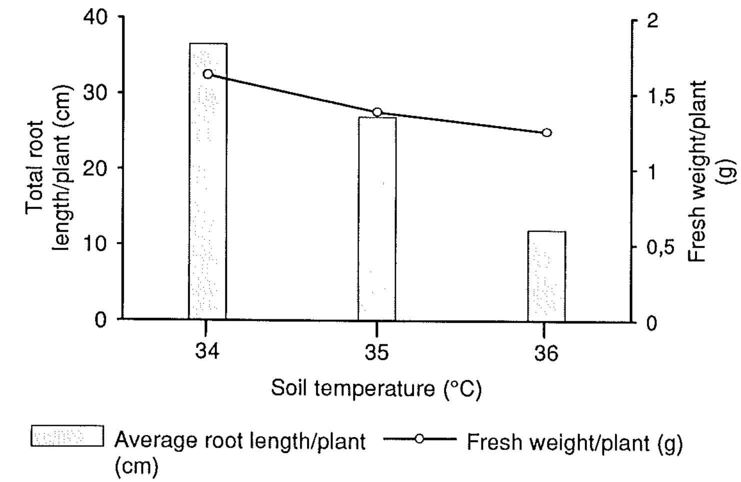
On an extremely poor, sandy soil in Senegal, CHOPART et al. (1979) observed deeper penetration of the soil by groundnut roots under mulch.

In maize, every degree Celsius that soil temperature climbs above 30°C causes a 10% reduction in yields (dry weight). When maize plants were subjected to soil temperature fluctuations in the ranges of 30-35°C, 30-38°C, 30-45°C, and 0-48°C, their growth decreased by 20, 26, 32, 44% respectively, and by about 54% as compared with a constant 30°C. Mulch helps prevent such temperature fluctuations (see Section 5.3.4). Plant heights were recorded 13 days after the maize seed began to swell. Maize grown at a constant 30°C was 50 cm high by this time. At temperatures fluctuating in the range of 30-48°C it had grown to only 24 cm (LAL 1975).

These results corroborate earlier studies by WALKER (1969), who investigated the influence of 26 days of constant soil temperature on the root and shoot growth of young maize seedlings. He found that in the 27-35°C temperature range, the weight of roots and shoots fell by 12% with each additional degree Celsius over 26°. Studies on the effect of temperatures exceeding 30°C on the root growth of soybean gave similar results (Figure 5.11). The average root length decreased drastically over 34°C.

LAL (1978) also investigated the effect of mulch on root formation. Applied between the rows, mulch clearly promoted the average and maximum depth of root extension. Lateral root extension was also enhanced. Under the mulch cover, the formation of roots near the surface increased. The results of these studies are summarized in Figure 5.11 and Table 5.8.

Figure 5.11. Influence of soil temperature on the shoot weight and root length of soybean seedlings



Source: LAL (1975)

Table 5.8. Root development in maize under different straw-mulch covers, measured 40 days after sowing, Ibadan, Nigeria

Treatment	Depth of root extension (cm)		Lateral root growth between the rows (cm)		Root weight (g/plant)
	Average	Maximum	Average	Maximum	
Total mulch cover	19.4	31	23.4	52	32.4
Mulch between the rows	21.6	33	24.1	65	26.0
Mulch on the row	17.6	45	20.6	43	23.2
Control (no mulch)	17.5	30	15.1	46	16.9

Source: LAL (1978)

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%.