

Sustainable Agriculture with No-tillage including Cover Crops and Crop Rotation

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Abstract: The results obtained by research's and also farmer's practices throughout the years in Paraná (South region) and other parts of Brazil prove that cover crops, as part of the productive systems, and also crop rotation are very economically feasible as well as ecologically sustainable. Crop residues provide a source of nutrients and inputs to soil organic matter and play an important role in maintaining a soil productivity. The understanding of how crop residues influence nutrient cycling and soil chemical and biological attributes combining the integration of residue management strategies into different cropping systems is a key to develop good soil fertility management. The continuous use of monocropping, can cause soil degradation and yield decrease. On the other hand, the no-tillage system associated with cover crops minimize soil degradation process, promote changes in the chemical, physical and biological properties of the soil, diminish the chemical external input needed, promoting higher biodiversity towards sustainability.

Key words: Soil management, no-tillage, conservation agriculture, cover crops, crop rotation, biodiversity, sustainable agriculture.

The absence of an integrated soil and water management system, mainly in tropical and subtropical regions, is quite common all over the world where the land is intensively cultivated. The common soil management practices in majority of these countries normally include the continuous soil ploughing, and no adequate cropping sequence or crop rotation which can add sufficient organic carbon to the system, or contribute to soil organic matter improvement. These activities have provoked soil erosion, soil nutrient depletion and decline in the productive potential of the agricultural land.

The addition of organic carbon to the soil through plant cultivation, as well as

through keeping plant residue, preferably on the soil surface, without ploughing the soils, are important measures to ensure organic matter improvement in the soil. Plants used as cover crop, given their capacity to produce vegetal biomass (shoot and roots) and important direct and indirect effects on the soil-water-plant system, play an important role in covering and protecting the soil surface from water and wind erosion. Also when they are part of rotation involving legumes they promote sustainable soil management in tropical and subtropical regions.

In some temperate climates, soil degradation due to mismanagement could be checked when brought under no-tillage system. Thus, the adoption of cover crops,

crop rotation and minimum disturbance of surface soil has promoted soil recovery and soil productive capacity in USA, Australia, Russia, etc.

The process of soil occupation in Paraná State, South Brazil, started more or less 60 years ago. Due to the absence of adequate occupation, planning and land use serious soil and water management problems have started. Paraná State, Brazil, is located between 26° East to 54° 30' West, and 23° 30' North to 26° 30' South. The area under tropical and subtropical forests was drastically reduced (from 84% to 24% in 1965 and to less than 10% in 1984) with agriculture covering both culturable as well as marginal areas. A total of almost 7 Mha is area cultivated with summer crops: soybean, maize, beans, cotton, rice, sugarcane, cassava, sorghum, coffee, fruits, vegetables, etc. On the other hand approximately half this area remains uncultivated in the autumn/winter, with serious risk of erosion (soil, water and nutrient losses) and also increasing weed infestation and consequently increasing labor and farm production costs.

The use of cover crops like radish, vetch, lupine, black oat, rye, millet, mucunas, pigeon pea, cowpea, crotalarias, etc., and also crop rotation systems with soybean, maize, wheat, cotton, sorghum, sunflower, etc., are increasing in different regions of Brazil and have now attained an area of over 23 Mha. There are many experimental studies on cotton-wheat rotation which yielded 2.26 to 5.0 t ha⁻¹ of cotton and 1.5 to 4.0 t ha⁻¹ of wheat, and also 6.0-9.0 t ha⁻¹ of maize and 3.2-4.5 t ha⁻¹ of soybean, varying mainly due to the rotation system, and also soil and climate conditions. Crop residue provides a source of nutrients and inputs to soil organic

matter and plays an important role in maintaining soil productivity.

An understanding of how crop residues influence nutrient cycling and soil chemical properties, integrating residue management strategies into different cropping systems, is a key to develop good soil fertility management practices. The continuous mono-cropping like maize-maize, rice-rice, cotton-wheat, soybean-wheat, etc., can cause pest and disease infestation, weed infestation, soil degradation and yield declines. On the other hand, no-tillage system, together with cover crops, minimizes soil degradation process, improves the soil attributes: chemical, physical and biological, and also diminishes the need for chemical fertilizers.

The results obtained in Paraná, South region and other parts of Brazil prove that cover crops, as part of the productive systems, are economically feasible, as well as ecologically sustainable. They also provide higher water storage in the soil profile, preventing the evaporation losses. These also result in greater crop productivity of cotton-wheat, soybean, maize, sunflower, sorghum rotations, conservation, maintenance and/or recovery of soil fertility. In addition to this, they economize on nitrogenous fertilizers (leguminous plants), higher weed control due to mulch effects, greater biological activity in the soil, higher biodiversity decreasing pests and disease infestation, represent a very promising way to manage soils for sustainability.

Alternatives for Soil Management

Generally the ancestral practice of ploughing the soil is a widespread soil management system all over the world.

In general the soil and crop management practices being adopted at present result in a soil depletion and a decrease in crop yields every year.

Presently the pre-planting soil preparation generally involves:

- Conventional tillage: Loosening and turning the soil with plough, mould board or a hoe.
- Minimum tillage: Superficial loosening of the soil (4-7 cm) or ripping of planting rows with a ripper tine (chisel plough).
- No-tillage or direct drilling: No-tillage of the soil and planting crops with special planters in previously undisturbed soil by opening a narrow slit, trench, or band only of sufficient width and depth to obtain proper seed coverage.

These practices are also called conservation tillage.

Conservation agriculture (CA) system

The CA can be described as an integrated management of soil, water and plant resources. CA relies on minimal soil disturbance, permanent soil cover, crop rotations or associations (such as the use of intercropping cover crops).

The principles and concepts of CA system involve a holistic approach, which can be adapted for different farming systems according to agro-ecological zones, and through harmonic integration of different components, such as cover crop species, crop rotation, no-tillage, terracing, intercropping, etc. The main aim of CA is to empower farmers to make more sustainable use of their land in ways that improve their income and welfare, and also save labor, promote soil water retention,

enhance soil fertility and improve crop yields (Calegari *et al.*, 2005).

Normally CA requires a certain degree of ground cover by crop residues or cover crops. The Soil Conservation Service (USA) classifies tillage practices according to the degree (%) of ground cover taken as cereal residues in units of mass (CTIC, 1994).

- Conventional Tillage: is when <15% or <560 kg ha⁻¹ of residues are on the soil surface;
- Reduced or minimum tillage: is when 15-30% or 560-1120 kg ha⁻¹ of residues are on the soil surface;
- Conservation tillage: is when >30% or >1120 kg ha⁻¹ of residues are on the soil surface.

This classification takes into account two key features of the no-tillage technique:

- no more soil disturbance and ploughing; and
- trying to add crop residues and cover crops, crop rotation, intercropping, and keeping the soil covered by mulch as long as possible.

According to Pieri *et al.* (2002), the Brazilian and Paraguayan farmers and also farmers in other countries consider the CA (no-till system) as a sustainable and environment friendly approach that ensures food security and alleviates rural poverty in tropical environments with vulnerable natural resources. Nevertheless the CA is an extremely complex system, and field experiences and strategies need to be validated in different agroecological zones.

No-tillage system

According to Phillips and Young (1973) no-tillage is planting crops by opening a

narrow slit trench or band of sufficient width and depth to obtain good seed coverage. On the other hand there are new no-till machines in the market that bury the seeds at regular intervals without opening the land. No other soil preparation is done. Cultivation is made unnecessary and unwanted weeds and grasses are controlled by weedicides. No-tillage is the only sowing method that allows the soil to remain covered with plant residues or growing plants throughout the year. Therefore in combination with mulch producing crops and adequate rotations, which avoid the raindrop impact on the soil surface, they are one of the most efficient production systems for tropical and subtropical regions to substantially reduce soil losses, improve soil fertility, increase crop yields and make sustainable land use possible.

Clearly the great challenge in no-till system is to identify the correct management system in order to organize the different components properly, i.e., proper use of herbicides correct time of application, correct fertilizer application, as well as adequate cover crops and appropriate crop rotation system. Definition of the system requires continuous observation in the field and a monitoring of soil characteristics.

Minimum tillage as an alternative to no-tillage

In some countries, specifically in some special agro-ecological zones and under conditions where no-tillage has some constraints because no mulch or crop residues are available on the soil surface, and mainly in dry savannas of west and south-eastern Africa, the minimum tillage is the second-best choice for soil management. Normally with this system a few reduced operations need

to be undertaken that lead to labor and energy consumption for soil and seedbed preparation.

In general, the lack of infrastructure is a less significant constraint in many regions. However, agricultural input (implements, fertilizers, herbicides), and information requirements are lower than for no-tillage techniques. The switch over from conventional (soil ploughing) to minimum tillage is a much smaller step than the direct transition to no-tillage. One of the major constraints for small-scale farmer is the increased demand on the farm management, particularly weed control and crop residue management (Steiner, 1998).

One of the greatest potential for minimum tillage is in sub-Saharan Africa, in dry savannas (800-300 mm), and area within those regions where ploughing is widespread.

History of Soil Management in Brazil

The conservation of soil and water in Brazil was not a priority until the seventies. Since the predominant system was perennial crops and pastures, erosion was not so severe and had not created such interest. Therefore, it was not considered to be a priority area until the so-called industrialization phase and agricultural intensification began in the country. With the expansion of area under arable crops and tractorization (which practically doubled in the Paraná in the seventies) in the absence of conservation technologies, led to accelerated soil erosion and then initiation of research on soil and water conservation (Bolliger *et al.*, 2006).

Over the years it became necessary to join efforts and systematize global integrated

actions, capable of answering complex demands through use of efficient techniques.

In Brazil, no-tillage (CA) system began more specifically in the state of Paraná at the beginning of the seventies, with a pioneer farmer, Mr. Herbert Bartz from Rolandia North Paraná. The main objective was to control erosion in southern Brazil where soybean and wheat were intensively cultivated. Afterwards, maize also began to be cultivated under this system.

In the eighties, technical data showed that the system should not be a mere new alternate soil management method, but rather evolve into a system integrated to different practices that should develop in an orderly, interrelated and dependent fashion. In 1984, there was around 300,000 ha land under no-tillage in Paraná (5% in the state itself), and after 1985, it covered an area of 800,000 ha in southern Brazil (Derpsch *et al.*, 1991). Now Brazil has over 23 Mha of land under no-tillage system, where Paraná State at present has the highest area (more than 4.8 Mha) under no-tillage.

From the total area under arable crops in Paraná State, approximately half remains uncultivated in the autumn/winter, though wheat normally is planted in 1-1.2 Mha, and early maize on about 1 Mha. In addition to this diversity of exploitations, recent transformation of agriculture (in the seventies), and urban-industrial development of the country contributed to this variance.

In the past 60-70 years the state of Paraná was subjected to expansion of agricultural areas that led to serious soil and water management problems.

For many years, water erosion was considered to be a serious environmental problem in agricultural sector, and the execution of programs having mechanical conservation practices were insufficient to control water erosion. This greatly contributed to increased awareness of the problem and led growers to organize search for common alternatives and solutions.

The search to reverse the erosion process in farming areas of Paraná followed three basic strategies: increase vegetation mulch on the soil; increase water infiltration in the profile and minimize run-off.

These three basic issues necessarily include the use of mulch plants (cover crops), which in addition to protecting the surface improve the physical structure of the soil because of the roots and residue that contribute to increased water infiltration rates in the soil.

At present, there is a serious concern on the part of most growers to find appropriate global planning for soil exploitation and use, maintenance and/or recovery of fertility levels and productive capacity, improving organic matter and preserving natural resources.

Many research results and the practices adopted by growers in different parts of the world indicate that minimum disturbance in the soil and perfect mulch of growing plants or their residues on the surface, are effective ways to protect and restore the productive potential of the soil.

An understanding of how crop residues influence nutrient recycling and soil chemical properties and combining strategic

integration with residue management in different cropping systems is the key to develop good soil fertility management (Schomberg *et al.*, 1994).

Soil Management and Effects on Soil Attributes

During the growing periods different crops do not impose the same effects on soil erosive processes. This is directly linked with the biomass production (shoot and root), soil cover capacity, crop residues stability on soil surface, and residue effects on the soil properties: soil density, soil aggregates, infiltration rates, porosity, etc.

Besides the crops (shoot and roots) the soil management practices influence dynamics of soil and water. Bertoni and Lombardi (1985) in Sao Paulo State, Brazil,

Table 1. Effect of different cash crops on soil and water erosion

Crops	Losses	
	Soil (t ha ⁻¹)	Water (rain %)
Beans	38	11
Cotton	25	10
Soybean	20	7
Maize	12	5

Source: Bertoni and Lombardi Neto (1985).

has shown that under conventional system (1 plough + 2 disc harrowings) higher soil erosion leads to nutrient and moisture loss and extent of loss depended on the cropping system (Table 1).

Research results from Campinas-SP region in Brazil (Table 2), showed soil and water loss from field having 6% slope where soybean was planted in rotation with black oat adopting different mechanized soil management practices (Table 2). The

Table 2. Effect of soil management practices on soil and water losses

Soil management	Soil losses (t ha ⁻¹ year ⁻¹)	Water losses (mm year ⁻¹)
No-tillage	1.1	13.1
Chisel plow	3.4	35.7
Disc plough	7.7	93.0
Heavy disc harrowing	9.0	109.5

Source: Castro *et al.* (1993).

results revealed that CA (no-tillage) had advantages over other soil management systems.

The soil compaction behavior in the no-till system is interesting. Laurani *et al.* (2004) showed that winter black oat increased the soil macroporosity. Stone and Silveira (1999) concluded that no-till irrigated system promoted higher water availability in the soil due to less soil disturbance. They found that the ploughing treatments (moldboard plow and disc harrowing) compacted the soil in deeper horizons (15-20 cm), while in the no-till system the resistance to infiltration was more in surface soil layers.

One positive aspect of no-till system is the reduction of tractor and labor use, and hence lower costs. Seixas *et al.* (2005) showed that the soybean root growth was more in ploughed plots than in no-till plots. In arid zones it is desirable to have better and deep root distribution for better soil moisture exploitation. Ralisch and Furlani Jr. (1996) evaluating the root distribution in a long-term experiment (10 years) observed that different soil management practices induced soil compaction in different layers and changed the crop roots distribution (Fig. 1). Similar results were obtained by Beutler and Centurion (2004).

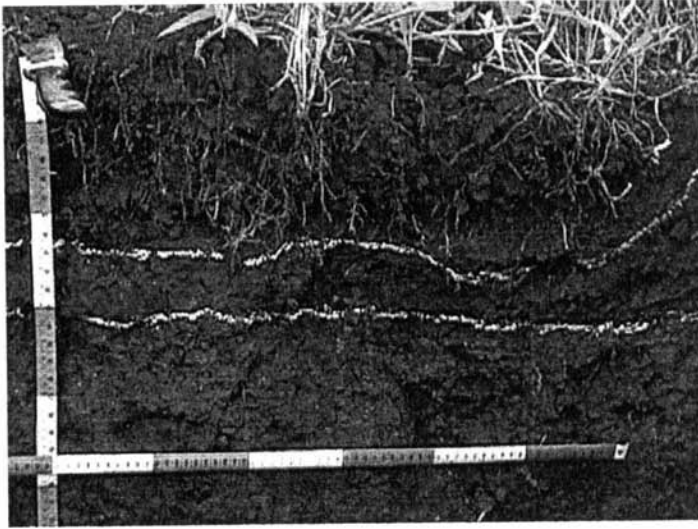


Fig. 1. Disc ploughing effects on soil compaction and roots concentration.

The continuous disc ploughing results in soil loss from upper 23 cm soil profile. The highest crop root concentration occurs at this soil depth (23 cm). In the 23-30 cm layer a soil compacted zone induced by the vertical pressure of the discs was observed, which prevented the root growth. When arid zones are considered these aspects must be taken into consideration, mainly because of the reduction of plants' ability for water extraction.

The soil compaction reduces water infiltration rates, decreasing the soil water storage, thus contributing to enhanced run off and erosion process. Simultaneously it reduces the soil water retention and consequently the soil water available in the system. Laurani *et al.* (2004) studied the ability of soil water retention by different winter crops, where two commercial and two cover crops were grown.

The grains (wheat and maize) were harvested and the remaining straw residue

were left on the soil surface. At lower tension, the cover crops promoted water retention and availability in the surface layers than the commercial crops (Fig. 2a). This probably was an effect of biopores increasing the macroporosity. In the second layer the early maize presented the lowest water tension, probably as a result of poor crop rotation in the system (Fig. 2b).

Therefore, for better soil physical and fertility management the general recommendation for the arid zones is to immediately stop the continuous soil ploughing in order to increase the water infiltration and retention in the soil profile. Keeping soil surface covered and adopting suitable crop rotation, according to the agro-ecological zone, is crucial to increase moisture in the soil profile. To overcome some soil physical constraints like soil compaction, a mechanical device for soil working may be developed. In this case, we recommend the use of chisel plow, and the use of disc plough must be avoided.

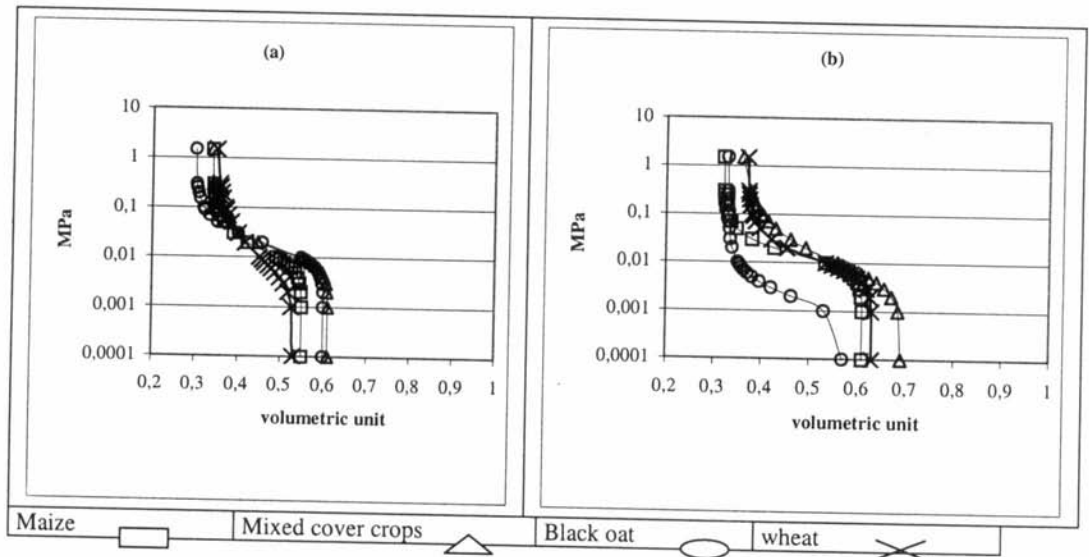


Fig. 2. Maize Mixed cover crops Black oat wheat Figure 02: Water retention in different winter crop treatments a) 0-10 cm and b) 10-20 cm soil deep (Laurani *et al.*, 2004).

Influence of Cover Crops, Tillage and Residue Management on Soil Properties and Crop Yields

Cover crops

Cover crops are planted primarily to protect the soil from direct impact of raindrops. Protection is provided by the growing plants themselves as well as by their residues that remain on the soil surface. In natural systems, nutrients released from litter are taken up by plants, resulting in efficient use of nutrients. In agro-ecosystems the two processes of release and uptake are often separated in time, resulting in low nutrient-use efficiency. This is particularly acute with N, where substantial amounts are lost by leaching, denitrification, and ammonia volatilization. In agricultural systems where cover crops are buried or left on the soil surface they decompose gradually and release nitrogen to the

following crop with less risk of nitrogen loss. The slow mineralization rate, for instance in wheat and sorghum residues, was beneficial to the subsequent crop (Wagger *et al.*, 1985).

The importance of soil cover to increase infiltration rates and reduce erosion has been shown by several workers (Manning and Meyer, 1963; Triplett *et al.*, 1968; Hudson, 1971; Greenland, 1981; Lal, 1975, 1982, 1987, 1990; Sidiras and Roth, 1984). In a 20-year study on erosion in Africa Roose (1977) showed that even under high rainfall a total soil cover with mulch (plant residues) of 4 to 6 t ha⁻¹ may protect the soil from erosion to the same extent as a secondary forest of about 30 m height.

Different multipurpose crops such as cover crops or grain and forage crops can be promoted, mainly for small-scale farmers in semi-arid areas. These protect and

improve soil properties, provide food and feed. Therefore, different species may be used, like *Vigna unguiculata* (cowpea), *Dolichos lablab* (lablab), *Cajanus cajan* (pigeon pea), *Mucuna pruriens* (mucuna), and also some other species that improve soil properties, like *Pennisetum americanum* (millet), *Brachiaria ruziziensis*, *Stylosanthes sop.* (stylo), *Clitoria ternatea* (butterfly pea), *Calopogonium mucunoides* (calopo), etc.

Results obtained with winter cover crops in South Brazil including Paraná, show that significant yield increases can be achieved if proper cover crop is included in the rotation system (Muzilli *et al.*, 1983; Derpsch *et al.*, 1986; Santos *et al.*, 1990; Bairrao *et al.*, 1988; Medeiros *et al.*, 1989; Calegari *et al.*, 1993; Calegari *et al.*, 1995; Bolliger *et al.*, 2006). Almeida and Rodrigues (1983, 1985) have shown that cover crops like black oats, oil seed radish, hairy vetch, can be effective in reducing weed population in the no-till system and consequently reducing the amount of herbicide needed. According to them there is a linear correlation between the amount of biomass produced by cover crops and their effectiveness in suppressing weeds. The effects on weeds may not only be through competition for light, but also the allelopathic effects due to plant exudates (Altieri *et al.*, 1978).

Sorrenson and Montoya (1984) working in South Brazil, concluded that herbicides are the most expensive component in no-tillage, accounting for approximately 25% of the total operational costs in soybeans and maize cropping. This is an important economic reason to include the appropriate cover crop in the rotation system.

In eastern Nebraska, Power *et al.* (1986) in a 4-year study, found that covering the

soil surface with crop residues favorably influenced the biological activity than that of the bare soil, especially biological activity compared to the N-mineralization process. Crop residues on the soil surface reduce soil temperatures and evaporation losses and is an excellent management practice for reducing the impact of a stressful climate. Thus, when residues are on the soil surface the soil water content rises and optimum conditions for microbiological activity are created, especially the surface soil is biologically most active where soluble carbon supply is maximum. These environmental changes will enhance the mineralization rate and availability and uptake of soil N by the growing crop.

Crop rotation

Based on many years of research from different parts of the world Cook and Ellis (1987) presented three principles about crop rotation:

- rotation of crops is better than continuous cropping even if the crops are non-leguminous or depleting in nature (maize compared with maize-oats);
- to be highly effective, a rotation system must include a legume; and
- the isolated use of rotation is not sufficient to maintain productivity; extra plant nutrients are needed to take full advantage.

The importance of the legumes in the rotation is not only addition of nitrogen to the system, but also the soil structure is improved by organisms that decompose leguminous organic matter. The usefulness of legume cover crop in maintaining or build-up of soil fertility has long been

recognized and legumes have been traditionally used for this purpose (Sturdy, 1939).

The monocrop can modify the environment through selective nutrient uptake from the same root depth, specific root exudates, favorable conditions for increase in some specific micro-organisms, effects of root exudates on soil pH, etc. Also the monocrop may increase the infestation of pests and diseases and also favor some weed species. Therefore, monocrop may interfere with soil-water-plant relations and also diminish soil fertility leading to lower crop yields.

On the other hand, crop rotations improve the soil aggregation and aggregate stability (Calegari *et al.*, 1994), decrease risks of soil compaction (Derpsch *et al.*, 1991; Dillenburg *et al.*, 1994), enhance water infiltration rates (Roth *et al.*, 1987; Calegari *et al.*, 1993) and decrease erosion process. Most data show that rotation in farming results in higher yields than does monocropping.

The use of cover crops and crop rotation in Brazil

The results obtained in Paraná and other parts of Brazil reveal that cover crops and no-tillage are economically feasible as well as ecologically sustainable, providing not only greater crop productivity, but also conservation, maintenance and/or recovery of soil fertility, greater biological balance in the soil, decreasing the effects of pests and or diseases. In other words they represent a very promising way to manage soils sustainably.

Cover crop species developed in Paraná State and other Brazilian states: Different

agroecological zones of Paraná State and also in other Brazilian regions, with several farming systems, present a large number of species of cover crops that had been largely used by farmers. These species grow in many regions in different cropping systems with cash crops such as, maize, wheat, beans, soybean, cotton, cassava, potato, groundnuts, sunflower, vegetables and also intercropped with perennial crops, such as, coffee, citrus, fruit trees, grapes, etc. Number of these crops are leguminous and fix atmospheric nitrogen that may enrich the fertility of the soil (Table 3). These also improve soil properties and growth of next crop, and also provide food and feed. Many cover crops are species used in crop rotation in Brazil. These cover crops may provide substantial amount of nutrients to soil and some species can be used by livestock when these are grazed (Tables 4 and 5). Some of these species are described here.

Winter species: Hairy vetch (*Vicia villosa*), common vetch (*Vicia sativa*), serradella (*Ornithopus sativus*), radish (*Raphanus sativus*), white lupin (*Lupinus albus*), blue lupin (*Lupinus angustifolius*), field pea-Iapar-83 (*Pisum sativum*-subspecies *arvense*), black oat (Iapar-61) (*Avena strigosa*) white oat (*Avena sativa*), raygrass (*Lolium multiflorum*), rye (*Secale cereale*), sweet pea (*Lathyrus sativus*), *Linum usitatissimum*, *Trifolium repens*, *Trifolium pratense*, *Lotus corniculatus*, corn spurrey (*Spergula arvensis*), X *Triticum secale*.

Summer species: *Crotalaria juncea*, *Crotalaria mucronata*, *Crotalaria spectabilis*, *Crotalaria breviflora*, *Crotalaria grantiana*, *Crotalaria paulina*

Table 3. Annual biological N fixation by legume crops

Crops	kg ha ⁻¹
Alfalfa (<i>Medicago sativa</i>)	127-333
Groundnuts (<i>Arachis hypogaea</i>)	33-297
Calopo (<i>Calopogonium mucunoides</i>)	64-450
Cowpea (<i>Vigna unguiculata</i> sin. <i>Vigna sinensis</i>)	73-240
Centrosema (<i>Centrosema pubescens</i>)	93-398
Crotalaria (<i>Crotalaria juncea</i> L.)	150-165
Tropical Kudzu (<i>Pueraria phaseoloides</i>)	100
Desmodium (<i>Desmodium</i> sp.)	70
Peas (<i>Pisum sativum</i>)	81-148
Common vetch (<i>Vicia sativa</i>)	90
Hairy vetch (<i>Vicia villosa</i>)	110-184
Stylo (<i>Stylosanthes</i> sp.)	30-196
Faba beans (<i>Vicia faba</i>)	88-157
Jack bean (<i>Canavalia ensiformis</i>)	57-190
Florida Hammock Milkpea (<i>Galactia striata</i>)	181
Chick pea (<i>Cicer arietinum</i>)	41-270
Pigeon pea (<i>Cajanus cajan</i>)	41-90
Clusterbean (<i>Cyamopsis psoraloides</i>)	37-196
Lentils (<i>Lens culinaris</i>)	35-77
Korean lespedeza (<i>Lespedeza stipulacea</i>)	193
Leucaena (<i>Leucena leucocephala</i>)	400-600
Black mucuna (<i>Stizolobium aterrimum</i>)	157
Perennial soybean (Neonotonia wightii Lacrey (sin. <i>Glycine wightii</i> Verdc.)	160-450
Siratiro (<i>Macroptilium atropurpureum</i>)	70-181
Soybean (<i>Glycine max</i>)	17-369
Lupins (<i>Lupinus</i> sp.)	128
White clover (<i>Trifolium repens</i>)	128-268
Sweet melilotus (<i>Melilotus alba</i>)	9-140
Egyptium clover (<i>Trifolium alexandrinum</i>)	62-235
Red clover (<i>Trifolium pratense</i>)	17-191
Subterranean clover (<i>Trifolium subterraneum</i>)	21-207
Trigonella (<i>Trigonella faenum grecum</i>)	44
<i>Vigna</i> sp.	63-345

Adapted from Calegari *et al.* 1993.

Crotalaria ochroleuca, *Crotalaria retusa*, *Crotalaria striata*, *Crotalaria anagiroides*, *Mucuna pruriens* (black, grey and dwarf varieties), *Canavalia ensiformis*, *Canavalia brasiliensis*, *Vigna unguiculata*, *Vigna umbelata*, *Vigna radiata*, *Arachis pintoi*, *Arachis hypogaea*, *Cajanus cajan*, *Dolichos lab-lab*, *Eleusine coracana*, sunflower (*Helianthus annuus*), *Indigofera* spp., *Stylishness* sp., *Calopogonio mucunoides*, *Pueraria phaseoloides*, *Glycine wightii*, *Centrosema pubescens*, *Macroptilium atropurpureum*, *Clitoria ternatea*, *Setaria italica* (annual), pearl millet (*Pennisetum americanum*), *Sorghum bicolor*.

Plants used as cover crop, given their high capacity to produce vegetal biomass and roots, play a crucial role when they are an integral part of orderly rotation systems with cash and food crops.

Effects of Cover Crops, Crop Rotation and No-tillage System on Soil Properties and Cash Crops

The legumes in rotation systems add nitrogen to the soil and improve the soil structure. Adopting no-tillage system (CA), involving cover crops or crop residues, and crop rotation, have improved the soil properties and crop yields. The organic residues added to the soil and the continuous no-tillage, contribute to development of soil fauna (Table 6).

These results obtained in North Paraná, show that as the soil is disturbed the earthworm population decreases. As more organic residues are accumulated on the soil surface it provides favorable conditions and earthworm population increases. Also the inclusion of cover crop after soybean

Table 4. Chemical composition of crops used as cover crop and animal feed at flowering stage

Cover crops	N	P	K	Ca	Mg	C	C:N	Cu	Zn	Mn
	(% of dry matter)						ratio	(ppm)		
<i>Crotalaria juncea</i>	2.50	0.19	1.20	2.31	0.47	45.25	18.10	14	44	179
<i>Crotalaria spectabilis</i>	2.17	0.09	1.59	0.49	0.37	50.83	23.42	8	23	126
<i>Cajanus cajan</i>	2.61	0.14	2.61	1.79	0.45	56.30	21.57	7	22	87
<i>Canavalia ensiformis</i>	3.19	0.15	5.62	1.35	0.63	50.15	15.72	9	62	254
<i>Canavalia brasiliensis</i>	2.49	0.13	1.68	0.20	0.16	51.24	20.57	4	14	17
<i>Mucuna pruriens</i> (grey)	2.50	0.15	1.40	1.20	0.27	52.30	21.12	16	28	183
<i>M. pruriens</i> (black)	2.49	0.13	1.40	1.17	0.27	52.15	21.06	14	29	174
<i>M. pruriens</i> (dwarf)	3.10	0.19	4.49	2.14	0.65	50.83	16.39	9	85	179
<i>Vigna radiata</i>	2.09	0.21	4.94	1.48	0.75	52.47	25.10	10	78	127
<i>Vigna unguiculata</i>	2.62	0.20	2.82	0.93	0.28	45.42	17.33	–	–	–
<i>Indigofera</i> sp.	2.17	0.14	1.54	1.20	0.32	40.36	18.60	13	24	53
<i>Calopogonium mucunoides</i>	2.16	0.12	1.56	1.40	0.29	46.73	21.63	9	15	172
<i>Pueraria phaseoloides</i>	3.68	0.29	2.14	1.30	0.41	54.10	14.70	11	27	155
<i>Glycine wighti</i>	2.60	0.23	2.39	0.99	0.35	45.03	17.31	8	32	102
<i>Centrosema pubescens</i>	2.34	0.23	1.19	0.66	0.45	47.60	20.34	10	32	67

Source: Adapted from Calegari, 1995.

enhances the arthropod number, and no-tillage is more favorable than CT.

On-farm research in North of Paraná, Santo Antonio farm (Calegari *et al.*, 1995) showed an increase in soil water infiltration from 20 mm h⁻¹ in conventional tillage to 45 mm h⁻¹ in no-tillage (soybean-wheat system) due to soil physical characters improved by crop rotation and no-tillage system. This increased soil water infiltration rate was also due to organic residues (roots, leaves, etc.) and soil micro-organism activity, including root exudates and fungal hyphae. After seven years, important changes in nutrient levels and organic matter, under different soil management systems were observed (Table 7).

The results revealed that after seven years the organic matter decreased when the soil was ploughed (conventional

system). In contrast when soil was not disturbed (no-till) increased amount of organic residues were added and the lower decomposition rates contributed to improved soil organic matter. In the plots where crop rotation and no-till was adopted organic matter build up was the highest (30.0 g dm⁻³). In the same way levels of other nutrients (P, K, Ca, and Mg) and also CEC were higher than that observed in other treatments. Comparing data from no-tillage plots after seven years in forest soil (undisturbed), P, K, and Mg accumulated with the residue addition and the levels were higher than those found in forest soil. These results revealed that the no-tillage system with crop rotation improved the soil fertility (Calegari, 1995).

In the field condition different rotation systems were evaluated and one that included white lupin, contributed to the

Table 5. Chemical composition of winter cover crops

Cover crops	N	P	K	Ca	Mg	C	Protein	C:N ratio	Zn	Cu	Min
Hairy vetch	3.82	0.30	2.03	0.78	0.27	37.87	23.87	10.05	26	9	61
Common vetch	2.87	0.23	2.88	1.05	0.41	37.10	17.94	12.90	24	9	87
Ornithopus	1.79	0.14	3.55	1.10	0.45	40.14	11.18	22.43	59	13	97
Radish (cv. Silletina)	2.68	0.17	2.80	1.54	0.76	38.58	16.75	14.45	49	8	84
White lupin	3.20	0.09	2.66	0.46	0.38	47.49	20.00	14.84	57	12	330
Yellow lupin	2.94	0.16	2.50	0.59	0.39	42.25	18.37	14.37	66	14	359
Blue lupin	3.19	0.19	2.29	1.20	0.49	37.83	19.93	11.86	24	13	230
Sweet Blue	2.28	0.10	1.75	0.59	0.42	37.87	14.25	16.61	32	16	147
Lupin (cv. Unicrop)											
Field pea IAPAR-83	2.09	0.12	1.50	0.70	0.20	39.77	13.06	19.02	8	22	52
Wheat	0.77	0.06	1.15	0.22	0.10	40.38	4.81	52.71	—	—	—
Sweet pea	2.23	0.10	2.90	0.39	0.19	41.91	13.93	18.79	22	11	52
Black oat	1.93	0.28	2.15	0.43	0.21	39.69	12.06	20.76	11	7	102
White oat	0.81	0.05	2.40	0.24	0.17	38.52	5.06	47.55	9	6	138
Ryegrass	1.34	0.06	2.60	0.41	0.22	59.22	8.37	44.20	23	9	214
Rye	1.22	0.07	1.40	0.18	0.14	44.59	7.62	36.54	15	6	53
Sunflower	1.80	0.15	2.40	1.55	0.62	39.95	11.25	22.19	31	18	96
Corn spurrey	2.13	0.22	3.45	0.52	0.77	41.92	13.31	12.78	44	11	136

Source: Adapted from Calegari *et al.*, 1993.

increased nitrogen input to the system, increasing the maize yield. The areas planted with black oat plus white lupin showed a higher accumulation of mulch on the soil surface, when compared with conventional system.

Comparing both the systems, summer crop yields in no-tillage were 34.4% and 13.7% higher for soybean and wheat, respectively, in conventional tillage. In addition, the crop rotation was more efficient, increasing soybean yield by 19.2% and wheat yield by 5.8% as compared to monoculture (Table 8).

Oliveira (1994) working in a Eutrophic Red Latosol (Eutrorthox) in North Paraná

State, evaluated the response of cotton to various winter cover crop systems and N fertilization. The mineral N equivalence (Neq) is defined by the amount of nitrogen applied on summer crops, cultivated after fallow or grass soil cover, to obtain similar yields with that obtained after legume cover crops without applying nitrogen (Smith *et al.*, 1987). These authors reported that the Neq from hairy vetch and red clover varied from 67 to 101 and 34 to 68 kg ha⁻¹ of N, respectively, to the cotton and 78 to 200 and less than 50 to 67 kg ha⁻¹ of N to maize crop. Also in Paraná, Muzilli (1978) and Muzilli *et al.* (1983) found that the Neq from common vetch and serradela were 80 kg ha⁻¹ and from white lupin was

Table 6. Soil fauna under no-tillage as compared with conventional and conservation tillage

	Conventional tillage	Minimum tillage	No-tillage
Earthworms m ⁻²	5.8	7.5	13.0
March 1979			
November 1981	3.2	5.2	27.6
Arthropodes 300 cm ⁻³			
Soybean/wheat	7.0	–	33.0
Soybean/cover crop	23.0	–	192.0

Source: Derpsch *et al.*, 1986.

higher than 90 kg ha⁻¹ of N to the maize crop; these are in accordance with Derpsch *et al.* (1991) and Calegari (2000), who found more than 90 kg ha⁻¹ of N from white and blue lupin to the maize and also Calegari (2000) found more than 120 kg ha⁻¹ of N from hairy vetch to maize crop.

The results obtained by Oliveira (1994) showed Neq of 160, 90 and 106 kg ha⁻¹ of N, respectively, to white lupin, black oat + lupin and radish. The nitrogen mineralization and uptake by cotton was variable and was dependent on different treatments. The lowest cotton yield (including seeds) was obtained in fallow

condition and varied from 2700 to 3000 kg ha⁻¹ (zero and 120 kg ha⁻¹ of mineral N, respectively). There was significant nitrogen response to the mineral N until 60 kg ha⁻¹ in all other treatments. The high cotton yield attained was after lupin (almost 3300 kg ha⁻¹, without mineral N). When it was complemented with 60 kg ha⁻¹ of mineral N the yield was 3500 kg ha⁻¹. These results suggest that it is possible to reduce the nitrogen demand of cotton with rotation and use of cover crops. When some legume is planted before cotton, more nitrogen may be available and need for chemical fertilizer may be reduced (Table 9).

Table 7. Comparative fertility levels on natural forest, no-tillage and conventional system (0-20 cm soil depth). Santo Antonio Farm; Floresta, Paraná - Brazil)

Treatments	Year	pH	O.M.	P	K	Ca ⁺⁺	Mg ⁺⁺	CEC	Basis*
		(CaCl ₂)	(g dm ⁻³)	(mg dm ⁻³)		cmolc	dm ⁻³		
Subtropical forest soil	1985	7.1	49.0	9.0	0.45	12.3	1.80	16.4	88
Soil sample at beginning	1985	4.4	28.0	4.6	0.30	5.32	1.23	11.80	58
W-S/W-S (convent.)	1992	4.8	26.7	8.8	0.61	3.75	1.56	11.27	52
W-S/W-S (no-till)	1992	5.7	29.1	19.5	0.67	5.73	2.88	12.96	71
W-M/O-S (no-till – Rotation)	1992	5.6	30.0	21.0	1.07	5.78	2.88	13.70	71

Source: Calegari *et al.*, 1995; W: Wheat; S: Soybean; M: Maize; O: black Oat; * Basis saturation.

Table 8. Crop yields (kg ha^{-1}) in different tillage and management systems, Santo Antonio Farm - Floresta - PR (average of 1985-86 to 1991-92)

	Soybean		Wheat	
	Yield	Per cent	Yield	Per cent
No-tillage	2816 ^a	134.4	2121 ^a	113.7
Convent. tillage	2094 ^b	100.0	1864 ^a	100.0
Crop rotations*	3040 ^a	119.2	2200 ^a	105.8
Monoculture*	2550 ^b	100.0	2078 ^a	100.0

Source: Calegari *et al.*, 1998; * No-tillage system.

Numbers in the columns followed by the same letter are not different (Tukey 0,05).

Costa *et al.* (1993) working for 10 years in North Paraná found when cotton crop was taken after white lupin there was 8% increase in cotton yield compared with cotton monocrop taken with chemical fertilizers. After soybean the cotton yield was 13% higher than cotton monocrop and when cotton was taken after maize + black mucuna, it was 5% higher than cotton monocrop.

In a clayey Oxisol, Calegari *et al.* (2005) found higher soil organic carbon in no-till treatment when the cover crops and crop rotations were included, and also higher values for AS (%), MWD and GMD were recorded. Under conventional system where the soil was disturbed every season the soil organic carbon decreased and had lower values for AS (%), MWD, and GMD, and also lower % of soil aggregates >2.00 mm were recorded, indicating system to be not sustainable.

In a field experiment after nine years with no-till and conventional system in clay soil in Southwestern Paraná (Pato Branco municipality), the maize yields showed significant differences according to tillage regime and nitrogen levels (Fig. 1). The no-till system even without addition of N gave higher maize yields than did

conventional tillage with N (90 kg ha^{-1}). The exceptions were wheat and radish as winter cover crops. Probably N immobilization in the wheat straw decreased the yield with no-till.

Also when nitrogen was applied with no-till, maize production was higher for all trials than conventional tillage. Maize yields are dependent on the previous crop and cultivation practices adopted in previous years. Because with no-till there was no response to N application (actually yield was lowered) from the legume cover crop treatments (lupine and vetch), and also with oats used as a cover crop, these results suggested that there was higher availability of N with these plants than with the wheat, radish and fallow treatments. Probably oat straw accumulated during several previous years and the organic matter accumulated on the soil surface contributed for this.

Table 9. Crop rotation systems and cotton yield

Rotation	Cotton yield (kg ha^{-1})
Soybean - cotton	1228 (133)
Groundnuts - cotton	1494 (162)
Black mucuna - cotton	2083 (225)
Cotton - cotton (monocrop)	924 (100)

Figures in parentheses is a comparison (%) with continuing cotton (100).

Under no-till with legume cover crop it is possible to obtain yields from this combination equivalent or more than 90 kg ha⁻¹ of N, which is not produced with conventional tillage. The maize yield increase was correlated with soil phosphorus availability and with phosphorus content in maize plant leaves. The greater phosphorus uptake is attributed to higher moisture content below the mulch and consequently higher phosphorus diffusion rate by plants.

No-tillage System in Savannah Areas of Brazil

In some of the Brazilian savannah areas average annual rainfall is 600 to 800 mm, concentrated mainly between October and March. The no-tillage system has spread in the last 6-8 years, and occupies about 4 Mha. The main crops are soybean, maize, cotton, sorghum, and to promote soil cover and improve the crop rotation, farmers are planting species like pearl millet, sorghum, sunflower, finger millet, *Brachiaria* sp. (*ruziziensis*, *brizantha*, etc.); in some areas also they are using black oat, and some legumes like pigeon pea, mucuna, crotalaris, etc. The cotton cultivated as monocrop (cotton-fallow), has presented several problems in some regions of Mato Grosso do Sul (Cerrados of Brazil) (Freire *et al.*, 1993). In the same way successive planting of cotton-beans or cotton-black oat for many years also has resulted in many undesirable conditions. To change this and improve soil properties (biological, chemical and physical) and consequently to enhance the cotton yield with adequate use of cover crops and crop rotation Medeiros *et al.* (2001), working in an Oxisol in Paraná (clay and sand soil), found

consistent results with the use of black oat (cv. Iapar-61) which is very efficient in keeping the soil covered, controlling weeds and saving moisture. With crop rotation the system improved the cotton yields.

In some regions of Mato Grosso do Sul and in some other regions of Brazil, where nematodes knot root is a serious problem, the rotation including cotton is a good strategy to be followed.

Lamas (2000) and others working in savanna areas of Brazil reported that the crop rotation, apart from improving soil, also significantly increased the cotton yield and the cotton monocrop is not sustainable. Many researchers have shown that in general maize is very effective when rotated with cotton (Table 10).

Table 10. Crop rotation effects on cotton yield

Crop rotation	Cotton yield (kg ha ⁻¹)
Maize/Cotton/Beans/ Groundnuts	1162 (141)*
Maize/Cotton/Groundnuts	1384 (169)
Rice/Maize/Cotton	2182 (266)
Cotton (monocrop)	821 (100)

Numbers with in parentheses are a comparison (%) with continuing cotton (100).

Source: Fundação Cargill (1984).

Fernandes *et al.* (1999) working in no-tillage system in a clay soil (67% clay) in Dourados Mato Grosso do Sul State (Brazilian Cerrados), after cultivating soybean (summer) and black oat (fall) for many years planted cotton and attained yield of 4.325 kg ha⁻¹ (fiber + seeds). They concluded that planting cotton in rotation with soybean and a grass (black oats and

in some areas wheat) is beneficial (Joao, 2000 Personal Information). Results obtained by IAC (Agronomic Institute of Campinas), in Pirassununga, Sao Paulo State, has shown that in the sequence maize + black mucuna (intercropped)/cotton planted in rotated strips, the cotton yield was 72% higher than cotton after cotton as monocrop. Evaluating the effects of different cover crops on cotton yield, Bolonhezi *et al.* (1999) working in a Red Latosol in Ilha Solteira, Sao Paulo State, and using 400 kg ha⁻¹ of 08-28-16 plus 50 kg N ha⁻¹ as top dressing (50 days after plant emergence), concluded that the use of suitable cover crops and the crop rotations are important to enhance cotton production (Table 11). Many studies conducted from 1950 until now by the IAC have shown that crop rotation decreased pests and diseases (mainly some nematode species) and also made possible more efficient use of machines, saving labor, decreasing the production cost and enhance cotton yield (Table 12).

For sustainable cotton production the cropping system must involve appropriate crop rotation, including cash and/or food crops and cover crops. According to Hernani

and Salton (1999) there are many possibilities of crop sequences suitable to improve production of cotton and other grain crops in the Brazilian Savanna areas.

According to Hernani and Salton (1999) there are many possibilities of crop sequences to the Brazilian Savanna areas in Brazilian "Cerrados", suitable to improve cotton and other grain production:

- Early soybean/maize/soybean/millet/cotton.

Another possibility for cold areas (temperate climate) that present low temperatures in Fall/winter could be planting the sequence:

- Maize/black oat or wheat/soybean/ wheat or vetch (hairy vetch or common vetch) or lupin (white or blue mixed with black oat or rye/cotton/radish (pivoting root) sole or mixed with grass (oat or rye).

All these possibilities must consider the agroecological conditions, the adequate sequence and timing for all operations (sowing, cover crop management, etc.), searching for monitoring the soil, and crops during the years.

Results of Cover Crops and Crop Rotation in Other Countries

Studies conducted by Wesley *et al.* (1994) in Stoneville, Mississippi, showed that the cotton yields from the cotton-sorghum rotation were significantly higher than yields of monoculture cotton and cotton rotated with soybean in both conventional and ridge-till production systems. McConnell *et al.* (1994) working in a Hebert silt loamy soil in Arkansas found cotton grown in conjunction with wheat and rye cover crops had lower yield in most instances than cotton

Table 11. Effects of cover crops on cotton yield

Previous cotton crop	Cover crop dry weight (kg ha ⁻¹)	Cotton yield (kg ha ⁻¹)
Pigeon pea	4182	2114 ^a
<i>Crotalaria juncea</i> (Sun hemp)	3950	1952 ^{ab}
Millet	3951	1621 ^{bc}
Castor beans	4059	1545 ^c
Fallow	ND	1551 ^c

Source: Bolonhezi *et al.*, 1999; Numbers followed by the same letter are not different (Tukey 0,05); ND: not determined..

Table 12. Cotton production in crop rotation system in different soil conditions

Soil condition	First crop	Second crop	Yield (kg ha ⁻¹)
Oxisol (clay)	Maize/Black Mucuna	Cotton	1240
	Cotton	Cotton	950
Sandy soil	Black Mucuna	Cotton	1224
	Cotton	Cotton	919
Area infested by nematodes	Black Mucuna	Cotton	1773
	Cotton	Cotton	978

Source: Martin *et al.*, 1984.

produced with wheat, rye or native vegetation as cover crops. Immobilization of soil N probably occurred when the grass cover crop residue decayed.

Studying the effects of cover crop, nitrogen fertilizer for no-tillage cotton production Varco (1994) worked in a Caledonia loam (fine loamy, siliceous, thermic Typic Paleudalf), where with conventional-tillage cotton monocrop was grown for many years. The results showed that legume cover crops, such as hairy vetch, can increase soil productivity in no-tillage cotton production when used alone or in combination with low rates of nitrogen fertilizer due to both N and soil moisture conservation. Also, non-legume cover crops, such as rye, can afford a yield advantage to no-tillage cotton, mainly as effects of soil moisture conservation, when it is a limiting factor.

In north-eastern Thailand the area under groundnut and soybean is increasing rapidly. These crops are grown in rotation with rice, maize and cassava. The possibility of including other legumes such as green manure crops in the cropping systems is also viable to offer more options in the crop rotation system. Toomsan *et al.* (1993) working in upland soils of this region on

groundnut followed by maize crop observed that where groundnut residues were returned to the soil, the maize yield after groundnut increased by 65%. The increase could be higher if there is minimum delay between groundnut harvest and maize planting. They concluded that in northern upland soils in Thailand, clearing and burning the residue results in a quick decrease in soil organic matter that could be restored with adequate management, including crop rotation with legumes, and return of legume and cereal plant residues in the soil, and the use of mulch to protect the soil surface.

Kang (1993) worked for a 10-year period with continuous crop on an Entisol in Nigeria where the area was occupied by maize in the main season (10 years), sweet potato in the minor season starting from the second year (3 years), followed by cowpea for the remaining 6 years. The results showed that the organic C level declined fastest in the bare fallow plot, followed by that in the unfertilized plot. With the fertilizer application (N, P, K), a higher level of organic C was maintained than in unfertilized plots. The retention of maize crop residue showed a slightly higher soil organic carbon level compared with crop residue that was removed. In addition it was observed that fertilizer application along

with crop residue retention led to higher maize yields than no fertilizer, and crop residue removal.

In northern Nigeria, maize grain yields were found to be higher following a groundnut crop than after crops of cowpea, cotton or sorghum. The yield increase was related to an increased availability of mineral N in the soil after groundnut (Jones, 1974).

In Zimbabwe, the yield of maize was greater after Bambara groundnut (7.6 t ha^{-1}) than after groundnut (6.2 t ha^{-1}), unplanted fallow (4.3 t ha^{-1}) or maize (3.9 t ha^{-1}) (Mukurumbira, 1985). Experimental results show beneficial effects, not only in the tropics, but also in temperate climate of the beneficial effects of the cover crops, crop rotation and also no-tillage system in improving soil properties, increasing crop yields, and also in enhanced biodiversity and environmental equilibrium.

Use of Technologies for Agricultural Development - Towards Sustainability

Improving soil management is a way to keep families engaged in the farming activity in a sustainable manner compatible with socio-economical resources. To guarantee long-term productive, competitive and sustainable agro-ecosystems, we must seek systems that contemplate, through biodiversity conservation, diversification in time and space, nutrient recycling and recovery and/or conservation of the physical, chemical and biological properties of the soil. Therefore, integrating conservation practices considerably help improve not only agriculture as a whole, but also the socio-economic conditions of rural farmers. This means that it is crucial

to plan agriculture, keeping environment in consideration, in places where it has greater chances of success, and where agroecosystems will act decisively to maintain acceptable dynamic balances in production and environmental quality.

The no-tillage system leads to better work distribution throughout the year, which results in the elimination of soil tilling, harrows and mechanical control of weeds. This condition will provide more time to arrange plant and manage different activities for better land diversification. With this system there is significant reduction in the soil loss, fertility improvement, better efficiency in use of soil water, crop yield increase, and there is greater production stability, in addition to the possibility of permanently using the land, thus proving that it also contributes to agricultural sustainability.

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