# Direct seeding mulch-based cropping systems (DMC) in Latin America

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## Abstract

Areas permanently cultivated under DMC systems (Direct seeding mulch-based cropping systems, which are part of the family of practices known as Conservation Agriculture) have increased remarkably in Latin America over recent decades, reaching around 50% of total cropped area in Brazil, Paraguay and Argentina. These systems have been developed to counteract soil degradation and to achieve more sustainable grain production. Under tropical and sub-tropical conditions the efficiency of such systems increases with the introduction of multi-functional cover crops growing in rotation with the main commercial crops or whenever climatic conditions are too risky for planting a commercial crop. The introduction of cover crops leads to a better utilization of available natural resources throughout the year, more biomass production, permanent soil protection and higher organic restitutions to the soil. DMC systems also offer environmental, economic and agronomic advantages to farmers. Nevertheless they are quite complex systems and their adaptation to specific local constraints and conditions is not straightforward, especially in the case of smallholder, resource-limited agriculture. Specific approaches have been designed, based on systemic and participatory research principles, to create, adapt and disseminate these systems among farmers by working mainly under actual farming conditions. The active participation of farmers and their organizations is fundamental at all stages, as well as that of other key stakeholders of the agricultural sector. Farmers, researchers and their key partners still need to meet several challenges to further increase the success and large-scale adoptability of DMC systems. These include understanding and enhancing the underlying biological processes, creating DMC systems less dependant on chemicals or external inputs, as well as fitting these systems for conditions of close interactions between agriculture and livestock production. These last two challenges are especially true for small-scale farmers operating in marginal environments. Also, the knowledge and experience about DMC systems functioning, creation and management, and about adoption stories, needs to be better systematized and made available through the development of synthetic tools such as data bases, dynamic models and global indicators of DMC system functioning and impact, as well as through enhanced networking among the different stakeholders. Putting together these various pieces will facilitate the conception and implementation of new projects aiming to enhance DMC adaptation and adoption.

## Media summary

Direct seeding mulch-based cropping (DMC) systems are currently adopted on large areas of Latin America to obtain a sustainable production of grain, increasing agronomic, economic and environmental efficiency.

## Key words

Direct seeding, Mulch, Cover crops, Natural resources management, Grain production, Tropical and sub-tropical cropping, Cropping system modelling, Adoption of technology.

## Introduction

In the humid tropics and sub-tropics, the climate is aggressive, soils are frequently deficient in nutrients and very susceptible to erosion, and organic matter mineralization rates are usually high. In this context, the application of conventional tillage techniques similar to that in use in temperate countries neither ensures sustainable management of agrosystems nor makes them cost-effective. In Brazil for example, the use of disc ploughs for growing major crops such as soybean or cotton has induced catastrophic soil erosion only 10 years after cultivation was initiated in the Cerrados region (the savannah ecosystem of central Brazil), with the loss of 30-50% of soil organic matter stocks. Under conventional systems, the yield potential of the corresponding soils has consequently declined despite the increased use of chemical inputs and the replacement of monocropping by crop rotations (Séguy et al. 1996). Furthermore, farmers from developing countries usually face severe constraints such as important climatic risks and uncertain economic conditions linked to globalization and low levels of subsidies for agriculture. Under such conditions, farmers urgently require more resilient and less risky production systems involving lower-cost technologies which at the same time offer higher, more stable productivity and profitability.

South American farmers, with the active collaboration of agronomists and other key actors of the agricultural sector, have developed over the past 3 decades new cropping systems responding in part to these requirements. These new systems, which are part of the wider family of practices known as Conservation Agriculture (CA), are based on no-tillage, permanent soil protection with vegetative mulch and direct seeding through the mulch. Referred hereafter to Direct seeding Mulch based Cropping systems (DMC), these systems have proved to be essential for implementing in practice the principles of sustainable crop production (Benites et al. 2003; Séguy et al. 2003). This paper gives an overview of DMC systems and their status in Latin America by analysing their efficiency, some of the basic factors behind their recent success and the remaining challenges to be faced in the near future in order to improve further over the current situation.

*Evolution of DMC systems in Latin America*

DMC systems have been widely adopted in the last three decades throughout the world, most notably in countries such as the United States and Canada, Australia but also in Brazil and Argentina, reaching an estimated area of 72 million hectares worldwide (Derpsch and Benites 2003; Benites at al. 2003). In the case of South America, adoption has accelerated considerably over the last fifteen years. In Brazil for example, the area under DMC has increased from less than one million of hectares in 1990 to around sixteen millions in 2003 (FEBRAPDP 2003). DMC systems now account for about 45% of all cropland areas in Brazil, 50% in Argentina, and 60% in Paraguay, higher than anywhere else in the world. Recent data from Wall and Ekboir (2002) show however that small-scale farms represent only a small proportion of the overall area under DMC (Table 1). This is in part because smallholders possess restricted access to land and to equipment and area per farm is very small in some countries (Ghana, Bangladesh or Paraguay). Until very recently, Southern Brazil and Paraguay as well as specific areas of Meso America are the only regions where significant number of farmers have adopted DMC systems, as a result of systematic investments in research and development specifically for smallholders by the government and other key stakeholders (Brazil, Paraguay), or because these types of systems were already traditional in the area (Meso America). The systems used are quite different among countries and do not necessarily represent similar intensity of application of Conservation Agriculture principles. In areas such as the Indo-Gangetic plains, or in the irrigated plains of Central Mexico, only one cycle out of the 2 yearly cropping cycles is planted under no-tillage, but residues from the previous crop are usually removed (Hobbs and Gupta 2002; Jourdain et al. 2001a). Conversely, in Brazil and in Argentina, many farmers have shifted permanently to no-tillage and maintain the soil covered on an almost permanent basis (Denardin 1998; Ribeiro 2001): therefore, these systems qualify as DMC systems.

**Table 1. Areas under CA and DMC systems on small farms in different countries in 2001/2002**

| Country | Area (ha) | N° of farmers | Area/farm (ha) |
|---|---|---|---|
| Brazil | 173,000 | 38,000 | 4.55 |
| India | 130,000 | 26,000 | 5.00 |
| Pakistan | 80,000 | 5,500 | 14.55 |
| Ghana | 45,000 | 100,000 | 0.45 |
| Bangladesh | 10,000 | 30,000 | 0.33 |
| Paraguay | 6,000 | 2,300 | 2.61 |

Source: Wall and Ekboir (2002)

*Key underlying principles for efficient DMC systems in the tropical and sub-tropical environments of LA*

While CA systems include very diverse combinations of conservation tillage, soil protection and crop rotations, DMC systems for their part are based on the rather strict, simultaneous application of these same key principles, ensuring the overall capacity of these systems to optimize natural resource management in the short and long term, and to provide satisfactory crop production year after year.

*No tillage*

In DMC systems the soil should ideally never been tilled, or as little as possible. Permanent no-tillage favours a better cohesion between soil aggregates which thus decreases soil susceptibility to erosion, particularly at the beginning of the cropping cycle, before it is protected by the crop canopy. Besides, tillage suppression reduces substantially crop production costs, as tillage is an expensive technique (fuel, labour and machinery cost). Finally, it introduces greater flexibility in the organization of the farm's activities by reducing peaks of labour and offering the opportunity of sowing earlier.

*Soil surface protection through mulch from crop residue*

Because the soil is no longer tilled, crop residues can be maintained on the surface as a mulch, protecting the soil against weather aggressions, provided they are not completely exported nor burnt. The combination of no tillage and mulching allows control of the primary cause of soil degradation in a tropical climate, i.e. soil water erosion due to rain drop impact and rainfall runoff. Furthermore, the presence of a mulch layer provides shelter and protection for the soil biota. By dampening soil temperature fluctuations, and by maintaining moisture, mulch enhances macro and micro-fauna activity. It also provides a buffer against compaction under the weight of heavy equipment or animals (Séguy et al. 2003). Conversely, mulch intercepts part of the pesticides applied by farmers: while this may reduce the efficiency of some herbicides, it generally decreases the levels of soil and water contamination.

*Crop rotations or associations*

Benefits of crop rotations are widely recognized in conventional tillage, but they are not compulsory for maintaining overall system productivity. In DMC systems crop rotations become essential as tillage suppression eliminates one of the key pest / weed management techniques used traditionally by farmers (Calegari, 2001). Added benefits of rotations include also increased biodiversity, a better use of natural resources through residue decomposition and more efficient nutrient cycling, better distribution of labor inputs and more diversified farm incomes. However, in some cases, crop residues maintained on the soil surface tend to become the refuge of some pests or disease agents thus increasing the risks of contamination in the next cycle (Altieri 2002).

*Producing biomass whenever possible*

With the objective of mimicking as closely as possible the functioning of natural forest ecosystems found in these regions, cover crops are being introduced in the DMC cropping systems before and/or after the main commercial crops. Their primary function is to produce biomass during periods when available resources are too limited or too irregular to allow a commercial crop. Generally they are able to recycle—through their strong and well-developed root systems—a major share of nutrients which would otherwise be leached away. They have therefore been called "nutrient pumps" (Séguy and Bouzinac 2001), a concept similar to that applied in the context of perennial systems with trees or forage grasses (Altieri 2002). The additional biomass that they produce is enough to keep the soil permanently covered, even under humid tropical conditions where residues decompose rapidly (Séguy et al. 2003).

*Optimisation of the multiple functions of cover crops*

In addition to the above-mentioned functions, cover crops are selected for their potential to fulfill multiple agronomic, ecological or economic functions which can supplement those performed by the main commercial crops (Anderson et al. 2001; Séguy et al. 2003). Cover crops contribute to increased rain infiltration and reduced evaporation, thus increasing the water available for crop transpiration (Scopel et al. 1998). They also contribute to the mineral nutrition of the main commercial crop(s) through mulch mineralization or indirectly through animal manure returns. Furthermore, they increase the nutritional status of livestock or human population through their forage or food value. In addition to their above-ground functions, cover crops fulfill important functions below-ground, thanks mainly to the activities performed by their root systems. They buffer efficiently many degradation processes. Examples include i) buffering against the natural or man-made processes leading to soil compaction, ii) restructuring of the soil thanks to the channels left by decomposing roots and the production of highly efficient aggregation substances, iii) tapping of soil moisture in deeper horizons below the root zone of commercial crops, which allows the production and maintenance of green biomass even during the dry season, iv) extraction of nutrients from poor acid soils (e.g. P mobilization by some legumes such as cassia generus) and recycling of nutrients such as (nitrates, K, Ca, and Mg) which are easily leached to deep soil horizons. The high level of biomass restitution to the soil and favorable conditions of temperature and moisture allowed by the mulch of cover crops residues induces high biological activity. Because of this activity, DMC systems promote high levels of recovery of nutrients by the various crops as well as a potential role in the fast detoxification of pesticide compounds, aluminium toxicity or excessive salinity.

Of course, not all cover crops fulfill these different functions with the same degree of efficiency, and some of them have been recognized widely throughout Latin America as being especially valuable (Table 2). An objective when screening for cover crops to be included in DMC systems, should be to satisfy simultaneously as many of the key functions as possible, in order to achieve the highest possible overall efficiency of the system (Séguy et al. 2003). Crop associations between *graminae* and legumes, because of their complementarities are often more efficient for many of the key expected functions. Ultimately however, the most suitable systems are those that, through the different crops in the rotations, best meet the constraints and production objectives of farmers in a given region (Anderson et al. 2001; Florentin et al. 2001).

**Table 2. Main cover crops used in Latin America and their respective efficiency for different functions**

| Main functions | Soil porosity | Soil Carbon Stocks | Production during dry periods | Weed control | N fixation | Grain-Livestock integration | Human food |
|---|---|---|---|---|---|---|---|
| *Brachiaria sp.* | +++ | +++ | +++ | +++ | - | ++ | - |
| *Eleusine coracana* | +++ | +++ | - | ++ | + | ++ | + |
| *Cajanus cajan* | ++ | + | ++ | + | +++ | ++ | ++ |
| *Crotalaria sp.* | ++ | + | ++ | + | +++ | - | - |
| *Mucuna sp.* | + | + | - | ++ | +++ | + | - |
| *Canavalia sp.* | ++ | + | +++ | + | +++ | - | - |
| *Avena strigosa (Black oats)* | + | ++ | - | ++ | - | ++ | - |
| *Pigeon pea* | + | + | - | + | +++ | ++ | +++ |
| *Sorghum + Brachiaria* | +++ | +++ | +++ | +++ | - | ++ | + |
| *Sorghum + Cajanus* | +++ | +++ | +++ | ++ | ++ | +++ | ++ |
| *Brachiaria + Cajanus* | +++ | +++ | +++ | +++ | ++ | +++ | ++ |
| *Avena s. + Vicia villosa* | + | ++ | - | ++ | ++ | +++ | - |

Efficiency in covering the function: - inefficient, + poorly efficient, ++ efficient, +++ very efficient

*Crop breeding for DMC systems*

Given the modifications brought about by DMC systems in terms of the soil profile characteristics and the environmental conditions for plant growth, significant interactions between genotypes and environment can be expected. To optimize these interactions, cultivars must at least be tested under DMC conditions or, even better, crop improvement programs should be established specifically for DMC systems. Cultivars from advanced generations (F3 or F4) must be tested simultaneously under constraining systems (monoculture and soil tillage) to select for robustness (water stress, polygenic resistance to diseases) and under favorable DMC systems to select for the highest possible productivity potential.
A key aspect is however to work simultaneously on improving the cropping system and the germplasm. Using such an approach, CIRAD and its partners in the northern Mato Grosso of Brazil were able to develop several highly productive rainfed rice cultivars, such as CIRAD 141 and Sucupira, which are already being grown on more than 300,000 ha. Yields superior to 8 t/ have been achieved with these cultivars in 1995, compared to yields lower than 2 t/ha achieved with the best available cultivars under conventional tilled systems in 1986 in the State of Mato Grosso (Séguy and Bouzinac 2001) (Figure 1).

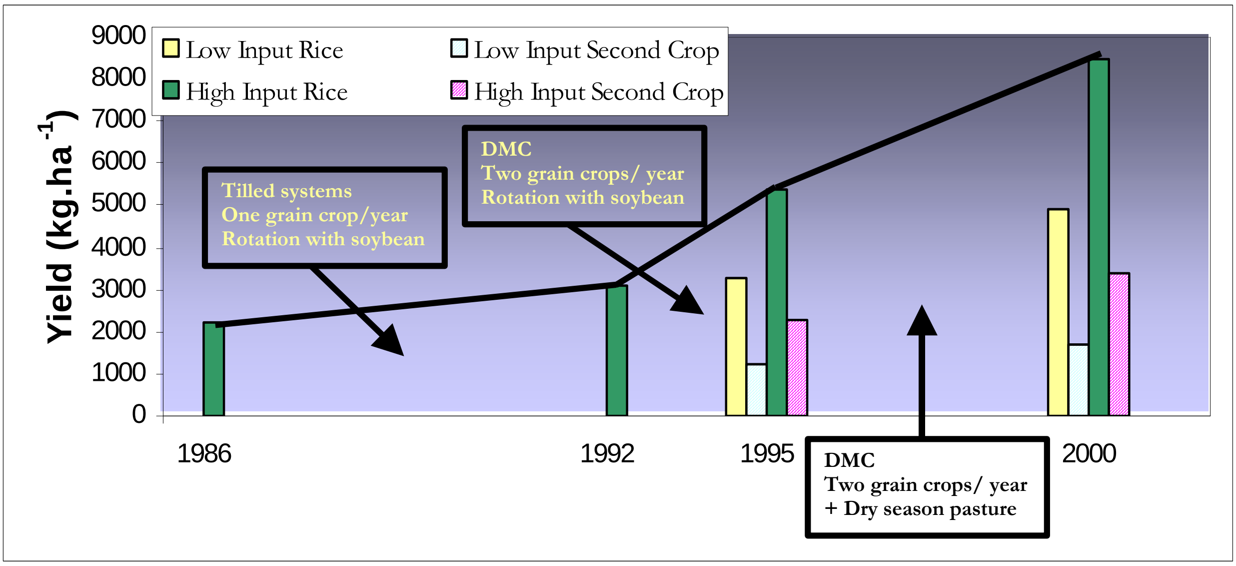


**Figure 1. Evolution of rainfed rice grain yield under DMC systems with successive crop and management improvements between 1986 and 2000 in the Cerrados region.**

Similar progress has been achieved for soybean. New cultivars obtained by EMBRAPA enable soybean planting under DMC systems near the Equator with a yield potential of about 4000 kg/ha. In the case of wheat and maize in southern Brazil, the EMBRAPA breeding programme has been established exclusively under no-till conditions, and no effort is made any longer to compare the behavior of the cultivars under conventional conditions, including for their resistance to diseases. With respect to cotton, the cultivar Coodetec 402 has shown its potential for being grown under DMC as a second season crop at half the cost of main season cotton with a productivity drop of only a third. This new DMC system allows farmers to face up to the unfavourable international market conditions for cotton (Séguy et al. 2001).

*Overall impacts of DMC systems in the tropical and sub-tropical climates of Latin America*

Favorable agronomic impacts of DMC systems have been widely documented in recent literature[1] and are related to the underlying biophysical functioning of these systems as described above (e.g. Clapperton 2003). Economic benefits derived from these favorable agronomic traits include lower production costs as well lower risks of failures (Ambrosi et al. 2001; Buckles et al. 1998; Fontaneli et al. 2000; Jourdain et al. 2001b; Séguy et al. 1996), and more flexible organization of farming activities thanks to lower work loads, increased opportunities for choosing a planting date and lower power requirements (Ribeiro 2001; Séguy et al. 1996; Wall 1999). A number of more problematic impacts have however been reported such as difficulties with weed control in dry regions, the appearance of some diseases or pests (yellow leaf spot and head scab for wheat or soil fungi for cotton), and competition for water use or nutrients between cover crops and main crops. In addition, small-scale farmers face a number of problems related to socio-economic issues (e.g. access to seeding equipment or land tenure rights, Ribeiro et al., 2001; Buckles et al., 1998).

At the heart of present-day limitations observed with DMC systems is the lack of experience by farmers, technicians and researchers alike about how best to manage these relatively novel systems. All those interested in using DMC systems must be willing and able to pay a significant learning and adaptation cost to make them work well under their own conditions. Additional research and development is also needed and in many cases in progress to overcome limiting factors associated with DMC systems as they are being identified by users (cf. section on challenges).

[1] i) Control of runoff and better water use efficiency in dry (Fischer et al. 2002; Findeling et al. 2002; Scopel and Findeling 2001) and in humid climatic conditions (Reyes et al. 2002), ii) Control of soil erosion (Scopel et al. 2002; Derpsch et al. 1991; Denardin et al. 1989; Denardin 1998), iii) Increased nutrient use efficiency in humid climate conditions (Reyes et al. 2002; Séguy et al. 2003), iv) Increased SOM contents and C sequestration in dry tropical (Scopel et al. 2002), in humid sub-tropical (Sá et al. 2001), and in humid tropical conditions (Séguy et al. 2001),v) Land productivity better or equivalent (Fischer et al. 2002; Séguy et al. 2003; Scopel and Findeling 2001)

*Approaches to the creation and improvement of DMC systems*
Distinct approaches have been used in Latin America to develop and adapt the principles of DMC systems presented in the preceding sections. A number of them have been quite successful eventually as judged by their adoption, and they generally share in one degree or another most of the following characteristics.

*An integrated approach to create, evaluate and adapt DMC systems*
The adoption and use of DMC systems by farmers implies radical departures from existing individual crop management practices and overall structuring of the cropping systems, including weed management, soil fertility management, farm equipment and labour organization. While adjustments are often made in a component and step-wise manner, CIRAD and its local partners in Brazil have developed a methodological framework over the last 20 years (Séguy et al. 1996) which includes an integrated approach based on full-scale comparisons of entire cropping systems while also leaving room for step-by-step adaptations whenever technical problems appear on specific components. This approach has proven to be especially useful when working within the context of large-scale farming, and research institutes such as IAPAR have used similar approaches for work within the context of small-scale farming (Ribeiro 2001). It entails three main steps:

- Conduct an initial diagnosis at the regional level to stratify the physical environment into homogenous landscape units in terms of climate, soils, topography and to characterize farmers' diversity and key problems within each unit.
- Establish long-term, large controlled trials in each landscape unit, preferably under actual farmer conditions, in which systematic comparisons are made among conventional systems (used as checks), best-bet DMC systems based on currently established technologies and future DMC systems based on promising experimental DMC technologies.
- Use the long-term trials as support for both more in-depth thematic research and for periodic farmer visits and exchanges.

The many cropping systems (usually 10 or more) included in these long-term trials differ typically from one another on only one or two key component technologies (such as crop rotation, or level of fertilization for example), a design which allows for the evaluation of individual components' influence on overall system's performance. Wherever possible, experimental units are large (typically several hundred square meters per treatment), which offers the opportunity to properly evaluate economic and practicability criteria (such as use of labour, or operation of commercial equipment) and also to subdivide the plots if need be over time. It also provides an excellent support for disciplinary researchers who need repeated sampling in undisturbed areas for studying underlying bio-physical processes (Johnson and Powlson 1994). Furthermore, these long-term trials offer the opportunity to anticipate the detection and solving of potential problems which may appear over time with specific technologies or DMC systems being tested, before farmers start getting them in their own fields after adoption has taken place (Séguy and Bouzinac 2001). If necessary, satellite treatments can be established next to the core experiment to work on such issues. Also, since these trials, or a fraction thereof, are replicated under contrasting environmental conditions, the appearance, extent and control of the eventual problems can be dealt with specifically for each environment, thus increasing the adaptability of the new DMC systems or technologies. Finally, these trials, because they are large and are usually established on farmers' fields provide an excellent support for organizing massive field days and farmers' exchange visits. Because they allow farmers to observe critically and in a comparative mode whole cropping systems or component technologies at work, these visits almost always lead to intense, fruitful discussions among farmers, technicians and researchers about their experiences, needs, worries and future plans. They also allow the visitors to assess under many different angles the attractiveness and adaptability to their specific conditions of the different options being tested.

*Diversification of DMC technologies to overcome constraints and satisfy farmers' objectives*
As a general principle widely-recognized since the advent of Farming Systems Research, the process required to ensure a new technology will be widely adopted by farmers must take into account the diversity of farmers operating in any given region and must answer as best as possible the diversity of their perceived or objective problems and needs. As a consequence of the efforts carried out in Latin America by the farmers themselves and by numerous research institutes such as IAPAR, EPAGRI, EMBRAPA, GTZ, and CIRAD, a large number of options have been developed for the major

components that make up fully functional DMC systems, providing a large array of solutions to diverse environmental and economic contexts. In terms of crop successions and rotations, several options are now available to optimize economical incomes, to fulfill the main required functions of the systems through an adequate use of cover crops, and to match the diversity of farm activities (grain production, grazing activities, and other productions) (Calegari 2001; Séguy et al. 2003, see also examples of rotations below). In terms of no-till equipment specifically suited to small-scale farmers, there are now many models available, including manual, animal-drawn or mechanized planters, sprayers or cover crop management tools such as “knife-rollers”for, thanks to effective partnerships between farmers, scientists and many private manufacturers (Ribeiro 2001). The resulting diversity of DMC systems now available explains part of their wide scale adoption in LA, it will hopefully facilitate their further adaptation and adoption in other regions and environments.

*A participatory, multiple stakeholder, farmer-driven process*
The processes that lead to the diversification, adaptation and evaluation of DMC systems are preferably conducted for, with and by farmers and as often as possible, under their own conditions (Séguy et al. 1996), as this has a direct impact on the subsequent adoption of these systems. Farmers’ organizations such as Clubes do Amigos da Terra, AAPRESID or large farmer cooperatives have been fundamental in the process of DMC adaptation and diffusion in Latin America (Landers 1998; Pieri 2001). Systematic reliance on grass-root farmer organizations has contributed to identify and formalise farmers’ key demands and necessities. It has also been a key ingredient for the formation of alliances and close partnerships between farmers and other key stakeholders of the agricultural sector such as private companies (herbicide and equipment manufacturers), government agencies, local and regional administrations (Triomphe et al. 2003). These innovation networks (Wall et al. 2003) have planned (albeit informally), coordinated and implemented the bulk of the research and development efforts invested in DMC systems. They have also greatly accelerated farmer-to-farmer dissemination of DMC-related information (Landers 1998; Ekboir et al. 2002). While institutions have had a key role, individuals also made unique contributions: a few very dynamic farmers, agronomists and decision-makers, played a fundamental catalytic role in the adaptation and dissemination process, by their charisma and by their ability to mobilize and organize others (Ekboir 2002; Coventry et al. 2003). The existence of catalytic agents may be especially important in the context of small holders (Ekboir 2002), even though active participation of farmers remains in all case essential (Landers 1998). Examples of such participatory approaches include the development and diffusion of direct-seeding implements in Southern Brazil: machinery created by private manufacturers was tested and improved through research and specific credits were allocated to small farmers for purchase of resulting commercially available equipment of these (Ribeiro 2001).

*Selected examples of DMC systems*
Table 3 provides an illustration of the diversity of DMC systems used by Latin American farmers, as well as some of their key characteristics. Some specific examples of such systems are described below.

*Small scale farmers in South Brazil (Sub tropical)*
The State of Paraná is located in the southern part of Brazil between latitudes 22$^{o}$ and 27$^{o}$ S. The climate is subtropical, with annual rainfall ranging from 1,300 to 2,000 mm/year following a fairly uniform distribution throughout the year. Small-scale farmers (<50 ha) constitute 84.5% of Paraná State farmers. They practice diversified DMC systems according to their specific conditions and objectives. (Ribeiro 2002). The comparatively poorer farmers produce both food and cash crops, they use animal traction and family labor, as well as low level of inputs. They usually plant their summer maize crop with an animal-drawn no-tillage planter, in a mulch of a winter cover crop of *Avena strigosa* + *Pisum sativum* killed with an animal-drawn knife-roller. Other crops planted under DMC include common beans. Herbicides are sometime used for controlling the weeds before planting and post –emergence. The first year of introduction of DMC systems, contour bounds are built to control runoff using an animal-drawn moldboard plough, after which elephant grass is planted, which is subsequently cut and used as livestock forage.

**Table 3. Some of the main DMC systems used in Tropical and Sub-Tropical Latin America**

| DMC System | Rotations and crops succession (*) | Physical conditions | Type of farmers Energy used | Main products | Advantages reported | Weak points reported |
|---|---|---|---|---|---|---|
| Rainfed maize in mid-altitude plains and hillside of Mexico (Low adoption) | Maize / Maize | - Semi arid to sub humid climate<br>- Andosols, cambisols and vertisols | - Small scale farmers (<20 ha)<br>- Manual and light motorization | - Maize grains<br>- Residues used as forage | - Water balance<br>- Control of erosion | - Light mulch<br>- Weed control<br>- Low adoption |
| Irrigated grains productions in mid altitude plains of Mexico (Bajio) (Confined adoption) | Maize or Sorghum / Wheat or Barley | - Semi arid to sub humid climate, irrigated<br>- Vertisols | -Small-scale and medium (3-15 and 30-100 ha)<br>- Complete mechanization<br>- High external input use | -grains for agro-industry<br>-limited sale of residues | - Lower cost<br>- Lower water consumption<br>- Flexibility in work calendar | - Difficulties with permanent no-till<br>- Interference of residue with furrow irrigation<br>- No markets for diversifying crop rotations |
| Maize in hillsides of Central America (Confined adoption) | Maize – Mucuna | - Humid lowland tropics<br>-Steep hillsides<br>- Andosols, Fluvisols | - Small scale farmers (2- 10 ha)<br>- Manual<br>- No or very low external inputs | Maize grains for home consumption and marketing of surpluses | - Control of erosion<br>- Low external inputs<br>- Easy management | - Only one cycle of maize / year<br>- Rats and snakes<br>- Localized landslides |
| Grains production in Cerrados Region in Brazil (Wide adoption) | Soybean or maize or rice or cotton – Maize or sorghum or millet or other cover crops | - Humid tropics<br>- Deep and acid Ferralsols (acidity is usually corrected before agriculture) | - Large scale farmers<br>- Totally mechanized with hard motorization | - Grains and fibers production<br>- Integration with livestock production using cover crops as forage | - Control of erosion<br>- Nutrients recycling<br>- Increase in SOM<br>- Organization of farm activities | - Technical management of certain crops (rice, cotton)<br>- Disease control |
| Large scale grains production in South-Brazil, Paraguay (Wide adoption) | Soybean or maize in summer – black oat or Ryegrass or wheat in winter | - Humid Sub tropics<br>- High slopes<br>- Ferralsols, sandy lithosols | - Large scale farmers<br>- Totally mechanized with hard motorization | - Grains production<br>- Integration with livestock production using cover crops as forage | - Control of erosion<br>- Nutrients recycling<br>- Increase in SOM<br>- Organization of farm activities | - Wheat production with fungus diseases<br>- Allelopathic effects of Ryegrass on Maize |
| Small scale grains production in south Brazil, Paraguay (Wide adoption) | Maize or Soybean in summer – Black oat + Pisum or Vicia or Ryegrass or pigeon pea | - Humid Sub tropics<br>- High slopes<br>- Ferralsols, sandy lithosols | - Small scale farmers (<50ha)<br>- Animal traction or limited mechanization<br>- No or very low external inputs | - Grains production<br>- Milk and meat | - Labor and external inputs savings<br>- Control of erosion<br>- Increased crop yields | - Weed control<br>- No markets for diversifying crop rotations<br>- Cover crops seeds production |

For their part, better-off farmers produce milk and soybean for the market, they own or hire tractors, and use higher levels of inputs. They direct-plant their soybean crop on the mulch of the last regrowth of a *Avena strigosa or* ryegrass cover crop managed through either a knife-roller or a knife-roller combined with herbicide, depending on the amount of Avena residues left and weed infestation. The cover crop is grazed several times at the beginning of the winter. *Vicia villosa* is another commonly used cover crop, either as a pure crop or in association with avena. When maize is planted, a dwarf variety of pigeon pea can be sown between maize rows, 40 days after planting, to contribute to fertility replenishment, improvement of the soil physical conditions. Frost usually kills the pigeon pea during the winter.

*Large scale farmers in South Brazil (Humid Sub tropical)*
Four different phases of can be recognized in the development of cropping systems in this region possessing conditions similar to those described in the previous section. The **first phase** involved soil fertility improvement, access to subsidized farm credits, within the context of a favorable world grain market. Such circumstances increased the area planted to soybean within its traditional growing region. The soybean economic boom triggered the expansion of Brazil's agricultural frontiers. At the same time, a number of traditional production systems, as well as forests and native pasturelands, were converted into simple grain production systems, based on wheat -soybean rotations or continuous soybean. An inadequate knowledge of the soil erosion process as a whole and a predominance of export-oriented agricultural policies, distorted the perception and awareness of farmers about the need for adequate soil management and conservation methods, despite acute erosion taking place. The **second phase** was centered on the diffusion of soil conservation practices. In addition to eradicating stubble burning and replacing ploughs with field cultivators, winter cover crops were introduced in areas which had previously lain fallow. The **third phase** was influenced both by the implementation of the National Watershed Programme, which aimed at developing the rural communities and by the multiplication of farmers' groups interested in developing DMC systems. Both initiatives stimulated the introduction of more diverse crop rotations, based on the integration of winter cover crops and the cultivation of corn. The **fourth phase** was centered on the development and diffusion of DMC systems, following a systemic research and development approach. Compared to the simple grain crop cropping systems they replaced, the DMC systems included winter and summer pastures used for grazing, hay, and silage, thus providing the basis for a diversified, integrated grain and livestock production system better suited to contribute to farming income stabilization. Today, DMC systems represent a functional approach to conservation agriculture that has reached more than 80% of the cropping area in this region (Denardin 1998).

*Large scale farmers in the Cerrados Region in Brazil (Humid Tropical)*
In the Cerrados region of Brazil (central plateaux between 10 and 20°S latitude), the climate is humid with yearly rainfall of 1200 - 2000 mm per year during a 8-10 month period. Diversified DMC systems were developed for the large-scale grain producers of this region to replace the inefficient tillage-based soybean monoculture system that produced only small quantities of biomass (Figure 2):

- DMC systems with two annual crops in succession under continuous direct seeding, the second crop playing the role of a 'nutrient pump' (Séguy et al. 2003).
- More recently, DMC systems with three crops per year, all under continuous direct seeding, consisting of one commercial crop (soybean, rice, maize) followed by cereals (maize, millet, sorghum, Eleusine) intercropped with forage species (from the genera *Brachiaria, Stylosanthes* and *Cajanus*, single-cropped or combined) that all function as powerful 'nutrient pumps' producing large amounts of biomass in the dry season which can be grazed or used as green manure (Séguy et al. 2003).

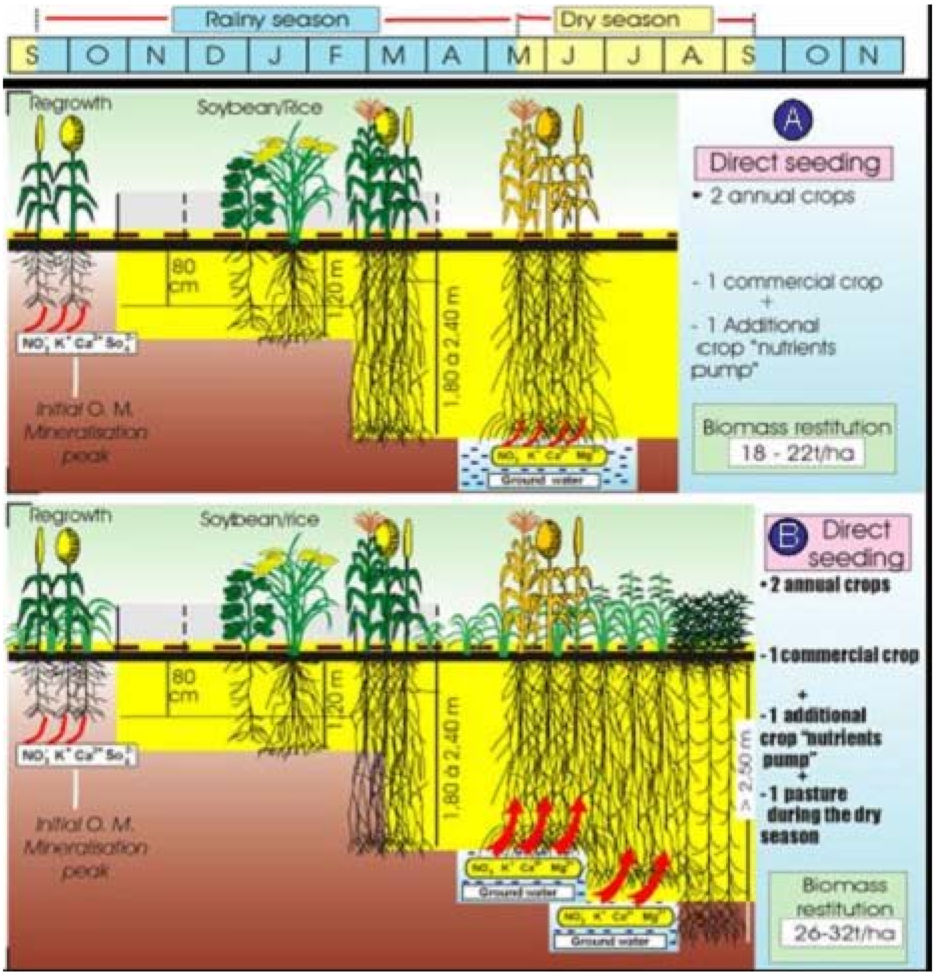


**Figure 2. DMC systems in the Cerrados region in Brazil (source Séguy and Bouzinac 2001). Different options are possible for the main commercial crop (rice, soybean or even maize), and for the second crop as well (maize, sorghum, millet). In option B different combination crop + pastures are available for the second cycle.**

In these last case, the combination 'commercial cereal crop + forage species' following the first commercial crop at the end of the rainy season, uses water substantially deeper than 2 m and has an active photosynthesis later during the dry season. This combination also displays very strong vegetative regrowth after the first rains of the following season or after dry season rain, thus ensuring a complete, permanent covering of the soil (Figure 2). As *Brachiaria sp.* are very efficient forages for cattle, the farmers may choose to convert their area into pasture or to stay in grain production for the next year. Such systems are frequently used under irrigated conditions or in wetter regions (more than 1500 mm) where it is frequent to have some periods of heavy rains during the firs crop cycle recharging deep water reserves. Under such conditions, total annual dry matter production (above and below soil) increased from 4 to 8 t/ha in the initial systems with a single annual crop to an average of around 30 tonnes/ha in the best DMC systems (Séguy et al. 2001).

*Issues and Challenges for further Adoption of DMC in Latin America*

Despite the significant adoption of DMC systems in South America, several issues and problems need to be discussed, if only because they correspond to actual worries of would-be users and other professionals throughout this region and elsewhere.

*Soil compaction under DMC systems*

Soil compaction is a natural process: under the flux of water in soil, cohesion between aggregates tends to decrease. In natural ecosystems this process is counterbalanced by an intensive biological activity in the soil profile. In cultivated areas, this compaction is accentuated by the random traffic of machinery, animals or humans (Mc Garry 2003). Systematic and regular tillage has been used in conventional cropping systems, to prevent as much as possible this problem, at least in the 0-20 cm top soil layer. Under DMC systems, activating and enhancing biological activity is the key to avoiding natural or maninduced compaction, as is the case in natural ecosystems. Stimulation of macro-fauna population and activity has been reported by Derpsch et al. (1991) and Scopel and Findeling (2001). Bulk density may well increase over time under DMCs but infiltration rates are always good because of a more favorable porosity structure: the pores are continuous and vertical (Mc Garry 2003; Scopel and Findeling 2001). If climatic conditions allow their introduction, plant species such as *Brachiaria sp*., *Eleusine sp.* or Tiftons (*Cynodon sp.*), are very efficient for avoiding compaction and restoring the soil structure because of their overall strong root systems and of the abundant roots they develop in the first 0-40 cm of the topsoil (Séguy et al. 2003). Under heavily mechanized conditions or drier regions where introduction of such species is hardly possible, controlled traffic can be an efficient way to limit machinery-induced soil compaction (Mc Garry 2003).

*Integrating livestock and cropping in the humid tropics*
In humid tropical conditions the more efficient species for recycling nutrients such as Brachiaria and Stylosanthes sp.are also good forage species. They can be grown as cover crops towards the end of the rainy season and grazed as soon as at the beginning of the following dry season and even more during the next cycles. Alternate periods between cropping and grazing are possible under different rotation schemes. Moreover, this succesionnal schemes offers the possibility of rehabilitating degraded pastures at basically no installation costs. Such is the case of the newly developed “Santa Fé” cropping system in the Cerrados, which associates a maize crop and a brachiaria pasture (Kluthcouski et al. 2000). Brachiaria is made to germinate after the maize either by delaying its planting or by planting it deeper. During the whole maize cycle, *Brachiaria sp*. is shaded by maize plants. At maize harvest however, the pasture is already in place, and grows very quickly over maize residues. Similar types of systems have been devised in southern Brazil, with a rotation of ryegrass used as pasture during winter followed by a soybean crop planted directly on the chemically killed pasture. The tight integration between forage and grain crops usually leads to a better use of the total farm land and a more intensive use of the pastures, with shorter turn-over and less pasture degradation. Similar DMC systems are being currently tested in other parts of the world, particularly within the context of small-holder agriculture in which cattle movements are not always controlled by farmers such as in Cameroon (Naudin et al. 2003).

*Biomass management in drier zones*
In semi-arid to sub humid tropical zones, a major issue is how to produce enough biomass to protect the soil and to maintain the global efficiency of the DMC systems, as competition for available biomass is frequently high due to grazing (Jourdain et al. 2001b, Erenstein 2003). Under such conditions, the amount of mulch derived from crop residue is often quite limited, resulting in partial soil cover at best[2]. Weed control becomes difficult especially when herbicides are difficult to purchase or to apply as in the case of small-scale farmers. However, even with partial mulching no greater than circa 1.5 t $DM.ha^{-1}$, the additional water available under DMC, may contribute to significant increases in total biomass production (grain + stover) (Scopel and Findeling 2001). Further improvements are possible if, whenever possible, small isolated rainfall periods, not sufficient for crop production, are used for planting a cover crop at zero cost. Also, overall forage resources can be optimized by planning their individual and collective management at the level of small regions, in order to decrease the pressure on biomass produced on cropping lands. Similarly, weed control needs to be conceived in an integrated weed management strategy in which rotations, stand density, spatial arrangement of plants and mulching all contribute to decrease overall weeds' pressure.

*Understanding better the impacts of DMC systems on soil biological activity*
While it is now generally recognized that biological activity is enhanced under DMC systems, the evolution of microbial populations, changes of species, and the consequences on the whole process of mineralization are still poorly understood. Similarly, little is known about the evolution of macrofauna species and their consequences on the physical properties of the profile (form and efficiency of soil porosity), on organic biomass fragmentation, on aggregate stability and on the protection of stable and unstable carbon. Biological mechanisms must also be better understood to provide sound recommendations to farmers interested in achieving high yield levels under DMC with reduced rates of

[2] Practicing no-tillage without protecting the soil has been shown to be even worse than conventional tillage (Scopel and Findeling 2001).

chemical fertilizers, taking advantage of the enhanced natural fertility processes in the short and longer term.

*Assessment of the overall impacts of DMC systems on biocides use and the environment*
There is mounting pressure from different segments of society to assess properly the impact of DMC systems on the use of biocides in agriculture as well as on the environment and human health. DMC systems have been accused publicly of significantly increasing the utilization of biocides, especially herbicides. Nevertheless, different aspects should be weighted carefully before reaching a final verdict. First, the actual use of pesticides (products, rates, frequency of applications) with DMC systems must be compared to that of the conventional systems they are displacing. For example, whereas rates of 4 to 5 l/ha of atrazine and simazine-based pre-emergent herbicides were used in conventional maize management in the Cerrados region in Brazil, now, these same types of herbicides are used post-emergence in DMC systems, at early stages of maize development, at rates of 1 or 2 l/ha. Moreover, very stable pre-emergent products have been substituted with post-emergent quickly degradable ones in the case of soybean production. Secondly, the introduction of cover crops in DMC systems may have important implications on pesticide use and management since they may help to interrupt some pest cycles, or may be used as natural insect traps, as illustrated by the observation that some bugs - virus vector for soybean - are clearly attracted by a cover crop of *Arachis pintoï*. Finally, comparative studies are also needed to understand the transformation kinetics for different molecules in the mulch-soil system and how this eventually affects water quality. It makes sense conceptually to consider that under DMC systems, a fraction of the biocides is intercepted by the mulch and directly exposed to the light and heat which activate their degradation. The other fraction, upon arriving in the soil matrix, could well be transformed in a short time thanks to the intense biological activity generally observed under DMC systems.

*Developing DMC systems less dependent on herbicides*
Despite the above considerations, present-day “classical” DMC systems are still very much dependent on biocides at planting time, because broad-spectrum or total herbicides are generally needed to control the cover crop and other weeds. In many cases however, and particularly for small-scale farmers, this dependence is both costly and risky, and may run counter to desires for achieving a fully ecological agriculture. In such situations, new systems and strategies are needed for controlling weed pressure and for decreasing the stocks of weed seeds present in the soil. Some of the key options to consider include i) the systematic use of cover crops able to compete with weeds whenever there is no commercial crop growing, and ii) ensuring the presence of a thick mulch layer during the commercial crop cycle which can shade the soil surface and in some cases liberate allelopathic substances. Generally, after a few years of these practices, weed pressure decreases significantly making the systems less dependant on herbicides (Kliewer 2003). Another option is to control cover crops mechanically with “Roller-knives”, which is mostly feasible for annual cover crop species, (Ribeiro 2001; Calegari 2003).

*Enhancing the adoption of DMCs by smallholders*
Despite the significant adoption rated of DMC systems in Latin America, their dissemination among small-scale farmers remains fairly marginal outside Southern Brazil, Paraguay and small parts of Central America (Buckles et al. 1998). Enabling and accelerating their adaptation and adoption in other places requires extracting the lessons, technical and process-wise, to be learnt from well-defined cases in which adoption took place, as well as using more widely the participatory approaches and associated principles described earlier, since they are particularly suited to the case of small-scale farmers.

*Systematization, capitalization and sharing of knowledge*
A wealth of experience and information is presently available on DMC systems. Nevertheless, this knowledge is too scattered among different experts, making the training of new agronomists, technicians or farmers difficult. Generally speaking, the fragmentation of information hampers its adaptation and transfer to those who most need to make use of it. It is thus urgent to find adequate ways to capitalize and synthesize the existing knowledge in a systematic way. Dynamic crop models could be an efficient way of synthesizing what is known about the functioning of DMC systems. This kind of tool could advantageously be used to predict DMC productivity and environmental impacts, to extrapolate DMC feasibility according to different farmers’ conditions, and to optimize crop management under such systems. Likewise, rigorous case studies of success and failure stories need to be conducted and compared

in order to learn as much as possible about the underlying factors and conditions. The information generated by such studies should be reported in adequate form and eventually fed into DMC data bases specifically designed for this purpose.
Different levels of organization and networking are clearly necessary in order to share efficiently these experiences and to disseminate efficiently the huge knowledge available about DMC systems:

- In Latin America, all the stakeholders involved in the promotion of DMC systems, and particularly farmers, are already fairly well organized at the local or regional level (such as APDC, "Associação do Plantio Direto nos Cerrados", in the Cerrados region in Brazil), at the national level (such as FEBRAPDP, "Federação Brasileira de Plantio Direto na Palha", in Brazil, and AAPRESID in Argentina) and at the continental level (such as CAAPAS, "Confederación Americana de Asociaciones de Productores para la Agricultura sostentable", in Latin America, These federations are already very active into disseminating DMC principles, advantages, and results to other actors in the agricultural sector who are not yet convinced of their interest.
- With respect to research, FAO is supporting continental-wide networks such as RELACO (Latin American Conservation Agriculture network), formed by national research institutions from member countries. These networks aim to bring together all scientific information on DMC systems in order to share widely the products of locally-conducted research and facilitate DMC technology exchange among the participants.
- Additionally, many other networks are presently striving to facilitate DMC development and dissemination in other regions of the world. CIRAD and its many partners for example are active through the AFD-funded “Agroecology Action Plan”, which aims to adapt DMC principles to different ecological and socio-economical conditions around the world (Séguy et al. 2003). GTZ (German Development Cooperation) has been supporting the ACT (African Conservation Tillage) network which overall objective is to promote and facilitate information exchange and partnerships in order to enhance the adaptation and adoption of DMC principles and practices in Africa, especially among smallholder farmers. The FAO, with its Conservation Agriculture Working Group, is actively promoting DMC systems worldwide through networking, information dissemination, training and support meetings.

The above-mentioned networks are just but a few examples of the many on-going initiatives which all contribute to a better systematization and exchange of information and experiences among all the actors that, in one way or another, are involved in the introduction and further development of sustainable production systems based on DMC principles. While a lot has to be improved in Latin America, there is also a host of experiences that this continent can share with the world community by taking advantage of 30 years of pioneering work on DMC and the dynamism of its people and innovation networks.

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