
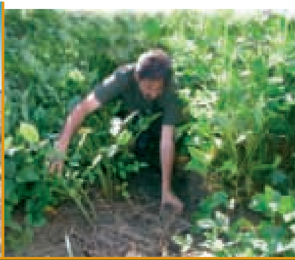

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Tropical crop–livestock systems in conservation agriculture

The Brazilian experience

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The Brazilian experience

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FOREWORD

Combining ecological sustainability and economic viability while maintaining or improving agricultural productivity has long been a matter of concern for FAO, as has reducing negative environmental impacts. Conservation agriculture, which aims for zero tillage with the maintenance of a surface mulch to protect the soil surface and increase biological activity in the topsoil, is increasingly becoming recognized as an effective system of crop production that protects the soil from erosion while reducing the overall use of agrochemicals.

Vast areas of forest have been cleared in the tropical areas of Brazil for establishment of pastures that become unproductive once the native fertility of the soil is exhausted; this leads to yet more forest clearing for new pastures. However, rotating pastures with field crops and resowing is one of the most effective ways of maintaining them in a state of high productivity, thereby reducing the need for more clearing.

This publication describes how pasture, fodder and livestock production have been integrated into conservation agriculture systems in Brazil's tropical zones. Integrated crop–livestock zero tillage systems (ICLZT) allow the sustainable production of high-yielding pasture without further deforestation; in this system, grazing livestock convert both pastures and crop residues into cash. The ability of pasture to build up the biological activity and physical quality of the soil is well known.

The lessons learned in Brazil by farmers and scientists can provide valuable insights on what could be done in similar ecologies elsewhere, including in Africa where the details of management will be different, but the biological principles learned in Brazil could be a roadmap to more sustainable intensification of some major crop–livestock production systems.

The manuscript was prepared by John N. Landers of Associação de Plantio Direto no Cerrado, Brazil. It is hoped that this publication will make the Brazilian experience in integrated crop–livestock zero tillage systems accessible to agronomists, advanced farmers, extension workers and agricultural decision-makers in other tropical and subtropical areas so that they can adapt it to their own conditions.

Shivaji Pandey
Director
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Thanks are especially due to the considerable input made by the editors, in particular – retired staff members Jim M. Suttie and Robert Brinkman, and Eric Kueneman, Caterina Batello and Theodor Friedrich of the Crop and Grassland Service for ensuring that this manuscript was brought to publication. Technical input from Josef Kienzle and further editing by Stephen and Mary Reynolds are also appreciated. Finally, all parties involved are very grateful to Dénise Welch, for her valuable inputs and for revising and incorporating the many drafts into this final version.

The technical contribution of Paulo César de Faccio Carvalho, Faculdade de Agronomia – Universidade Federal do Rio Grande do Sul (UFRGS), Porto Alegre, Brazil has been much appreciated by FAO in its effort to disseminate information on tropical crop–livestock systems in conservation agriculture. He has also contributed, during his assignment with FAO as a visiting scientist, to reinforcing information knowledge management and partnership with EMBRAPA, UFRGS, IAPAR and Universidade Federal do Paraná (UFPR) on crop–livestock integration systems in Brazil.

The cover design and layout were done by Pietro Bartoleschi and his studio in Rome. Chapter 1–4 photographs, unless otherwise acknowledged, are by the author. Chapter 6 photographs came from Theodor Friedrich.

CONTENTS

ACRONYMS AND ABBREVIATIONS

a. i.	Active ingredient
ANA	(Brazilian) National Water Agency
ANAE	Association Nationale des Acteurs de L'Ecole
APDC	Zero Tillage Farmers' Association for the Cerrado Region
AU	Animal Unit
CA	Conservation agriculture
CEC	Cation exchange capacity
CIMMYT	International Maize and Wheat Improvement Center
CIRAD	Centre de Coopération Internationale en Recherche Agronomique pour le Développement
DAP	Days after planting
DM	Dry matter
DMP	Deforestation mitigation potential
DOEN	Dutch Foundation of Charitable Causes Lotteries in areas of sustainable development, culture and welfare
EMBRAPA	Empresa Brasileira de Pesquisa Agropecuária
FAO	Food and Agriculture Organization of the United Nations
FEBRAPDP	Federação Brasileira de Plantio Direto na Palha
GTZ	German Agency for Technical Cooperation
GUS	Groundwater ubiquity score
IAPAR	Instituto Agronômico do Paraná
IBGE	Instituto Brasileiro de Geografia e Estatística
ICLZT	Integrated crop–livestock zero tillage system
INEMET	Instituto Nacional de Meteorologia
INPE	Instituto Nacional de Pesquisas Espaciais
INPEV	Instituto Nacional de Processamento de Embalagens Vazias
IPM	Integrated pest management
IRR	Internal rate of return
IUCN	World Conservation Union
LUI	Land use intensity
NPV	Net present value
SOM	Soil organic matter
SSA	Social Security Administration
TDN	Total digestible nutrients (obsolescent energy standard)
UFPR	Universidade Federal do Paraná
UFRGS	Universidade Federal do Rio Grande do Sul
WWF	World Wide Fund for Nature
ZT	Zero tillage

CHAPTER 1

Introduction

Brazil is a world leader in conservation agriculture (CA); initially the emphasis was on crop production through the now well-known principles of maintenance of a layer of crop residues on the surface, zero tillage (ZT) and crop rotations (see definition in Box 1). Now Brazil is pioneering the integration of livestock production, grazed pasture and forage crops into CA, grazing being so managed as to provide adequate surface litter for the needs of ZT. A pasture phase in a rotation is renowned for building up soil organic matter (SOM) and improving soil structure. Pasture in ZT rotations with annual crops can be regenerated much more profitably and with less risk than the older systems where pastures were ploughed out before being resown.

This publication is aimed at agronomists, advanced farmers, extension workers and agricultural decision-makers. It describes how CA has been developed in the tropical and subtropical areas of Brazil and broadened from a crop production system to an integrated crop–livestock way of farming. Within Brazil there are many nuances in approaches adopted by farmers and ranchers; there is not one fixed package for all situations. However, the biology of the sustainable intensification made possible by adoption of ZT has common principles.

Lessons learned in Brazil not only help Brazilian agriculture, but provide insight on what farmers can do elsewhere. While the examples described in Chapter 5 refer to large farms, many smallholders are now applying ZT technology as well, giving proof that the principles are not scale specific. Farming systems have to be developed to suit the agro-ecological and economic characteristics of a region, but it is hoped that many of the lessons learned and technologies developed in the Brazilian tropics and subtropics can be adapted for use by farmers in other regions.

BOX 1. **The definition of conservation agriculture (CA)**

CA is a concept for resource-saving agricultural crop production that strives to achieve acceptable profits together with high and sustained production levels while concurrently conserving the environment. CA is based on enhancing natural biological processes above and below the ground. Interventions such as mechanical soil tillage are reduced to an absolute minimum, and external inputs such as agrochemicals and nutrients of mineral or organic origin are applied at an optimum level and in a way and quantity that does not interfere with, or disrupt, the biological processes.

CA is characterized by continuous minimum mechanical soil disturbance (i.e. direct planting of crop seeds); permanent organic soil cover, especially by crop residues and cover crops; and diversified crop rotations in the case of annual crops or plant associations in the case of perennial crops.

Source: Adapted from FAO, conservation agriculture homepage.

Broadly similar agro-ecological conditions to those in the Brazilian ZT areas are widespread in parts of Africa and South and Southeast Asia, for example (see maps in Nachtergaele and Brinkman, 1996).

CONSERVATION AGRICULTURE IN THE BRAZILIAN TROPICS

This publication concentrates on integrated crop–livestock zero tillage (ICLZT) technology which has developed principally in the Cerrado biome (wet-dry tropical savannahs), extending to the Atlantic Forest biome (see Figure 1). In principle, wider application is possible for the Amazon and the Caatinga biomes, the latter representing the northeast semi-arid tropics. There has been little development with ICLZT systems in the Caatinga, but there is some research and farmer experience in the Amazon biome, principally with soybeans and upland rice sown into degraded pastures.

This publication has six chapters. The introduction gives an overview of CA, ZT and ICLZT systems before outlining their history and development in the tropical areas of Brazil. The second Chapter describes livestock and field crop production in the wet-dry and humid tropical areas of Brazil and provides the background for ICLZT. The third chapter gives the principles of the integrated systems and gives

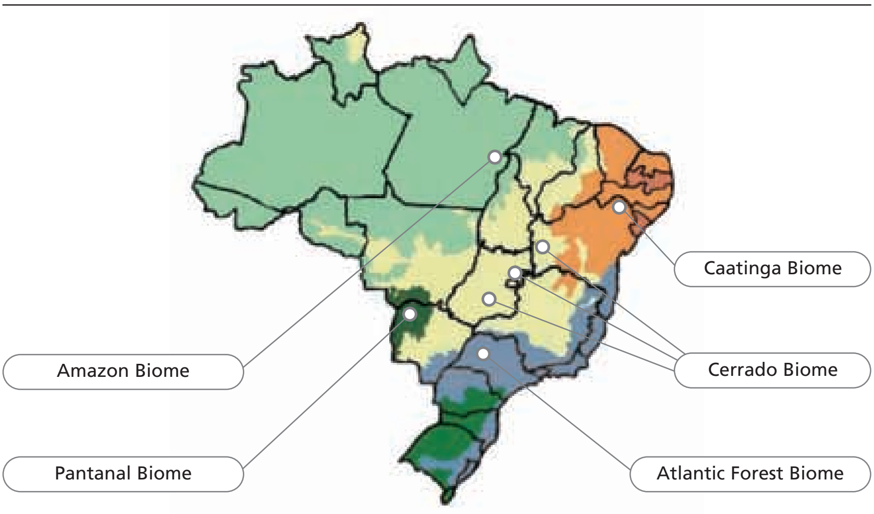


FIGURE 1: Location of the Cerrado, Amazon and other major biomes

Source: Instituto Brasileiro de Geografia e Estatística - IBGE, Brazil.

summaries of the ten main technologies as well as discussing fodder, crops, stubble grazing, pasture crops, grazing management and the grazing of cover crops. The fourth chapter discusses mechanized operations and soil fertility management under ZT. The fifth provides financial analyses and a series of case studies. The final chapter on sustainable agriculture and policy considerations describes how land use intensification can mitigate or obviate further forest clearing for pasture establishment and deals with the positive environmental benefits of CA and its impact on reducing the use of agrochemicals. The chapter ends with policy recommendations for conversion incentives to ICLZT technology, particularly for small farmers.

Background

Agriculture has had different emphases in the Amazon and Cerrado regions: beef, upland rice and small-scale dairying in the former; large-scale beef and soybeans in the latter, with maize, upland rice and cotton of secondary importance. Most clearing for pasture in the last 20 years has been on infertile soils, subject to rapidly falling stocking rates as initial fertility declines and little or no fertilizer is used. This has led to even more clearing to compensate for loss of carrying capacity.

About 55 percent of the Cerrado biome has been cleared (Machado *et al.*, 2004), as opposed to 16 percent of the Amazon biome (INPE, 2006). Land prices have risen; cattle farmers are selling to crop growers and moving to frontier areas to continue clearing. Land use intensification, through integrating ZT crops with livestock systems is the most viable route to preserve biodiversity on a large scale, provided that there are policy incentives for it and disincentives to clearing new land.

The Cerrado biome

The descendants of seventeenth century mining pioneers grew subsistence crops (on the less than 7 percent of the area which had fertile soils) and reared beef cattle on the savannas, which were gradually impoverished through burning at the end of every dry season to generate regrowth.

Improved pasture choices in the Cerrado were dictated by soil fertility. On the few areas of fertile soils under forest (Nitisols) (IUSS, 2006), mostly colonized by 1970 (Goedert, 1985), Molasses Grass (*Melinis minutiflora*), Jaraguá (*Hyparrhenia rufa*) and to a lesser extent, Colonial Guinea Grass (*Panicum maximum)* were sown. From 1972 these were replaced by *Brachiaria* spp. as fertility dwindled, or the pastures were renovated after a crop phase. In the latosols and quartz sands (Ferralsols and Arenosols) (IUSS, 2006) of the Cerrado the opportunity to mine native fertility by burning the sparse scrub is low, compared to Amazon forest. Pastures were established after one or two pioneer crops of rice, using very low fertilizer rates and minimal levels of lime, with little or no maintenance fertilizer. Sano *et al*. (1999) estimated that over 70 percent of Cerrado pastures were degraded.

Soybean production, the principal engine of development in the Cerrado, began significant growth from 1980. The Cerrado, with its gentle topography, wide interfluves, many tablelands, but essentially infertile soils, was opened for grain crops by migrant farmers from the southern states, mostly Rio Grande do Sul, using soil amendment technology from the 1960s (McClung *et al*., 1958; Mikkelsen *et al.*, 1963). This technology was refined by the Brazilian Agricultural Research Corporation (EMBRAPA), but only came into its own with the advent of the first real tropical soybean cultivars “Cristalina” and “Doko” in the late 1970s.

Early development of large-scale arable cropping was based on subsidized agricultural credit. Conventional tillage was mainly with disc harrows which caused disc pans and surface capping, and progressively lower rainfall infiltration rates with erosion losses of up to 20 tonnes of topsoil/ha/year (de Maria, 1999) and rapid depletion of the already low soil organic matter, exacerbated by monocropping of soybeans. Contour banks, required as a precondition for rural credit, were inadequate for downpours of over 100 mm/hr and economic losses due to erosion gradually worsened as soil structure deteriorated. Zero tillage came into use when conventional tillage on infertile Cerrado soils was becoming unattractive, since soil amendments amounted to about 25 percent of direct costs and erosion losses were significant in terms of replanting and lost soil amendments. Since about 1990 a significant number of crop farmers have diversified into beef cattle, moving towards ICLZT systems, as they acquired capital and diversified their risks, or bought degraded pastures to expand soybean production.

On Cerrado latosols and quartz sands (Ferralsols and Arenosols), (IUSS, 2006), improved pastures were based on *Brachiaria decumbens* with some *B. humidicola* from 1972 onwards, usually undersown in upland rice, with low initial fertilizer levels. The *B. decumbens* cultivars (Basilisk and IRI 562) were replaced from about 1990 by *B. brizantha* cv. Marandu and, to a lesser degree *B. ruziziensis.* Improved cultivars of *Andropogon gayanus, Paspalum atratum* and *Setaria anceps* and attempts to introduce pasture legumes had limited success. Predominantly extractive management led to progressive pasture degradation (Macedo, 1997) and impoverishment of cattle farmers, who tend to sell land to crop farmers and move to new frontiers. In rotation with crops, on amended Cerrado soils, new, less stemmy and less clumpy *Panicum maximum* cultivars (Tanzânia, Mombaça, Centenário and Vencedor) have supplanted the old Guinea grass since 1990.

The Amazon biome

In the nineteen-seventies, farmers began to develop areas with fertile soils in the Amazon in southern Pará, Acre, central Rondônia and northern Tocantins states, where a forest-covered region with areas of podsolic soils of some initial fertility (Acrisols) (IUSS, 2006), supported

Colonial Guinea Grass for up to 15 or 20 years. Guinea grass was short-lived on poorer soils and was replaced by *Brachiaria humidicola* and *B. decumbens*, and since about 1990, by *B. brizantha,* with a cycle of up to 10 years before requiring renovation. Large areas of short-lived Guinea grass, colonised by weeds and bush were abandoned due to high renovation costs, especially where there were unrotted stumps. Cattle expansion has pushed land clearing into rain forest on infertile soils with a much shorter depletion cycle.

Pasture development was mostly by incomers from south Brazil, spurred by subsidized credit (Mahar, 1989). Small farmers (local and immigrant) in the Amazon opened forest land with subsistence crops, intersown with pasture in the second or third year as increased weed pressure made annual crops unprofitable. Pasture was established cheaply between the stumps. Large farmers either bought land with established pasture, or carried out more expensive mechanical clearing and broadcast pasture seed after a burn. Pastures were established without ploughing so there was some erosion control.

Where pastures are renovated with full land preparation, usually undersown in rice, the only conservation measure, when present, is contour banks, which can only be made once the stumps have rotted (about 20 years after forest clearance). Contour banks are only effective so long as the soil maintains a good infiltration capacity. This decreases after pasture renovation due to compaction from cattle hooves and reduced ground cover, through overgrazing, exacerbated by clumpy grasses like Colonial Guinea. Weeds from South Brazil were introduced in dirty pasture seed. Residual effects from former widespread use of Picloram herbicide for brush control in annual cropping have not been assessed on a regional scale.

As pasture quality declined, migrant small farmers were forced to intensify into milk production or depend on weaner-calf operations in conjunction with extractive crops like cassava. Few had the capital to invest in perennial crops on a significant scale, and extension services in the Amazon and access to credit have historically been weak for this sector (Camargo *et al*., 2002). Many farmers are in settlement projects with 100 ha plots and have nearly exhausted the forest as a fertility source. Where small farmers adopted conventional tillage it was almost invariably with machinery hired from larger farmers, rarely employing contour banks.

Traditional populations used slash and burn on small 2–3 ha forest plots with a long fallow and were close to sustainable, but with marginal income.

History of zero tillage in the tropical zones of Brazil

The first known tests with ZT in tropical Brazil were in Matão, São Paulo state (Atlantic forest biome) in the 1960s, with a sod-seeder for introducing legumes into pasture – however, this did not become general practice (J. Harrington, personal communication, 1998). Herbert Bartz began ZT on his farm in Rolândia, Paraná state, in 1972, just north of the Tropic of Capricorn, and has used it continuously thereafter. His experience is mainly suited to southern Brazil.

According to Landers (1994), in 1979 small farmers in Rondônia were already jab planting beans (*Phaseolus vulgaris*) into rice straw after desiccation with paraquat as a means of weed control. From 1981 onwards, mechanized tropical ZT began to develop, with soybeans, maize and other crops in the Cerrado, reaching over 9 million ha in the tropical areas in 2004–05, with some encroachment on the transition forest in Northern Mato Grosso. Nearly all of this is in mechanized grain production. Today ZT is being further developed in Roraima, Rondônia, Amazonas and Pará.

The advent of tropical ICLZT technology in the mid 1990s enabled the sowing of grain crops directly into desiccated pastures, revolutionizing crop and pasture production through a synergy which benefited both. Since 1992 the Zero Tillage Farmers' Association for the Cerrado Region (APDC) has actively promoted ZT and, latterly, has been in the forefront of promoting the ICLZT technology (Lara Cabezas and de Freitas, 1999; Landers, 2001). Zero tillage is now the dominant production system for annual crops in Brazil and is increasing rapidly in importance for pasture renovation and establishment of perennial crops. ICLZT has shown tremendous potential for land use intensification, reducing the rate of clearing of native vegetation (see discussion in Chapter 6).

CONSERVATION AGRICULTURE

The term "conservation agriculture" was adopted during the First World Congress on Conservation Agriculture, Madrid 2001, organized by FAO and the European Conservation Agriculture Federation (Saturnino and Landers, 2002).

Zero tillage is the preferred technology for CA[1], the principles of which are summarized in Box 2.

BOX 2. **The 3 main principles of conservation agriculture (CA)**

1. Direct planting of crop seeds
2. Permanent organic soil cover
3. Crop rotation

Source: Adapted from FAO, conservation agriculture homepage.

The distinguishing and most important element of CA is that crop residues remain on the surface, including those of cover crops (green manures). The many functions of this surface organic layer, slowly decomposing to humus, transform an untilled soil into a living, dynamic system which must be managed to maximize these functions and derive the benefits which they confer, resulting in increased SOM, greater P availability and faster breakdown of agricultural chemicals. Conservation agriculture replicates the closed cycle of nutrients and surface litter of a mature rain forest, bringing highly productive farming into harmony with nature. Water-holding capacity increases in proportion to SOM and improved soil structure through an increase in water-stable aggregates (Blancaneaux *et al.*, 1993); water economy also improves since mulch reduces evaporation losses. Stone and Moreira (1998) measured reductions in irrigation demand of over 30 percent with an erect cultivar of *Phaseolus vulgaris* planted in a thick mulch. The functions of surface residues are shown in Box 3.

To plant in permanent residue cover it was necessary to develop specialized planters and drills that cause minimal disturbance. These are now available worldwide in manual, animal-drawn and mechanized models (see Chapters 4 and 6). The sowing mechanism consists of a

[1] In the pure interpretation of CA, tillage is not considered necessary for the creation of soil structure. Therefore, CA encourages ZT, with the aim being no soil disturbance whatsoever. However, CA is also a process with differing degrees of perfection, and in some cases a minimum disturbance of the soil may be unavoidable. Examples of this include strip tillage in cold and wet climates, superficial ripping of the seedrow after pasture to break up the compaction caused by animals, or even ripping in the row as long as the soil is too degraded to maintain a structure (Friedrich, personal communication).

BOX 3. **The functions of crop and weed residues kept on the soil surface**

- Weed suppression by shading or allelopathy;
- Retention of soil moisture through the mulch effect;
- Improvement of soil surface temperatures to within the limits for biological activity;
- Reduction of the velocity of surface flow, reducing erosion potential and increasing total rainfall infiltration;
- Elimination of the direct impact of rain drops on the soil, thus preserving soil aggregates and avoiding surface capping;
- Nutrient recycling with slow liberation throughout the growth period of the crop;
- Alteration of crop residue breakdown products through essentially aerobic decomposition, in favour of the less acidifying humic acids and complexing of aluminium in organic non-soluble forms;
- Alteration of the microclimate for emerging seedlings, protecting them from wind-blown sand and excessive insolation (only applies to standing stubble);
- Provision of organic substrates to feed soil flora and fauna;
- Generation of humus and other products of organic matter decomposition which stabilise and increase organic carbon (Amado and Costa, 2004) and improve soil structure;
- Food and shelter for wildlife.

Source: FAO, conservation agriculture homepage.

trash disc which cuts the crop residue and allows the fertilizer and seed to be placed beneath it with minimum soil disturbance, leaving the soil protected against rain and sun.

Multi-annual crop rotations, which are complementary to ZT in CA systems, may include cover crops to build up residue levels, provide fodder, and improve nutrient recycling from the subsoil. By not repeating the same crop in the same season in successive years, the cycles of diseases, pests and weeds are broken, promoting biological controls and reducing agricultural chemical use and costs of production – this is discussed in Chapter 3.

Contrary to early predictions, once all plough-pans are removed (as a pre-condition to adoption) and movement of lorries and heavy grain trailers is restricted to roadways, ZT maintains soil structure at depth by the preservation of macropores derived from old root holes and the galleries and burrows of soil mesofauna, such as earthworms, beetles and their larvae. Basic infiltration rates after two hours under these conditions have been measured at 120 mm/hr, far higher than even tropical rainfall intensity over the same period (Amado, 2005); without such macropores this drops to 30 mm/hour or even 20 mm/hr when soil is compacted. The macropores thus provide effective erosion control under ZT; long term ZT farmers are removing their contour banks because they no longer need them when they have infiltration rates higher than rainfall intensity and a good residue cover protecting the soil. An average of 30 erosion experiments in Brazil (De Maria, 1999) showed a reduction of 79 percent in soil losses under ZT compared to conventional tillage (5.6 tonnes/ha/annum under ZT and 23.3 tonnes/ha/annum with conventional tillage, while soil regeneration is estimated at 10 tonnes/ha/annum).

The reduction in the negative impacts of erosion on-farm and off-farm is, in itself, a huge environmental advantage. Farmers report increases in terrestrial and aquatic fauna under CA. Aquifer recharge is discussed in Chapter 6, which analyses the deforestation mitigation potential of land use intensification with ICLZT. Perhaps the most impressive point about farmers using CA is their change of attitude to working with nature instead of against it (see Figure 2 below and more details in Chapter 6).

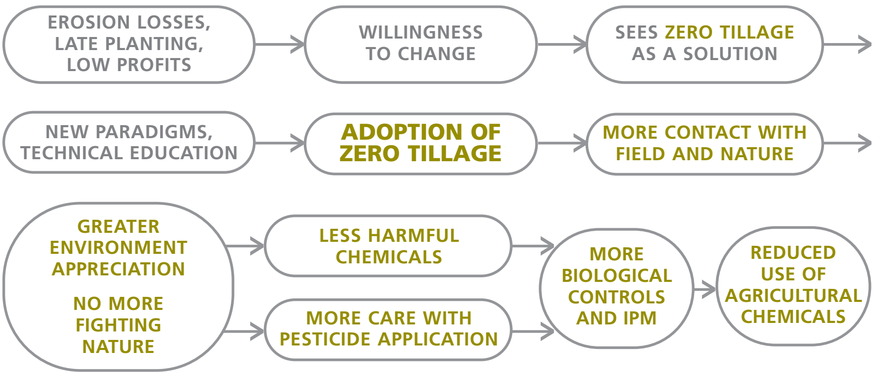


FIGURE 2: Zero tillage, the pathway to lower use of agricultural chemicals

PLATE 1: A trash disc cutting through crop residue – note the heavy spring to aid penetration.

PHOTO: CASE DO BRASIL

PLATE 2: Planting into a flattened cover of black oats (in areas with cool winters). The tractor has double rear wheels and 4 wheel-drive to reduce compaction. The cover after planting is poor, but adequate to stop erosion.

How does conservation agriculture work?

The first operation of the agricultural year is desiccation of cover crops and/or weeds with non-selective contact herbicides of negligible environmental impact. Thereafter, specialized planters, or drills, cut the crop residue with trash discs and slot the fertilizer and seed into the soil with minimal residue disturbance (Plates 1 and 2). The only subsequent operations are application of agricultural inputs (if required) and harvesting. Combine harvesters are fitted with straw spreaders or choppers to give even cover of crop residues.

Conservation agriculture has engendered a more responsible attitude towards the environment, regarding nature as an ally, and not as a foe. The CA farmer combines crop rotations and maintenance of surface residue with cover crops, integrated management of weeds, pests and diseases, rational fertilizer practices, integration of crop and livestock enterprises, watershed management and other environmental concerns. This confers sustainability on the system and assures zero or low levels of chemical residues in agricultural products, well within prescribed legal limits. Landers (2001) estimated values for ZT and ICLZT environmental impacts in Brazil.

INTEGRATED CROP–LIVESTOCK SYSTEMS WITH ZERO TILLAGE

Zero tillage has facilitated the development of ICLZT in the Cerrado biome, with wider application, in principle, in the Amazon, Atlantic Forest and Caatinga biomes. Arable CA systems encompass a whole farm, with both crops and livestock. Integration of beef fattening or rearing with annual crops started as diversification under conventional tillage. The new tropical ZT technology (Broch *et al*., 1997; Lara Cabezas and de Freitas, 1999) eliminated the erosion risk from ploughing, gave higher crop yields and tripled pasture carrying capacity while reducing costs, as shown by Landers *et al.* (2005) in Chapter 5.

Farmers have encouraged technology development, facilitated trials on their farms and often used technology ahead of research results. The backup of wide-spectrum and interdisciplinary field research (governmental and private) has resulted in credible long-term farm results, specialised training and extension programmes.

A new era for tropical CA began in the 1990s, triggered by ICLZT, which gave the potential to increase farm profitability and reduce clearing of native vegetation through land use intensification. A crop phase is the most cost-effective means of maintaining highly productive pastures. Many cattle rearers lack cropping skills – in which case a long term rental agreement with a crop farmer, guaranteeing winter grazing on the stubble until the first crop land reverts to pasture, can satisfy both sides, especially if *Brachiaria* spp. are undersown in the summer crop. Crop farmers diversify into cattle more readily, not least because, in good years, they have capital to invest and wish to spread their financial risk; ranchers are more averse to ICLZT because of (generally unfounded) fears of losing carrying capacity.

The principal benefits of adopting CA using ICLZT are summarized in Box 4. At present, many of them are financial intangibles, but farmers report them consistently as indirect financial benefits; direct financial benefits are analysed in Chapter 5.

The gross margins at different levels of intensification of land use are analysed in the real farm example shown in Figure 3. The benefits of ICLZT are higher than for crop and livestock systems conducted separately, illustrating that the benefits discussed above translate into profits. In Figure 3, from left to right, beef cattle and crop enterprises progress to an integrated crop livestock system on pasture and, finally, to fattening yards with green chop and silage from an irrigated area. The average of the first two bars is 26 percent; this should be compared with the 46 percent of the third bar.

BOX 4. Benefits of adopting CA using ICLZT

1. Increased profits through reduced production costs;
2. Risk reductions through diversification;
3. Very low, or zero, pasture renovation costs;
4. Opportunities for strategic winter grazing on crop areas;
5. Increased whole-farm herd carrying capacity as a result of point 4;
6. Reduced disease, pest and weed pressures in crops;
7. Great reduction in environmental pollution through erosion control;
8. Consequent reductions in use of agricultural chemicals;
9. Maintenance of a high average stocking rate on rotated pastures;
10. Consequent mitigation of the demand for clearing new land;
11. Improved soil structure for annual crops through soil aggregation by grass roots;
12. Increased biomass generation for surface residues;
13. Increases in SOM, CEC and water-holding capacity;
14. Reduced fertilizer needs through recycling and reductions in leaching and phosphorus fixation;
15. Improved rainfall infiltration rates, reducing erosion and flood peaks and increasing aquifer recharge;
16. Reduced silting of reservoirs, especially those used for hydro-electricity generation;
17. Faster depreciation of farm machinery;
18. Rationalization of overhead costs;
19. Professionalization of farmers and employees, with higher returns to labour;
20. Evening-out of income and labour peaks over the year;
21. Stabilization of the rural population and agribusiness job creation;
22. Generation of incremental employment in agro-industry.

Source: Adapted from Broch, personal communication (2002).

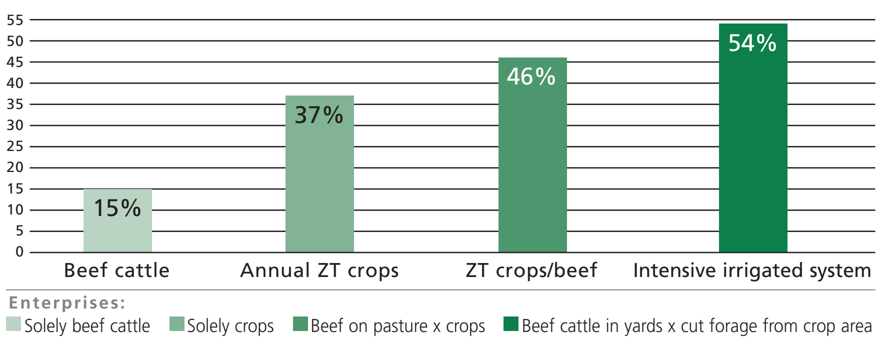


FIGURE 3: A comparison of gross margins at different levels of crop x livestock integration

Source: R. Merola, unpublished farm data.

Dissemination of ICLZT technology

A series of seminars, demonstrations, farmer technology meetings and training courses involving ICLZT have been carried out since 1997, mostly initiated by the private sector, more recently with active participation of EMBRAPA, which now leads these efforts (Landers, 1999). State extension agencies, which primarily serve family farmers, have been active in ICLZT in the last few years. In 2003 the Rice and Beans centre of EMBRAPA published a complete manual of results on ICLZT (Kluthcouski *et al.*, 2003) and in 2005, the Ministry of Agriculture, Livestock and Food Supply launched a programme specifically to promote ZT, with training, demonstrations and research. In 2004 APDC initiated its "Stewards of Our Water" project with Petrobras and in 2006 a joint APDC-National Water Agency (ANA) project was launched, using ZT and ICLZT as the principal instruments to improve on-farm water conservation. The "Pure Oil from Soya" project financed by Stichting DOEN from the Netherlands aims to reduce chemical use in soybean production. These projects obtain secondary financial support from the private sector, state and municipal governments.

CHAPTER 2

Livestock and annual crop production in wet-dry and humid-tropical Brazil

LIVESTOCK TYPE

Beef cattle breeds in tropical Brazil are dominated by the Ongole zebu from India, which has been the subject of selective breeding since the first importations in 1870. The Nelore is the principal breed of Indian origin, which has other minor derivatives (Oliveira, 2002). Other breeds from the sub-continent are losing popularity as they are upgraded with superior Nelore bulls. *Bos taurus* breeds dating from the colonisation period and Santa Gertrudis (*B. taurus* x *B. indicus*) are of minor importance. European beef breeds are not adapted to the tropics. For fattening, crosses of Nelore or other zebus and European breeds are favoured; artificial insemination is also used. Cows from these crosses come into heat at about 24 months, as opposed to 30 months for pure Nelore (A. C. Campos, personal communication, 2005). Magnabosco *et al.*, (2002) demonstrated the effect of genetic selection for performance on pasture: superior genotype animals showed a 26 percent improvement in weight gain over poorer ones.

Most of Brazil's milk comes from Holstein-Friesian cattle and their crosses, of which the Girolanda is the most popular. At tropical elevations over 600 metres, pure Holstein-Friesian perform well when given optimal conditions of feed and shade. Progeny testing and selective breeding programmes are advanced, as are specialised suppliers of semen and embryo transplant services. Holsteins were predominantly of North American origin, but recent imports of stock and semen from New Zealand and other countries are genetic types selected for performance on pasture. There are a few specialized Jersey herds.

Water buffalo thrive where they have access to water. Except for Pará's Amazon flood-lands the water buffalo population is low in the rest of Brazil. They are now expanding from the Amazon lowlands to the lower tropics, due to their hardiness and adaptation to poorer feed. There is an excellent example of almost subtropical ICLZT with water buffalo in Rolândia-PR, of many years standing, where biomass in excess of 6 tonnes/ha is made into hay for winter feed on permanent pasture (H. Bartz, personal communication, 1994).

Herd size and performance

Brazil's cattle herd grew from 153 million in 1995–1996 to 205 million in 2004, an annual growth rate of 3.7 percent. Of these, 60 percent are in the humid and wet-dry tropical states comprising the Amazon and Cerrado biomes. The Cerrado figure is estimated since IBGE figures are by state, not biome. The importance of the Cerrado in beef production is evident. About 60 percent of Brazil's 99 million ha of planted pastures are in wet-dry and humid tropical regions: see Table 1.

TABLE 1: **CATTLE POPULATION AND PASTURE AREAS IN BRAZIL IN 2004**

REGION	CATTLE	NATIVE PASTURE	CULTIVATED PASTURE
	(HEAD)	(HECTARES)	
Brazil	204 512 737	78 048 463	99 652 009
Cerrado*	84 596 782	17 443 641	45 320 271
Amazon**	39 787 138	9 623 763	14 762 858

* States of Mato Grosso, Mato Grosso do Sul, Goiás and Federal District, Bahia west of the São Francisco river, plus 50 percent of Minas Gerais.
** States of Amazonas, Rondônia, Tocantins, Acre, Amapá, Pará and Roraima.

Source: Instituto Brasileiro de Geografia e Estatística - IBGE data for 2004 - website (2006).

Average performance parameters for Brazil's cattle herd are given in Table 2. The southern winter offsets the dry season in the Cerrado, and most of Brazil's herd is in these two regions, so these figures are considered representative for the wet-dry and humid tropics. The livestock sector in tropical Brazil is at the end of an extractive phase where the solution has traditionally been to expand onto newly cleared land. From about 1980, expansion was mainly on dystrophic latosols (Ferralsols) or quartz sands

(Arenosols), which required liming and had little inherent fertility. Pasture establishment under rice, seldom using more than 300 kg/ha of NPK 4.14.8, was common. Stocking rates fell fast and clearing continued to compensate for both loss of carrying capacity and herd expansion.

TABLE 2: **AVERAGE PARAMETERS FOR BRAZIL'S CATTLE HERD AND IMPROVED TECHNOLOGY SYSTEMS**

INDEX	NATIONAL AVERAGE	IMPROVED SYSTEM	HIGH TECHNOLOGY SYSTEM
Calving rate (%)	60	>70	>80
Mortality to weaning (%)	8	6	4
Weaning rate (%)	54	65	75
Post-weaning mortality (%)	4	3	2
Calving interval (months)	21	18	14
Age at slaughter (years)	4	3	2.5
Herd offtake (%)	17	20	22
Carcass weight (kg)	200	220	230
Kill out (%)	53	54	55
Stocking rate (AU/ha)	0.54	0.72	0.96
Liveweight gain (kg/ha/yr)	64	98	145
Weight gain (kg of beef/ha/yr)	34	53	80

Source: Macedo (1999).

BACKGROUND FOR ICLZT

Integration of beef fattening or rearing into annual crop systems began as a hedge against low soybean prices, but with the advent (*ca*. 1994) of the new tropical ZT technology (Broch *et al.*, 1997; Lara Cabezas and de Freitas, 1999), its multiple benefits to both crops and pastures soon became evident.

Dry season pasture production determines a farm's year-round carrying capacity and beef prices rise in this period. In this publication "carrying capacity" refers to the dry season stocking rate. Typical rainfall patterns are shown for Amazon and Cerrado sites in Figure 4. Rainfall intensity increases to the northwest and is greater in the large cattle-growing area of South Pará, with a dry season of 2–3 months, compared to 4–6 months in the Cerrado. Better winter rainfall in the Amazon region allows higher dry season stocking rates and cattle enterprises give a higher average return per hectare than in the degraded

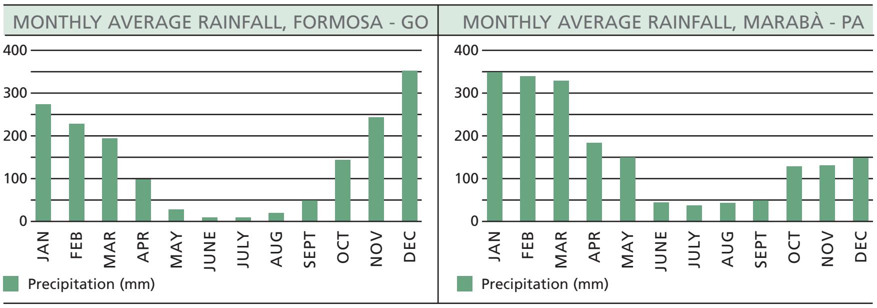


FIGURE 4: **Monthly rainfall distribution at typical Cerrado and Amazon sites**

Source: Instituto Nacional de Meteorologia - INEMET.

pastures of western São Paulo (models No. 4 and No. 5 respectively in Chapter 5 and Camargo *et al*., 2002).

The author estimates that about 85 percent of pastures in the Cerrado are *Brachiaria* with somewhat less in the Amazon biome, while *Panicum maximum* cultivars make up less than 5 percent in the Cerrado. Introduction of *Brachiaria* in the Cerrado raised average carrying capacity from 0.3 AU/ha to 1.0 AU/ha (Macedo, 1997). *Brachiaria* pastures on Cerrado latosols can last up to 5 years without further fertilizer; Guinea grass cultivars give higher carrying capacity on more fertile soils, but decline rapidly with loss of fertility. The winter carrying capacity of native pasture is between 0.1–0.05 ha/AU with annual burning to generate regrowth at the height of the dry season. Under this regime mortality was high and steers lost weight badly over the dry season, reaching slaughter (220–240 kg carcass weight) in three to four years.

Extensive beef producers have been slow to invest in management technology, (e.g. fertilizing pastures, electric fencing, pasture legumes and integrated crop–livestock rotations) but have rapidly taken up new grasses, such as *Brachiaria brizantha* and new cultivars of *Panicum maximum,* which show a very high benefit/cost ratio (Camargo *et al*., 2002). Extractive management led to gradual decapitalization of beef farmers, which, together with resistance to change, has impeded the modernization of the industry. Growing maize and sorghum for silage is quite widespread and dry season fattening pens have gradually increased since the early 1970s. Since about 1990, there has been a significant diversification of crop farmers into beef, moving towards ICLZT.

Vaccination against foot-and-mouth disease, control of ectoparasites and ear tagging are obligatory in beef-exporting states and the rule in the other states, except for ear tagging. Mechanical milking is increasing rapidly, although most small producers still hand-milk; silage or green chop are used extensively in winter and concentrate feed is based on maize and soybean meal with additives. Small farmers are traditionally milk producers on improved pastures; in the South of Pará there is a concentration of small milk producers, currently in crisis due to falling carrying capacities and lack of access to new land (Homma *et al.*, 2001).

Available pasture technology permits profitable intensive cattle operations (Yokoyama *et al.*, 1999; Landers *et al.*, 2005; and Vilela *et al.*, 2001). Electric fencing facilitates rotational grazing and the adoption of ICLZT is a low-cost way to turn residual fertility from the crop phase into profit. Fertilizing pastures is considered uneconomic at prevailing beef prices.

The process of pasture degradation

Inadequate replacement of nutrients and overstocking are the chief causes of pasture degradation in the Cerrado (Vilela *et al.*, 2004); Figure 5 shows the general sequence of degradation processes. Before going into an ICLZT system the degree of pasture degradation must be taken into account, to decide whether full land preparation is required. Besides fertility decline and overstocking, brush invasion and large paddock size are the major limitations to pasture productivity in the Amazon.

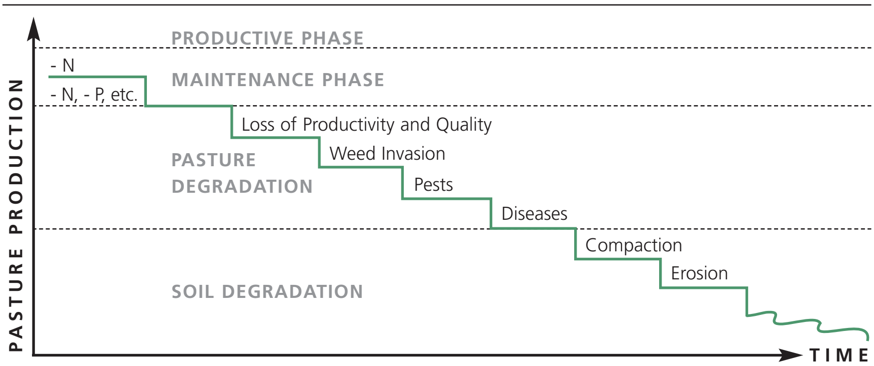


FIGURE 5: Schematic representation of the soil degradation process

Source: Macedo (1999) in Vilela *et al.* (2004).

PLATE 3: Light green/yellowish colour may be an indication of N deficiency.

PHOTO: C. BATELLO

PLATE 4: An overgrazed *Brachiaria* pasture, with low regrowth capacity, invaded by termite mounds.

Continuous degradation through extractive management (as shown in Figure 5) brings successive reductions in carrying capacity. These begin with N and P deficiencies, as shown in Plate 3, and end up in the loss of soil cover and consequent soil degradation through compaction and erosion. Overgrazing is the most common form of poor pasture management. Ideal management seeks to keep the pasture with full ground cover and always in the productive phase, by adjusting stocking rates or rest periods to avoid over-grazing, and adding fertilizer and lime when necessary. Short high stocking periods in the maintenance phase are tolerable. An example of the end of the pasture degradation phase, about to enter the soil degradation phase is shown in Plate 4, where annual beef production would be about 40–50 kg/ha/year and dry season stocking rate is below 0.5 AU/ha. Nitrogen deficiency is the principal limiting factor in Brazilian tropical pastures (Boddey *et al.*, 2004) followed by phosphorus, sulphur, calcium, magnesium and zinc (Vilela *et al.*, 2004).

In the Amazonian pasture areas of southern Pará the 2–3 month dry season and better quality Guinea grass carried 1 to 2 AU/ha over the first five years, depending on initial fertility. When it dropped to about 0.5 AU/ha, due to fertility decline or bush encroachment, the pasture was renovated with *Brachiaria* spp., with carrying capacity ranging from 1.5 to 2 AU/ha in its first five years. Thus, *B. brizantha* or *B. humidícola* replaced Guinea grass as fertility was mined, restoring profitability with a second extractive phase (Kaimowitz and Angelsen, 2001).

CHAPTER 3

Principal integrated zero tillage crop–livestock systems

GENERAL CONSIDERATIONS

Zero tillage is not sustainable without crop rotation, always with a different crop in the same season of the subsequent year. Rotations comprise a number of single-year crop successions. In tropical Brazil a second crop may be sown in the second half of the rainy season: where rainfall is inadequate a fallow is used. Examples of typical rotations are found below and others are detailed in the case studies (Chapter 5).

Soybean-millet is a common crop succession in one year, but soybean-millet followed by soybean-millet is not a rotation, it is a crop succession repeated. The greater the number and the higher the diversity of crops and genera involved in a rotation, the higher the biodiversity and the greater the potential for biological control of diseases, pests and weeds, through cutting the build-up of inoculum or populations; even nematodes can be efficiently controlled by some pasture grasses (Vilela *et al.*, 2004) and leguminous cover crops. A pasture phase in a rotation builds up SOM, improves soil structure, nutrient and water availability (Vilela *et al.*, 2004), and allows reductions in the levels of pesticides and fertilizers used. High SOM and crop residue levels reduce the potential pollution of aquifers and surface water by acting as chemical and physical buffers (Amado and Costa, 2004).

Crop successions within the rotation must be balanced so as to maintain an average of over 6 tonnes/ha of dry matter in crop residues. Production of adequate biomass to build up SOM and maintain profitability is helped by a pasture phase. Cover crops can assist when late or winter rains are adequate. Sá *et al.* (2004) demonstrated increases of root mass of between 11 and 76 percent at 5 and 10 tonnes DM/ha of residues with a positive regression on hybrid maize yields.

Table 3 shows the impact of the cover crop on the yield of the following crop in Minas Gerais (the performance of sunflower depends on low soil pathogen levels and absence of free aluminium) and Table 4 shows which main crops can follow which preceding crops from the point of view of soil diseases and plant nutrition. The table also shows recommended and unsuitable following crops, illustrating the principle of rotating crop families. In Table 3, with results from Minas Gerais, yields varied significantly for different preceding crops with both maize and soya, with a general advantage for dicotyledonous preceding crops, except for black oats (*Avena strigosa*) preceding soya.

TABLE 3: **EFFECT OF COVER CROPS ON MAIZE AND SOYBEANS (1997-98) IN MINAS GERAIS**

MAIZE		SOYBEANS	
COVER CROP	YIELD (KG/HA)	COVER CROP	YIELD (KG/HA)
Pigeon pea	6 628 a*	Sunflower	3 558 a*
Niger oil**	6 367 ab	Black oats	3 521 ab
Sunflower	6 195 bc	Forage radish	3 440 ab
Pearl millet	5 981 bcd	Sorghum	3 437 ab
Maize	5 964 cd	Pearl millet	3 258 b
Sorghum	5 727 d	Maize	3 002 c

* Letters indicate statistical differences at the 5% level (Tukey)
** *Guizotia abyssinica*

Source: Lara Cabezas, unpublished data (2003).

Table 5, with data from Roraima, 3° N, shows that soybean following pigeon pea was very inferior to soybean following a graminaceous crop (with or without another legume). This has been corroborated by Döwich (2002) for Bahia and Kluthcouski *et al.*(2003) at several sites, indicating the fundamental nature of this principle. The sources of these yield increments are still to be elucidated.

Biological activity in the soil is increased under ZT. The most important discovery in this area, using *Brachiaria* spp. as a cover crop, has been the reduced incidence of soil pathogens, as shown by Da Costa and Rava (2003), who measured reductions in *Rhizoctonia* (*R. solani*) and White

TABLE 4: **RECOMMENDATIONS FOR CROP SUCCESSIONS IN ZERO TILLAGE ROTATIONS**

PRECEDING CROP		MAIN CROP	FOLLOWING CROP	
Not recommended	Recommended		Recommended	Not recommended
forage radish, phaseolus bean, pigeon pea, hairy vetch, mucuna, lab lab, trefoil, and sunflower	maize, sorghum, finger millet, wheat, rice, oats (*A. sativa*), maize + mucuna and maize + phaseolus bean	**SOYBEANS**	maize, sorghum, finger millet, forage radish, sunflower, rice, oats, hairy vetch and wheat	
sorghum, rice, finger millet and wheat	soybeans, oats, phaseolus bean, mucuna, maize, sunflower, sunn hemp, forage radish, hairy vetch, maize + mucuna and lab lab	**MAIZE**	oats (*A. sativa*), forage radish, sunflower, finger millet, wheat and soybeans	
forage radish, bean, hairy vetch, pigeon pea	maize, soybeans, finger millet and oats	**COTTON**	oats, forage radish, wheat, soybeans, maize, sorghum, finger millet and rice	sunflower, phaseolus bean, hairy vetch and trefoil
forage radish, mucuna, pigeon pea, trefoil, hairy vetch and lab lab	forage radish, mucuna, pigeon pea, trefoil, hairy vetch and lab lab	**SUNFLOWER**	maize, sorghum, rice, finger millet, oats, wheat, and forage radish	soybeans, cotton and phaseolus bean
trefoil, pigeon pea, soybeans, forage radish, lab lab, hairy vetch and sunflower	maize, sorghum, rice, oats, finger millet and mucuna	**PHASEOLUS BEAN**	maize, sorghum, rice, finger millet, wheat and oats	forage radish, soybeans and sunflower
finger millet and rice	maize, pigeon pea, soybeans, forage radish, crotalaria and mucuna	**SORGHUM**	sunflower, oats, phaseolus bean, soybeans, trefoil, forage radish, mucuna, hairy vetch, pigeon pea and lab lab	wheat, maize, sorghum and finger millet
wheat, sorghum and finger millet	forage radish, crotalaria, pigeon pea, mucuna, trefoil, oats, maize, sunflower, lab lab and phaselous bean	**UPLAND RICE**	sunflower, trefoil, phaseolus bean, hairy vetch, oats, soybeans, forage radish, mucuna, pigeon pea and lab lab	wheat, maize, sorghum and finger millet
rice, sorghum, finger millet and black oats for seed	maize, crotalaria, phaseolus bean, sunflower, pigeon pea, mucuna, lab lab, soybeans and cotton	**WHEAT**	mucuna, sunflower, crotalaria, cotton, phaseolus bean, maize, sorghum, finger millet, lab lab, pigeon pea and soybeans	maize and rice
none	any crop	**OATS**	any crop	wheat after black oats to seed
cotton, sunflower, wheat, sorghum and upland rice	soybeans, maize, phaseolus bean, oats and finger millet	**PERENNIAL PASTURE**	soybeans and phaseolus bean	cotton, oats, rice, sunflower, maize, sorghum and wheat

Source: Broch *et al.* (1997).

TABLE 5: **EFFECTS ON SOYBEAN YIELDS OF GRASSES AND LEGUMES AS PRECEDING COVER CROPS, IN RORAIMA STATE**

PRECEDING COVER CROP	YIELD (KG/HA)
Brachiaria spp.	3 775
Native grass + *Stylosanthes guianensis* cv. Lavrado	3 632
Stylosanthes guianensis cv. Lavrado	2 828
Pigeon pea	2 815

Source: Gianluppi (1999).

Mould (*Sclerotinia*) infections of 75 percent and also in *Fusarium solani.* This principle has revolutionized rainfed and irrigated Phaseolus bean production when planted into desiccated *Brachiaria*, sometimes leading to farm yields of over 3 000 kg/ha (corroborated by Kluthcouski *et al.*, 2003).

Dos Santos (2003) analysed different systems of ICLZT in terms of weight gain (in beef) and financial returns to the beef enterprise (see Figure 6). The introduction of a fast-establishing annual (hybrid forage sorghum), gives grazing 20 days earlier compared to conventional establishment of *Panicum maximum*. Alternatively, a mixture of pearl millet (*Pennisetum americanum*), or finger millet, (*Eleusine coracana*) with *P. maximum* can achieve the same result (A.B. van der Vinne, personal communication, 2003).

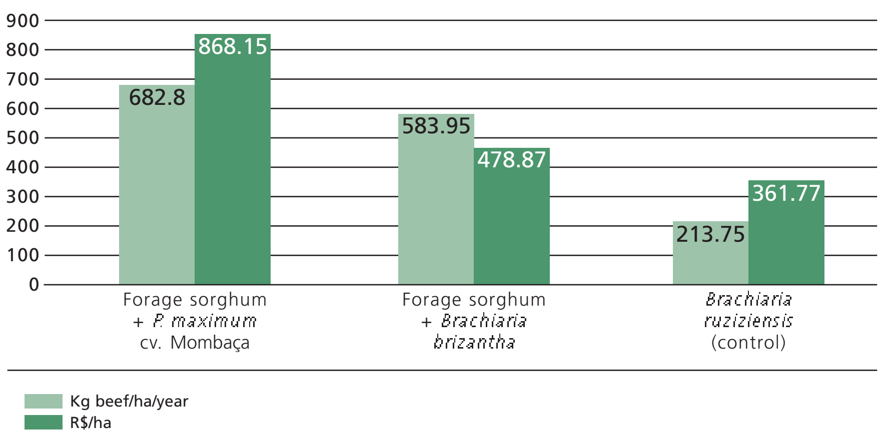
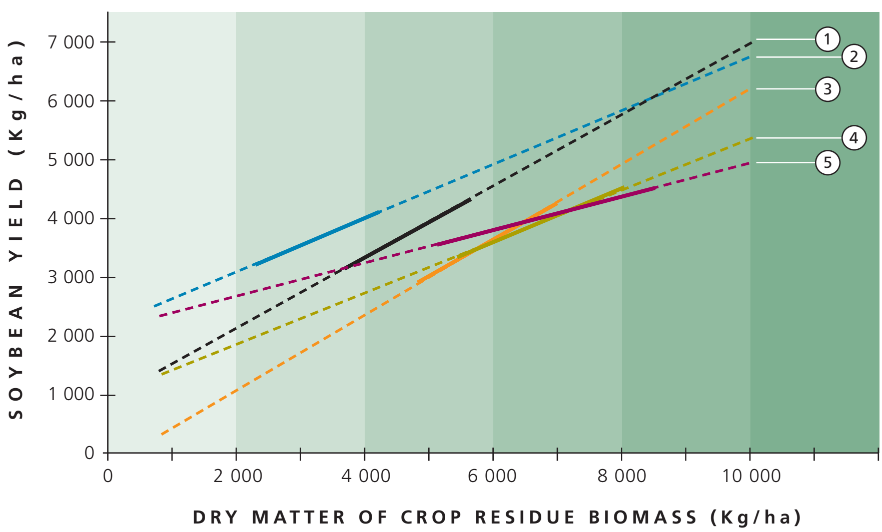


FIGURE 6: Performance of three systems of ICLZT in terms of weight gain and net profit in Brazilian reais*

* US$ 1.00 = R$ 2.91, average for Nov. 2003

Source: Dos Santos (2003).

There is a direct correlation between the amount of crop residue dry matter and the yield of the following crop, as shown by Séguy and Bouzinac (2002). The farmer must know this to gauge the opportunity cost of the pasture consumed (see Figure 7), but this requires a level of cost analysis beyond that of most farmers. Pasture renovation with ZT can be done without a crop phase, by desiccation of the old pasture, re-seeding with fertilizer and liming, using part of the technology described on the following pages.



Regressions* of yield of a medium cycle soybean variety FT-114 on quantity and type of biomass of the preceding crop. 1997/2000, Agronorte, Sinop, Mato Grosso, Brazil

(1)	Finger Millet - Y_{pg}	$Y_{pg} = 0{,}5957X + 948{,}76$	R = 0,91
(2)	Pearl Millet - Y_{mi}	$Y_{mi} = 0{,}4528X + 2181{,}6$	R = 0,90
(3)	Sorghum - Y_{so}	$Y_{so} = 0{,}629X - 154{,}63$	R = 0,97
(4)	Sorghum + *Brachiaria R.* - Y_{so+B}	$Y_{so+B} = 0{,}4327X + 978{,}98$	R = 0,80
(5)	Pearl Millet + *Brachiaria R.* - Y_{mi+B}	$Y_{mi+B} = 0{,}2787X + 2110$	R = 0,70

Biomass (dry matter) production interval

* 6 replications x different fertilizer levels each year

FIGURE 7: Correlation between total annual dry matter generated by the preceding crop and the yield of the following soybean crop

Source: Séguy and Bouzinac (2002).

Systems typology

Livestock systems in ICLZT are independent of the crops grown; the main ones are:

(i) Fattening steers to slaughter weight;
(ii) Rearing operations selling steers to (i);
(iii) Combined rearing and fattening operations;
(iv) Cow calf operations selling weaners to (ii) and (iii);
(v) Breeding-to-slaughter integrated operations;
(vi) Intensive dairy operations;
(vii) Small, non-intensive, dairy operations.

All may or may not include supplementary feed with silage, cut fodder and concentrates. In beef-from-pasture operations this is confined to the dry season and creep (supplemental) feeding of calves at high management levels. Use of salt or mineral mixes is general, even in the most extensive systems, and mineral supplements usually include protein or urea to improve digestibility of dry season forage. Feedlot fattening can be grafted on to (i), (iii) and (iv), considerably increasing intensity of land use. Pure feedlot fattening is not discussed here as it is an independent alternative to fattening on pasture.

There is no over-arching crop system typology. The chief distinction is between rainfed and irrigated cropping, which is rarely without a rainfed area. Few farmers change their basic cropping pattern when adopting ICLZT, although they may undersow maize or oversow soybeans with grasses or grow earlier varieties to allow greater winter pasture production as a second crop. Some advanced farmers irrigate intensively-grazed pasture. Cattle farmers adopting ZT cropping (a lesser trend) usually choose soybeans or cotton as their main cash crop. The latter is late-sown in December, which allows time for early bite grazing at the onset of the rains with pearl millet, finger millet or forage sorghum.

Basic ICLZT systems have a crop and a pasture phase in rotation and comprise:

(i) Winter stubble grazing on summer cropland;
(ii) Summer crops with winter pastures (undersown or oversown);
(iii) Summer crop plus second crop plus stubble grazing in winter;
(iv) Crop production for feed supplement (silage, sugar cane, elephant grass, hay, green forage), usually a minor area within another system;
(v) Some combination of these.

Common rotations

Soybeans are often mono-cropped for several years during the low disease-weed-pest pressure period after land clearing and are universally dominant in rainfed farming, with maize in rotation, when practised, every two to four years. Soybeans do not return enough biomass to the system for long term sustainability. While physical soil degradation has been severe under conventional soybean cultivation it has been hardly noticeable under ZT, leading many farmers to disregard a pillar of CA, crop rotation.

Maize is essential for adequate biomass generation in a CA rotation, but in frontier areas the market is weak; higher transport costs per unit value and higher storage requirements (both double those of soybeans) severely limit its use in rotations. In such regions rice is often grown as a pioneer crop after clearing (Séguy *et al.,* 1998), or in pasture renovation (Kluthcouski *et al*., 1999). New rice cultivars can exceed 5 tonnes/ha (Séguy *et al*., 1998). Cotton and Phaseolus beans have the advantage of late sowing, allowing more grazing on winter pasture. In the western Cerrado and in Amazonia a second crop of maize can be highly profitable. Alternatives to maize as a second crop in lower rainfall areas are pearl millet (*Pennisetum americanum),* sorghum (*Sorghum bicolor*) and finger millet (*Eleusine coracana)*, or pasture grasses sown in association with the main or second crop.

A common starting point for adoption of ICLZT would be a 10 to 20 year-old degraded pasture. The most generalized ICLZT rotation would be: Yrs 1, 2 and 3 soybeans in summer and stubble grazing in winter; Yr 4. maize, undersown with *Brachiaria brizantha* or *B. ruziziensis;* years 5–7 or 5–8 pasture.

The most sophisticated rotation would be: Yr 1 cotton-winter fallow, Yr 2 soybeans-second crop maize, Yr 3 soybeans-second crop maize undersown with finger millet and *Panicum maximum*, Yr 4 one-year *P. maximum* ley. This maximises the stocking rate on the pasture up to 4–5 AU/ha, resulting in 75 percent of the farm in crops (Vinne, 2001).

The simplest rotation would be that of Case Study 5, a predominantly cattle operation, with: 6 year-old pasture converted to Yr 1 maize for silage and/or grain, undersown with grass, Yr 2–7 pasture (enriched, or not, with pigeon pea).

Crop successions used as building blocks for rotations

Crop successions, which are the building blocks for any desired rotation, can be classified as follows:

- Crop establishment in degraded pastures;
- Pasture establishment in, or immediately following, an annual crop (for permanent or temporary pasture). This could include dual use of a cover crop both for grazing and subsequent soil cover;
- Use of crop areas for silage or green chop production as supplement for cattle;
- Enrichment of existing pastures with legumes. This is practically limited to sowing pigeon pea directly into existing pasture;
- Sowing annual crops into a permanent grass or legume sward;
- Opportunity grazing of crop stubble in the dry season.

SUMMARIES OF THE TEN MAIN ICLZT TECHNOLOGIES

1. Crop establishment in degraded pastures

Excessive impediments to mechanized cultivation, or toxic aluminium levels in the 0–20 cm layer, may require full land preparation to remove irregularities and incorporate lime. When necessary, operations should be carried out towards the end of the rains and an annual fodder sown immediately to provide enough winter grazing to more than compensate for loss of the old pasture. This removes the chief concern of the rancher (i.e. lack of winter forage). These fodders must be grazed to suppress flowering or they will mature and die back. If they set seed, it will fall to the ground and germinate with the first rains. Either from regrowth or seed, ground cover can be generated and ready for desiccation prior to sowing the annual crop (see Box 5). In the case of subsoil deficiency in calcium or sulphur deficiency, gypsum can be applied along with lime, whether incorporated or not.

If no impediments exist the degraded pasture is desiccated at the beginning of the rains with a systemic, non-selective herbicide (glyphosate, or ammonium gluphosinate). Specialized ZT planters (Plates 19, 21 and 23–25) place seed and fertilizer below the residue. A narrow in-row tine or special fertilizer boot behind the cutting disc (Plates 26 and 27) is necessary in old, degraded pasture to break the compacted surface layer, allowing deep fertilizer placement and penetration of crop roots.

BOX 5. **Critical points: Crop establishment in degraded pastures**

(i) Pasture should be heavily grazed or cut prior to desiccation, which is done when leaf area has recuperated enough to absorb the herbicide;
(ii) Clumps (tussocks), if not well rotted, will cause the planter to jump and leave seed exposed on the surface even after rotary chopping;
(iii) An interval of up to 21 days is needed after desiccation to allow root fermentation – a light second desiccation is usually required just prior to sowing.

Where there is no compacted layer or excessive residue to clog the tines, offset double discs of different diameters for both seed and fertilizer are used (Plates 26 and 27; more information in Baker, 2007). Thereafter selective herbicides are used *ad hoc* in the crop. A one-year pasture ley maximizes the proportion of crops in the rotation for a given herd size, which is an option when crop prices are high.

PLATE 5: Adhemar Tietze, pioneer guacho farmer in Sinop, Mato Grosso state, shows desiccated *Brachiaria* residue in ZT soybeans.

When soil conditions are adequate any annual crop can be sown with this technology – soybeans (see Plate 5), phaseolus beans, maize, cotton etc. There is a special bonus with phaseolus beans because of the low level of soil disease and nematodes after desiccating *Brachiaria* (Da Costa and Rava, 2003; and Vilela *et al.*, 2004).

2. Establishing pasture in annual crops

The most common options for establishing pasture in annual crops are: undersowing (see Plate 6), intersowing and oversowing.

Rainfall availability is greatest with undersowing and least with sowing after harvest. CAT Uberlândia (2005) has shown no difference in maize yield when 9 kg/ha of *Brachiaria ruziziensis* seed was sown at the two and four leaf stages of maize, but the two leaf sowing gave quicker establishment and allowed earlier grazing. Kluthcouski *et al.* (2003) affirm that *Brachiaria* undersown in maize can be shaded to the

PHOTO: I. DÖWICH

PLATE 6: Nelore cattle on *B. brizantha*, established under maize.

point of not requiring herbicide to check it (tropical grasses are C_4 plants, hence shade intolerant). For manual systems, a jab planter can be used, mixing seed with fertilizer or some inert granular material, but if the stand is not uniform shading will be inadequate and some yield loss will occur from competition from *Brachiaria* in the unshaded areas.

PLATE 7: *Brachiaria* spp. intersown in maize at 20 DAP.

Oversowing can gain up to three weeks on same-day sowing after harvest, which is crucial because the amount of rainfall after germination is correlated with establishment and dry matter yield. However, conditions for establishment with oversowing are not always adequate and this risk must be accepted against the potential benefit and low cost factors. Intersowing is carried out by planting in the inter-row of the crop after emergence (see Plate 7 and also Plate 8).

Maize undersown or intersown with *Brachiaria* is the most important method for establishing pastures (see Box 6 for more details), and may have nurse crops other than maize e.g. rice (Kluthcouski *et al.*, 2003). Grass may be undersown, mixed with fertilizer at sowing, dropped onto the row in front of the trash disc from additional seed hoppers or by shallow drilling two rows in the inter-row at the 2–4 leaf stage of the maize. Excessive


PHOTO: C. BATELLO

PLATE 8: *Brachiaria* intersown in maize; note the height of the grass shortly before maize harvesting.

BOX 6. **Critical points: Establishing pasture in annual crops**

(i) *Brachiaria* seed mixed with fertilizer should be sown in maize 7–10 cm deep in lighter soils and 3–4 cm deep in heavier ones to delay emergence (Cobucci and Portela, 2003); some farmers have reported up to 10–20 percent yield depression in very wet years (about 1 in 10 frequency) with this method, using *B. brizantha*, but little with the less aggressive *B. ruziziensis*;

(ii) Seed mixed with fertilizer should be sown the same day or vigour may be affected, especially with fertilizers containing high K or N levels (Kluthcouski *et al*. 2003). Experience indicates a possible problem of seed burn if, in a dry spell, the soil has inadequate moisture to dilute the fertilizer;

(iii) Unless the soil is very well structured, the ZT planter or drill must be equipped with a narrow in-row sub-soiling tine to break the 5–10 cm compacted zone in the old pasture – alternatively, larger diameter fluted trash discs might be tried;

(iv) Panicums and other small-seeded grasses are unsuited to deep planting and must be shallow-drilled, about 1 cm; at present insufficient information is available to define the parameters for undersowing small-seeded grasses in general.

grass growth can be checked with sublethal doses of Nicosulfuron of 8–12 gm a. i./ha (Cobucci and Portela, 2003). Experiments in several locations and years showed little or no significant difference in maize or sorghum yields (Kluthcouski *et al*., 2003), see Table 6.

In upland rice, undersowing has been common under conventional tillage and works well with ZT when the grass is sown in the rice row to control shading. Although some yield reduction of rice has been observed (Kluthcouski *et al.*, 2003) – the same depths of sowing should be observed as for maize. undersowing is possible in soybeans: reduced post-emergent applications of haloxyfop-methyl are promising and Cobucci and Portela (2003) recommend one quarter of the full application to check *Brachiaria* spp., but this technology is not well field-tested and results will be very dependent on the metabolic activity of the grass.

3. Sowing pasture after early harvest

Usually, but not always in the Cerrado, there will be sufficient rain to establish a pasture up to late February (see Box 7). The ideal method for sowing is with a ZT drill in closely-spaced rows (approx. 15 cm), straight after harvest (i.e. behind the combine on the same day). Drilling is preferred, but most farmers do not have a drill and broadcast the seed with

TABLE 6: **EFFECT OF UNDERSOWING BRACHIARIA SPP. ON MAIZE CROP YIELDS**

CROP	YIELD (kg/ha)[1]	
	PURE STAND	UNDERSOWN WITH GRASS
Maize [2 and 3]	6 354–6 877	6 401–6 795
Forage maize [2]	48 367	48 467
Grain sorghum [4]	3 687	3 581
Forage sorghum [4]	32 333	32 867
Soybeans [2 and 5]	2 971–3 056	2 677–2 414
Rice [6 and 7]	1 968–2 072	1 503–1 859

[1] Average of six repetitions;
[2] Average of four locations;
[3] Average of two locations: Santa Helena de Goiás-GO e Luziânia-GO.
Refers to application of 6g of a. i./ha of nicosulfuron in maize undersown with grass;
[4] Average of two locations: Santa Helena de Goiás-GO, Luziânia-GO and Mimoso-BA;
[5] Average of three locations: Santa Helena de Goiás-GO, Campo Novo dos Parecis-MT and Mimoso-BA. Refer to application of 24 g of a. i./ha of haloxyfop-methyl in soybeans undersown with grass;
[6] Average of two locations: Luziânia-GO and Mimoso-BA;
[7] Average of Luziânia-GO. Refers to application of 120g of a. i./ha of clefoxydin in rice undersown with grass

Source: Adapted from Kluthcouski *et. al.* (2003).

BOX 7. Critical points: Sowing pasture after early harvest

(i) Adequate rainfall to get through the dry season should be guaranteed by early sowing;

(ii) Local trials are necessary to optimise sowing date with variations in rainfall, soils, varieties, etc.

a fertilizer spreader, covering it by running a closed levelling disc harrow over the stubble. This low-cost method leaves about 40–60 percent cover, but it oxidises organic matter and increases the evaporation of precious moisture. In addition, it only has a moderate chance of success after February (i.e. it is best after an early harvest, but then the farmer's choice would be for a second cash crop, so pasture establishment with this system will always be in moisture-short situations). Finally, care must be taken to minimize soil and residue disturbance – ideally, over 70 percent cover should be maintained to guarantee erosion control.

An innovative São Paulo farmer's solution to this problem was the adaptation of a levelling disc, welding angle iron bars across old, worn, discs, which leaves the cover practically intact. A chain harrow, or light anchor chain, between two tractors, are superior solutions and faster operations, incorporating the broadcast seed into the crop residue with minimal disturbance. Desiccation may be unnecessary if the weed burden is very low. Previous history of the field, plus spot observations should determine this option – persistent weeds, such as *Sida* spp., *Cassia rotundifolia, Commelina* spp. and *Digitaria insularis* should not be present. As much starter fertilizer at planting as the farmer can afford (emphasizing P) will assist in promoting good weed suppression and providing early bite. The amount of winter pasture in the first year will be governed by rainfall and overgrazing should be avoided.

4. Grass oversown in soybeans or maize

Oversowing can be done with a fertilizer broadcaster or by aerial seeding after field-testing to check the required overlap. Commonly-used forages in soybeans at full grain maturity are: pearl and finger millets and *Brachiaria* spp., but Guinea and Molasses grasses have also shown some success (Landers, 1994). This system is cheap (just the seed plus application), offset by high risk of failure if rain does not follow shortly after seeding; the Cerrado and Amazon transition forest regions experience short dry spells of ten days or more during January-March (Goedert, 1985) when soybeans are maturing. Oversowing into maize increases the risk since there is no leaf-fall to cover the seed; it should be carried out at the beginning of canopy senescence, when more light penetrates to ground level. With any main crop, the earlier it is sown and the shorter its cycle, the greater amount of rain will fall on the second (oversown) crop (see Box 8). Rarely will the conditions exist for oversowing of the whole cropped area. However, the cash value of additional dry season grazing is very high. Beware of ants, beetles, other insects or birds reducing establishment by removing seed – an increase in seed rate may be required. Seed dressing with insecticide in this sowing mode is dangerous for birds and small animals, and should be avoided. However, fungicidal dressing can be useful to combat high pathogen pressure in the surface litter. *B. ruziziensis* germinates better on the soil surface than *B. brizantha.*

BOX 8. **Critical points: Grass oversown in soybeans or maize**

(i) The best chance of success is when soil is moist at sowing and rain falls within a few days;
(ii) The risk/benefit ratio must be clearly understood, or an eventual failure will lead to abandoning this practice;
(iii) Seed rates must be 2.5 or 3 times higher than for drilling – for seed rates with drilling see Table 7;
(iv) The best time to oversow in soya is between seed maturity (when the green grain comes easily away from the pod) and beginning of leaf fall and, under favourable circumstances, with at least light rain, up to 50 percent leaf fall (Landers, 1994);
(v) Pelleting to improve germination potential has not been promising, but new hygroscopic materials would be superior to rock phosphate pelleting (W. Lara Cabezas, personal communication, 2003).

TABLE 7: **RECOMMENDED SEED RATES FOR SOME TROPICAL GRASSES**

GRASS SPECIES	SEED RATE (kg/ha PLS)*	SEEDS PER GRAM (No.)
Andropogon gayanus	2.5	360
Brachiaria brizantha	2.8	150
Brachiaria decumbens	1.8	200
Brachiaria humidicola	2.5	270
Brachiaria ruziziensis	2.0	230
Paspalum guenoarum	1.5	300
Paspalum notatum cv. Pensacola	1.5	610
Panicum maximum cv. Tanzânia 1	1.6	960
Panicum maximum cv. Tobiatã	2.5	680
Panicum maximum	1.2	1 900
Setaria anceps cv. Kazungula	1.2	1 490

* Pure live seed (= germination % x purity %).

Source: Adapted from Kluthcouski *et. al*. (2003).

5. Grass regenerating during the first crop after ZT planting of a crop in old pasture

As the crop canopy thins, seeds will germinate from the surface seed bank (see Box 9). Under rainfed conditions *Brachiaria* spp. will not be daylength-triggered to flower before it is time to desiccate for a second

BOX 9. Critical points: Pasture regenerating from surface seed during the first crop after ZT planting of a crop in old pasture

(i) It is important to achieve a full canopy quickly to suppress any grass which germinates;

(ii) Graminicides should not be used in the summer crop, except at sub-lethal doses, to check competition from the grass, if necessary (Cobucci and Portela, 2003); this may have variable results due to differential response at varying levels of metabolic activity;

(iii) Longer cycle crops or harvest delay due to rain may cause excessive grass growth which hampers harvest – maximum combine speed is achieved by removal of the row divider points, except the lateral ones (see Plate 9).

PLATE 9: Removal of row separator points reduces the quantity of grass passing through the combine and permits high speed harvesting.

crop, so the seed bank will dwindle. The decision to leave for winter pasture or desiccate post-harvest with a half dose of systemic desiccant will depend on the grass stand and the weed load. Dense stands of *Brachiaria* are good at weed suppression.

6. Planting forages on crop land for silage, green chop, dry season grazing or as a cover crop

Forage sorghum, pearl millet or finger millet can be drilled with ZT as a second rainfed crop for green chop forage, silage, grazing or cover crop biomass (see box 10). Sowing in January, or first half of February, will maximise rainfed dry-matter production, but this is seldom done, since the forage would compete with an economic second crop. Drought-resistant crops are usually sown after March 1st. Drilling is the preferred method for millets. Because of high residual nutrient levels from the preceding crop, little, if any, fertilizer is used.

Irrigated silage and green chop, if possible, should be scheduled away from competing with beans or other high value crops in the dry winter, when these are grown – there is inevitably a conflict with green-chop for fattening yards whose demand is constant. Seed rates for forage sorghum are between 8 and 12 kg/ha in 50–70 cm rows, for pearl millet 15–20 kg/ha and finger millet 10–15 kg/ha, both in 15–25 cm rows. Seed depth for sorghum should be 3–4 cm and <2 cm for millet. In high fertility conditions under irrigation, for silage production, specialised sorghum hybrids can out-yield maize (up to 70 tonnes of silage/ha), at reduced fertilizer rates, while maize reaches about 45 tons/ha under the same conditions (farm data, S. Conrado, Cristalina – GO 2003).

Some intensive systems have been producing two crops plus dry-season grazing: Séguy and Bouzinac (1997) report soybean yields of 4 000–4 600 kg/ha, 1 500–3 500 kg/ha of second crop grain plus 1–1.5 AU/ha for 90 days in the dry season with a mixture of the three forages. This gave a total gross margin for the annual succession of US$ 150–350/ha.

7. Pasture renovation with forages sown jointly with grasses, for early grazing

A specially-designed ZT combination drill has three hoppers (grass seed, forage seed and fertilizer). A set of trash discs cut through crop

BOX 10. **Critical points: Use of crop land for silage or green chop as supplement to cattle, for dry season grazing or a cover crop**

1. Rainfed areas:

(i) Taking maize silage may allow a second crop to follow or, with sorghum x Sudan grass hybrids, a second cut;

(ii) Harvesting may leave ruts or compaction which require conventional tillage to remove, but where *Brachiaria* is undersown, its root development can counter the compaction; planting the silage/green chop crop on desiccated pasture would be ideal in this respect;

(iii) Regrowth from sorghum after the last cut can give valuable dry season grazing or biomass as a cover crop, to be desiccated prior to the next crop. Note: in frost-prone areas, cattle must be removed after frost, to avoid possible hydrocyanic acid poisoning;

(iv) For grazing, these forages should not be allowed to initiate flowering – this will maximise regrowth and tillering.

2. Irrigated areas:

(i) Silage and green chop are best cut in the drier months of April to September (silage to June only), to avoid soil compaction and formation of ruts;

(ii) Phaseolus beans are the prime irrigated crop and are grown from May to July (90 day cycle); rotation with a grass (especially *Brachiaria*) is highly beneficial for disease control (Nasser *et al.*, 2001; Da Costa and Rava, 2003) and soil structure improvement for the bean crop. Light grazing may be started as early as 30 days, but on loose soils care must be taken that the cattle do not uproot the plants.

residue, followed by a narrow fertilizer boot with scarifier tine in the row (to cut through the 5–10 cm surface-compacted zone in the old pasture and place the fertilizer about 15 cm deep), as shown in Plate 10 (detailed view in Plates 26 and 27). This is followed by alternate sets of offset double disc furrow openers with different size discs for the grass and the forage sorghum, respectively, at about 15–18 cm spacing with open clod-busting rollers behind.

PHOTO: M. SCALEA

PLATE 10: A seeder-scarifier for sod seeding.

8. Pigeon pea sown into existing pasture to improve winter grazing quality

For sowing pigeon pea into existing pasture (see Box 11), the seeder-scarifier (Plate 10) is used or a normal ZT planter is used with a fertilizer knife to break the surface-compacted layer, and not a double disc. Fertilizer (especially phosphate) applied in planting will also renovate the grass and the pigeon pea can fix up to 150 kg/ha of N, also improving grass vigour (Dos Santos, 2003). The extra protein of the legume allows cattle to utilize poor quality winter grass efficiently. Pigeon pea seed rate should be 50 kg/ha and planting depth 4–5 cm. This technology can be adapted for *Leucaena leucocephala* and other legumes, although there is little local experience. *Leucaena* suffers from severe leaf drop in the dry season, and did not fulfil early promise (C. U. Magnabosco, personal communication, 2003).

BOX 11. Critical points: Pigeon pea sown into existing pasture to improve winter grazing quality

(i) The lime and aluminium status of the soil should be adequate for pigeon pea, otherwise liming is required;
(ii) Lime should be surface applied, with, at the very least, four months of rain prior to sowing;
(iii) Cattle trails should be scarified, termite mounds and erosion gullies removed;
(iv) Grazing management should allow time for the pigeon pea to resprout;
(v) A pigeon pea variety should be selected with characteristics similar to the Brazilian “Bonamigo Super N”, which is usually avoided by the cattle until the grass protein content falls below the critical 6 percent for maximum rumen activity;
(vi) On many soils, the pigeon pea nodulates with native rhizobia, however performance may be enhanced by inoculating with a specific strain.

9. Sowing perennial legumes into maize

This technology has good potential, but requires more development of control mechanisms to check established perennial legumes (sub-lethal doses of selective herbicides, or for small farmers, mechanical treatments);

(see Box 12). A forage legume is established by undersowing in maize either using a pelleted insecticide applicator coupled behind the seed discs or by mixing the seed with phosphatic fertilizer and directing the fertilizer spout towards the soil falling back in the furrow after the seed disc (Landers, 1994). This implies pre-planting fertilization for the maize and topdressing of K and N, or a combination planter with three hoppers. The most compatible legumes were Siratro (*Macroptilium atropurpureum*) (see Plate 11), followed by centro (*Centrosema pubescens*), but kudzu (*Pueraria phaseoloides*) and glycine (*Neonotonia wightii*) were more competitive.

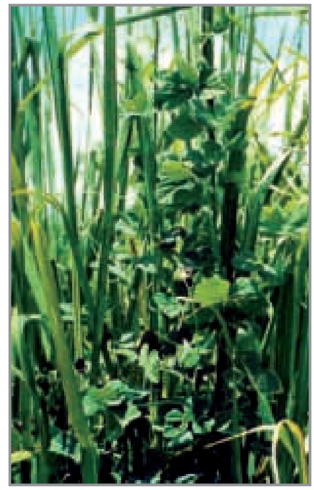


PHOTO: H. M. SHELTON

PLATE 11: Siratro (*Macroptilium atropurpureum*), a deep-rooted perennial forage legume, is very compatible for sowing into maize.

BOX 12. **Critical points: Sowing perennial legumes into maize**

(i) A selective herbicide compatible with both maize and legumes (e.g. alachlor), can be used in the establishment year to control weeds at normal dosage rates for maize;

(ii) 2,4-D is not effective on vigorously growing perennial soybean and some Stylos, while some maize hybrids may be susceptible to stalk breakage;

(iii) Local tests are required to find the best companion legume – non-climbing ones might be better e.g. *Stylosanthes* spp., but not *Arachis pintoi*, which is too vigorous;

(iv) The legume may be a bit weedy in the establishment year, but after that it comes away fast after the first rains and smothers annual weeds;

(v) Care must be taken not to allow the legume to compete excessively with the maize, when severe yield depression will result;

(vi) Legume tendrils on the maize may slow combine speed for grain harvest but do not affect silage choppers, and the legume enhances the quality of the silage.

For silage, this system is excellent, leaving a full soil cover and giving high quality winter grazing which can be used as a protein bank. Also, the legume and surface litter will reduce surface compaction from machinery. A double straight disc between the rows, at about 10 cm from the maize row, can cut the tendrils and prevent the legume from climbing on the maize.

10. Sowing soybeans in a permanent grass sward

This technology has been tested in Mato Grosso (Séguy and Bouzinac, 2002); the idea is not to kill the grass (see Box 13), but to arrest growth up to soybean grain maturity. A Tifton cultivar of *Cynodon dactylon* was used with reported soybean yields of over 3 000 kg/ha. The grass, which can be grazed in the dry season, helps to suppress annual weeds and provides biomass for soil cover. The same authors obtained 90 days winter grazing for 1–1.5 AU/ha with this system and a total gross margin of US$ 200–400 per ha for the annual succession.

> BOX 13. **Critical points: Planting soybeans in a permanent grass sward**
>
> (i) Correct sub-lethal doses of graminicides may be necessary to check grass growth; effectiveness will depend on the physiological activity of the grass;
>
> (ii) The compatibility of other crops with this system needs to be tested, in order to obtain a sound rotation.

OPPORTUNISTIC GRAZING OF STUBBLE IN THE DRY SEASON

Pigeon pea undersown in maize for stubble grazing

This is a traditional practice reported by Von Schaffhausen (1949). Pigeon pea seed is mixed with the fertilizer and deep sowing (10–15 cm) delays its emergence in the maize row, where it remains shaded until maize senescence (see Box 14). Manual jab planting in the row would follow planting of maize after 30 days. In the second year the pigeon pea should be rotary chopped before sowing and the regrowth sprayed

BOX 14. **Critical points: Pigeon pea undersown in maize for stubble grazing**

(i) Pigeon pea seed may be mixed with the fertilizer and sown in the maize row – it must be of high vigour and sown the same day as mixed;

(ii) Second year plants, if not wanted, are killed by ground level rotary chopping followed by a directed narrow band in-row application of glyphosate or sulfosate on the re-sprouts (if any) – this can be achieved by rotating fan nozzles to a diagonal position and adjusting application rates accordingly, giving a savings of over 50 percent on herbicide cost – application must follow the original planter rows and cover the same width as the planter.

with a systemic desiccant herbicide or a split dose of paraquat (1.5 and 1.5 L/ha of commercial product). If left to grow in the second year, it will need to be regularly grazed or it will become too woody for a combine cutter-bar or easy manual eradication. However, it could then still serve as a source of firewood or fodder for a small farmer.

Grazing stubble in the dry season

Nonavailability of fences and watering facilities can limit the use of stover by cattle. Electric fences are cheap, with an investment cost in Brazil of about US$ 80–100 per kilometre. The ratio of stubble area to permanent pasture area is crucial to performance in this system. The greater this is, the more positive the impact on farm total carrying capacity (for more details, see Box 15).

PASTURE GRASSES

Pasture grasses need to be selected according to the soil fertility level and internal soil drainage, a problem mostly confined to wetlands. Table 8, for the Cerrado region, shows the fertility requirements of the principal pasture grasses used in the wet/dry Brazilian tropics. There is very little information on which grasses are suited to integrated crop–livestock rotations in the Amazon region, but this table would be a good starting point, except for poorly-drained soils, where of the recommended

BOX 15. **Critical points: Grazing stubble in the dry season**

(i) Cattle compete with the ZT cropping system for the residue – incomplete soil cover leads to greater weed infestation, but a 70 percent cover is enough to prevent erosion in most circumstances;
(ii) Soybean haulm is especially susceptible to untimely rains that accelerate its decomposition;
(iii) Mineral salt with a protein additive is essential to effective rumen throughput and hence total feed assimilation, and is provided in roofed salt troughs, usually not removed during cropping – movable types on skids are preferable;
(iv) Putting the cattle on the stubble also permits deferring grazing on permanent pasture to later in the dry season, with some recovery from residual soil moisture and late rains.

grasses, only *Paspalum atratum* and *Brachiaria humidicola* are suited (the native Pará grass, *Brachiaria mutica* is also suited to wetlands), while *Andropogon gayanus* and *Setaria anceps* are suited to drier climates.

In spite of the availability of a wide range of tested pasture legumes, there has been negligible uptake of mixed grass-legume pastures in Brazil, due to:

(i) real or imaginary difficulties in grazing management of these pastures;
(ii) excessive cost of seed, due to inefficient establishment of the legume and high market prices because of low demand; and
(iii) lack of efficient establishment systems for mixed pastures, which could start by undersowing legumes in maize and direct drilling the grass at the onset of the following rains, when the legume would have the advantage of an established root system and be able to compete with the grass coming up from seed. Landers (1994) indicated how to establish pasture legumes with maize using alachlor as a selective herbicide for both. On-farm research is required on these aspects.

For pasture grasses, Table 8 can be used either for initial species selection, or to indicate when corrective P fertilization should be carried out. Full fertilizer and lime recommendations for these forages are found

TABLE 8: **ADAPTATION OF GRASS SPECIES TO SOIL FERTILITY LEVELS**

SPECIES	FERTILITY LEVEL DEMANDED	ADEQUATE P LEVEL*
Andropogon gayanus cv. Planaltina	Low	2 to 9
B. decumbens cvs. Basilisk, IRI 562	Low	2 to 9
B. humidicola cv. IRI 442	Low	2 to 9
B. ruziziensis	Low	2 to 9
Paspalum atratum cv. Pojuca	Low	2 to 9
B. brizantha cv. Marandu	Moderate to high	3 to 15
Setaria anceps cv. Kazungula	Moderate to high	3 to 15
P. maximum cvs. Vencedor and Centenario	Moderate to high	3 to 15
P. maximum cvs. Colonião, Tanzânia-1, Mombaça and Tobiatã	Very high	5 to 21
Pennisetum purpureum cvs. Elefante, Napier	Very high	5 to 21
Cynodon spp. cvs. Coastcross and Tifton	Very high	5 to 21
Sugar cane	Very high	n.a.

* Mehlich (g/m³) Low value corresponds to <15% clay and high value to >60% clay i.e. lower P demand on soils with lower C.E.C.

Source: Sousa and Lobato (2003), with addition of some cultivar names.

in Sousa and Lobato (2003). The traditional Molasses and Jaraguá grasses (*Melinis minutiflora* and *Hyparrhenia rufa*), adapted to poorer soils, have been out-performed by the Brachiarias and their use is now rare. Quinn *et al.* (1963) showed the inferior performance of Molasses grass compared to Colonial Guinea Grass in all situations, and inferior performance of Jaraguá in high fertility situations, but holding its own under low fertility.

COVER CROPS FOR GRAZING

Pearl Millet, *Pennisetum americanum.* This can be used purely for biomass production, for high-quality grazing, for hay or for seed, although rarely yielding more than 500 kg/ha of grain in late autumn sowings, due to rainfall limitations; the protein content of its grain is almost twice that of maize (Scalea, 1999). Harvest is by combine harvester (by hand on small areas) and most farmers produce their own seed. Breeding programmes have still not released hybrids; these should make millet a good option as a grain crop for very late summer plantings as it can extract nutrients from depth and can be sown on residual fertility, with just a small top-dressing of N.

Pearl millet can be a host for army worm, but it controls nematodes well and its residues apparently encourage less slugs in irrigated conditions than those of maize. Millet is a slow starter, accelerating development from about 30 days after sowing. After the first month, in spring it can produce over 100 kg DM/day, but much less as days get shorter. Millet can smother weeds sufficiently to eliminate, or reduce, post-emergent herbicide use and has a similar effect in autumn once a good cover is achieved. Under grazing it should not be allowed to initiate flowering, in order to continue in vegetative mode.

Black Oat, *Avena strigosa*. This is not widespread in the tropics and is limited to latitudes close to the tropic of Capricorn (São Paulo, Paraná and Mato Grosso do Sul states) or altitudes above 1 000 m, as it does not take well to heat. It dies back in summer and only requires rolling, obviating pre-plant desiccation and often eliminating the need for post-emergence herbicides, besides acting as a good recycler of nutrients and incorporator of calcium in depth by translocation to its roots. When grazed it should not be allowed to initiate flowering to maintain it in the vegetative phase.

Forage Radish, *Raphanus sativus.* This crop has a deep tap root and is a good recycler of N and other nutrients and has excellent forage value. It is more a subtropical crop and performs best near the tropic of Cancer, but has been used successfully at 16° S and 1 000 m altitude. Its small seed requires care in sowing. This crop is a good precursor for maize. Forage radish's thick, carrot-like roots act as biological sub-soiling agents. It may advantageously be mixed with other cover crops, especially black oats, giving complementary cover, with a different growth cycle. The Instituto Agronômico do Paraná has released improved varieties of both black oats and forage radish.

Cut forage and silage crops

Commercial hybrids of maize and forage sorghum or sorghum x Sudan Grass hybrids are the principal forages used for silage, and some open-pollinated varieties from the Guinea coast of Africa have shown promise (Séguy and Bouzinac, 2002). Resprouting ability after the dry season is an important quality to evaluate in sorghums. Sugar cane, elephant grass and recently, *Brachiaria brizantha* cv. Marandu are the most important plants for cut forage. The importance of the latter is that it can fit into a rotation as a catch crop, whereas sugar cane and elephant grass occupy the same land for several years of ratooning. Kepler (2000) recommends cutting maize silage no lower than 30 cm, leaving the potassium-rich, indigestible lower stems. The recommended stage for cutting maize for silage is full grain maturity (black layer at the base of the grain). Sunflower can also be used for silage.

Pasture and grazing management

The merits of continuous versus rotational grazing will not be discussed; in general, the former show superiority at lower stocking rates. Rotational grazing is generally preferred in ICLZT systems in tropical Brazil. Table 9 gives a guide to managing the main grasses. On a pasture which is still in

TABLE 9: **GRAZING MANAGEMENT OF TROPICAL GRASSES**

GRASS	HEIGHT AT ENTRY (cm)	HEIGHT AT EXIT (cm)	GRAZING PERIOD (days)	REST PERIOD (days)
Andropogon	40–45	15–20	1–3	28–30
Brachiaria brizantha	30–40, 50–60	15–20, 30	1–3, 1–7	28–30, 28–42, 30–35
B. decumbens	30–40, 50–60	15–20, 30	1–3, 1–7	28–42, 30–35
B. ruziziensis	30–40	20–25	1–7	28–42, 30–35
P. maximum	50–60, 80–100	25–30, 40–45	1–3, 1–5, 7, 7–10	35, 35–40, 35–42
P. maximum cv. Tanzânia	50–60, 70–80	25–30, 35–40	1–3, 7	35–42
P. maximum cv. Tobiatã	50–60	25–30	7	35–42
Pennisetum purpureum Schumach. cv. Napier	110–120	50–60	1–3, 3–7	35–45, 45
P. purpureum cv. Elephant Grass	60–80	20–25, 30–40	1–3	45, 45–50
Hyparrhenia rufa (Nees) Stapf	30, 30–40	10, 15–20	1–3, 7–10	30, 35–40
Digitaria decumbens Stent	25–30	10–15	1–3	21–28
Setaria	30–40	15–20	1–3	30
Cynodon nlemfuensis and *Cynodon dactylon*	25–30	5, 10–15	1–3, 1–7	21–28, 25–30
Melinis minutiflora Beauv.	30–40	15–20	3–7	35 – 45

Source: Bonamigo (1999).

the maintenance phase, subdivision and rotational grazing on a 30–40 day interval can give a significant boost to production. In this situation, the investment in more animals to profit from the higher carrying capacity is greater than the investment in electric fences (now common) and watering facilities (Smith, 2004). See the example of Case Studies No. 1 and 6 in Chapter 5. Continuously grazed permanent pasture, or temporary winter pasture, both need to recover after the first rains; the latter to regenerate biomass for desiccation in order to provide adequate residue cover (at least 30 days). Temporary grazing on the crop area must allow grazing on part of the permanent pasture to be deferred until the onset of the rains, preferably in bottomland with better moisture availability (see Case Study 1 in Chapter 5). At this critical period beef prices are still high and stockyard or supplemental feeding with silage or green chop may be attractive alternatives (See Case Studies 1, 2 and 5).

Kluthcouski *et al.,* (2003) recommend an initial light grazing of grasses undersown in maize directly after harvest, to encourage tillering and to correct any etoliation problems. For mature pasture, these authors recommend grazing at the highest level of protein (flower initiation), however, in practice, as flowering is not year-round, the critical height in Table 9 can substitute for this criterion.

Weight gains of 1 kg/day were recorded between April and June on a sorghum + *B. brizantha* mix, stocked at 3.5 head/ha. This pasture also furnished maintenance grazing until the onset of the rains (Kluthcouski *et al.*, 2003). "Early bite" with forage sorghum intersown with a permanent pasture species gives grazing of the sorghum at 30–45 days after sowing. A comparison between the calendars of ZT and conventional tillage in crop–pasture rotations, using the above system, was made by Dos Santos (2003), as shown in Figure 8. The elimination of time for land preparation and the inclusion of forage sorghum for early bite gave a considerable advantage in pasture carrying capacity over the time of the comparison.

Adjustment of stocking to pasture production is necessary to avoid overgrazing and reduction of regeneration capacity. Martha Junior *et al.* (2004) have developed a methodology to calculate the grazing and rest periods in a rotational grazing system according to desired weight gain, forage availability and pasture recuperation capacity, based on the values

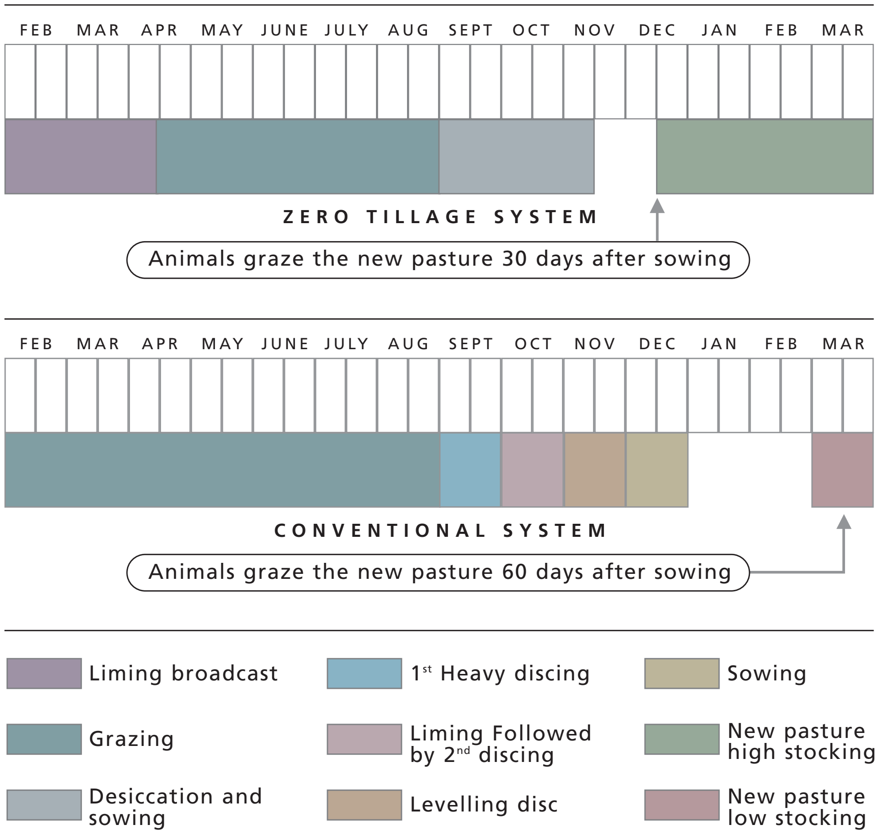


FIGURE 8: Comparison between the calendars of a ZT-based crop–pasture rotation and one based on conventional tillage

Source: Dos Santos (2003).

TABLE 10: **PASTURE MANAGEMENT PARAMETERS AT DIFFERENT INTENSITIES OF LAND USE**

	INTENSITY OF LAND USE			
PASTURE PARAMETERS	EXTENSIVE	SEMI-INTENSIVE	INTENSIVE	VERY INTENSIVE
Return period (days)	56	42	38	36
Forage Production (kg DM/day)	30	50	70	120
Grazing efficiency (%)	45	50	55	55
LIVEWEIGHT CLASS	STOCKING RATE (AU/HA)			
200 kg	1.18	2.18	3.36	5.75
300 kg	1.30	2.42	3.72	6.38
400 kg	1.41	2.61	4.03	6.90

Source: Martha Junior *et al.*, (2004).

in Table 10. The net offer of forage in a paddock, adjusted for grazing efficiency, is balanced by the total demand for a given number of animals and the number of grazing days in the rotation. This could be refined by using total digestible nutrients (TDN).

LEGUMES IN PASTURES

The establishment and management of grass-legume pastures have, so far, been beyond the management capacity of most farmers in tropical Brazil, although adapted cultivars and experimental results are available. Where it has been done, results are highly encouraging, see below, but management for legume survival is critical. Undersowing, oversowing, sowing the legume before the grass and seed pelleting or coating require more study.

Pigeon pea is a notable exception and its use in ZT sowing into pasture (or in maize, for stubble grazing — Von Schaffhausen, 1949), is well-established and increasing. The most successful perennial legume has been *Stylosanthes guianensis* cv. Mineirão, but it is slow to establish and its seed is high-priced (normal for a new cultivar with little outlet).

Liveweight gains on different pastures were maximized by using a *Stylosanthes guianensis* protein bank, with *Brachiaria brizantha*, giving gains of 577 kg/ha/year as compared to 258 kg/ha/year with *B. brizantha* alone. Another grass/legume pasture (*B. decumbens* + *S. guianensis*) gave an intermediate performance (Macedo, 1999). *Leucaena leucocephala* protein banks suffer from severe dry season leaf drop, making them only suitable to very restricted areas with a relatively high water table, but which do not become waterlogged in the rains. Protein banks avoid the complications of managing a mixed sward, and access once a week can be adequate.

CHAPTER 4

Mechanized operations in zero tillage and soil fertility management

Operations are described in order of occurrence, starting from managing residues, through pre-plant desiccation, planting-drilling and post-planting operations. This is followed by considerations of liming, gypsum application, summaries for N, P and K and a section on soil sampling under ZT. Liming and fertilizer application use conventional technology and are therefore not discussed in detail.

RESIDUE MANAGEMENT

The first rule in residue management is to ensure even distribution of crop residues after harvest; this helps to suppress weeds and facilitate planting/drilling operations. Combine harvesters should use a straw spreader or chopper to ensure this. Argentine rolls (knife rollers) are effective on some cover crops, especially black oats and should cross the direction of future planting rows. Vertical flail choppers and horizontal rotary choppers may be used to flatten maize or cotton stalks and break down clumps in pastures prior to desiccation. The latter tends to produce windrows, and planting diagonally across windrows reduces clogging.

SPRAYING DESICCANTS AND OTHER CHEMICALS

Pre-sowing desiccation is the most important operation in ZT. Weeds not properly controlled during desiccation are very costly to eliminate with selective herbicides. After sowing, the same selective herbicides are used as for conventional tillage; local or regional research-based information should be sought, with recommendations for the specific conditions of the farm.

Marking for desiccant application is absolutely necessary; besides surveying the fields and leaving permanent markers in fence lines, marking foam applicators at the tips of the spray boom are available and Brazilian farmers have developed a system (shown in Figure 9), which uses two tractors and a cable attached to the rear of the first tractor and the front end of the second. Since there is more weight on the rear wheels of the first tractor, it keeps the second in line. The first tramline is marked with poles at half the sprayer width from the field edge and as the first tractor goes along this line, the second leaves tracks in the stubble; the first tractor then follows the second tractor's tracks successively and the double passage leaves enough of a track to be followed during the spraying operation. Planting lines should be parallel to the tramlines (which help to keep tractor drivers straight), or may be transverse, accepting a minor loss of stand in the tramlines. Tramline spacing should be a multiple of planter row width.

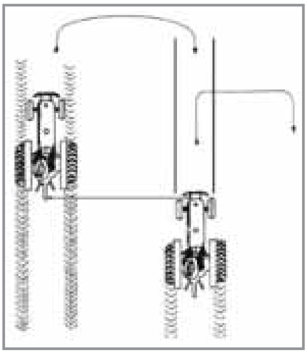


FIGURE 9: System of marking for pre-plant desiccation and later spraying operations, using two tractors and a cable for a gauge.

Sprayers range from 20-litre backpack, single-nozzle types to self-propelled versions with 24-metre booms and 2 000-litre tanks. Spray planes are widely used by large farmers.[2] Spray technology is a specialized affair and will not be dealt with in depth. Systemic desiccant herbicides must be applied as large droplets; low volume applications improve herbicide absorption and sprayer efficiency, but require higher skill in application. Reducing the amount of water applied from 200 litres/ha to 30 litres/ha substantially increases area sprayed daily and can permit reduction in chemical application rates. Stressed plants do not absorb herbicide effectively; the best timing is during vigorous growth, avoiding the middle of the day with its high temperature and low humidity.

An innovation for large farms is the drag system of applying chemicals. Two tractors drag a line of nozzles fed from a hose attached to

[2] Although application of desiccants (herbicides) by airplane is often done in practice, FAO does not recommend this technique, due to the environmental considerations involved.

a cable between them – the length of the cable can be up to 100 metres, giving a very high work rate for desiccant application.[3]

Desiccant application rates in pasture depend on the species involved. *Brachiaria ruziziensis* requires about half the dosage of glyphosate or sulfosate/ha compared to *B. brizantha*; *B. decumbens* is intermediate, while *B. humidicola*, panicums and other grasses require even higher dosages – a summary of manufacturers' recommendations for tropical Brazil is shown in Table 11.

TABLE 11: **APPLICATION RATE CHART FOR GLYPHOSATE[1] FOR DESICCATION OF OLD PASTURE, ACCORDING TO GRASS SPECIES**

HIGH SUSCEPTIBILITY	MEDIUM SUSCEPTIBILITY	LOW SUSCEPTIBILITY
B. ruziziensis	*B. brizantha* [2], *B. decumbens* [2] *P. maximum* [2] (except cv. Mombaça)	*P. maximum* [2,3] cv. Mombaça *Cynodons* [2,3] *P. notatum* [2,3] *A. gayanus* [2,3] *B. humidicola* [2,3]
1–1.5 kg/ha [4]	2–2.5 kg/ha [4]	2.5–3.0 kg/ha [4]

[1] Wettable granules (commercial product) assumes 100 L/ha application rate of the spray mixture.
[2] For medium and low susceptibility grasses, apply 2/3 of the dose and wait 15–20 days before applying the rest.
[3] For the low susceptibility grasses apply 2/3 of the application in autumn and the rest in spring.
[4] For plants germinated in the same year, or still with a small root mass, rates can be reduced.

Source: Monsanto Brazil.

Choice of herbicide depends on a survey of the weed spectrum and stage of growth, leading to an evaluation of susceptibility. Selective herbicides may be mixed with the desiccant for specific weeds – check the local-regional weed control recommendations and a chart of compatibility for active ingredients and spreaders.

Spot-spraying, which can be very cost-effective to control isolated patches of problem weeds, should be done before the overall desiccation, or later as a complement to eliminate misses. This permits higher application rates or admixtures of specific herbicides for problem weeds. It can be done manually with backpack sprayers or with lances coupled to the tank of a boom sprayer (isolating, or removing, the booms), or even by hand-hoeing, or pulling, if

[3] This drag system, although convenient for many farmers, is not technically recommended by FAO as a controlled quality application.

populations are small. In the case of a heavy green mass at desiccation (cover crop or weeds), up to three weeks should be allowed between spraying and sowing, to allow dissipation of allelopathic products from root decomposition (Constantin and De Oliveira Jr., 2005) which depress yields as they decompose, as shown in Table 12. For further information about spraying desiccants, see Box 16.

TABLE 12: **EFFECT OF PLANTING 21 DAYS AFTER DESICCATION ON INCREMENTAL MAIZE AND SOYBEAN YIELDS COMPARED TO SAME DAY PLANTING AND PLANTING 7 DAYS AFTER DESICCATION**

CROP	YIELD INCREASE OVER SAME DAY DESICCATION-PLANTING (Kg/ha)	YIELD INCREASE OVER PLANTING 7 DAYS AFTER DESICCATION (Kg/ha)
Maize	1 110	654
Soybeans	468	408
Local farmer average yield with ZT soybeans	674	Not determined

Source: Constantin and De Oliveira Jr. (2005).

BOX 16. Critical points: Spraying desiccants and other chemicals

(i) Water must be clean and free of suspensions – clay and organic matter absorb the spray chemicals and reduce effectiveness;
(ii) Fine sand or other particles can clog nozzles;
(iii) Always test sprayers before use, for correct operating pressure, nozzle overlap, individual discharge (volume/time) and replace worn nozzles etc; calibrate for application volume;
(iv) To judge application rate of chemical required, imagine the root reserves of the plant; the greater the live root mass, the higher the application rate;
(v) Wait for dew to dry before spraying, or leaf runoff may reduce active ingredient absorbed;
(vi) Do not sow before desiccation, as rain may not allow desiccant application before crop emergence;
(vii) Recently germinated plants, with small root mass, are easily controlled with low dosages of contact herbicides.

PLANTING AND DRILLING

These operations are normally carried out on desiccated areas, with or without cover crops, or on rolled cover crops, such as black oats, which dispense with desiccation.

PHOTO:C. H. CASTRO ALVES

PLATE 12: Hand jab planter, commonly called a "matraca", with both fertilizer and seed hoppers.

Manual jab planters have been adapted for ZT by reinforcing and narrowing the tips to give better penetration into untilled soil. They are commonly equipped with a double tip and apply fertilizer at the same time as the seed. Both fertilizer and seed flows are adjustable. Plate 12 shows a hand jab planter; to operate it is jabbed into the ground with the point closed and then the handles are pulled apart, allowing seed and fertilizer to drop into the planting hole. On closing, the seed and fertilizer points are re-charged. A normal work rate for maize planting in 1m rows would be 1 ha/man day.

Animal drawn planters. There are a variety of models in Brazil, mostly single row types, pulled by a single horse or mule or a pair of oxen (see Plate 13). Most have a trash-cutter disc up front, followed by a fertilizer knife and an eccentric double disc for the seed (see Plate 14). The simplest model with no trash disc and no furrow closing wheels is not suitable for heavy residues and can leave seed uncovered. Some versions have depth wheels for both seed and fertilizer, others only one for seed; their position and size are variable and furrow-closing mechanisms are also varied, sometimes absent, the most common being double-angled wheels.

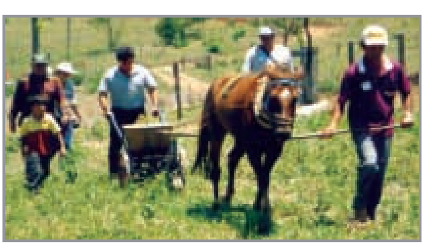


PLATE 13: An animal drawn drill under demonstration, planting into desiccated pasture.

PHOTO: C.H.C. ALVES

PLATE 14: Details of construction of another model.

Fertilizer distribution is of variable quality between models and seed distribution is invariably with a horizontal perforated disc. Some models use discs commonly available from large manufacturers, which facilitates local availability when different spacings are required for new crops. A canola or sorghum disc works well with pearl and finger millets.

Tractor-mounted and tractor-drawn planters and drills. Tractor-mounted models are limited to small units (maximum five rows) as well as self-propelled walking tractor machines (see Plate 15), some with a rotary hoe furrow opener. Larger units are tractor-drawn with their own transport wheels and vary from 4 to 20 row units – they are usually hydraulically-operated.

Three basic types of seed distribution are available:

- planters using perforated disc or pneumatic seeders;
- small-grain drills using continuous flow distribution of seed, mechanical or pneumatic;
- multi-purpose machines for all grain sizes.

PHOTO: C. BATELLO

PLATE 15: A self-propelled single axle walking tractor, with attached two-row direct-planter, suitable for CA systems.

In tropical Brazil, the first category is overwhelmingly the most important. Since small grain production is minor compared to maize, soybeans and cotton, seed drills are restricted to rice, wheat and barley; extra investment in a drill is considered unprofitable for cover crops in the tropics. This is a short-term view, since the common practice of incorporating broadcast cover crop seed with a light discing incurs some loss of surface residues, which are difficult to maintain anyway, and which also wastes precious moisture, through evaporation and delayed planting.

Trash-cutting discs, which have been getting larger and vary from 40–56 cm in diameter, may be straight or fluted, (wavy) or rippled to ensure proper turning through good contact with the soil, with the fluted types more suited to sandy soils. The straight type is the most common in Brazil. Fertilizer coulters have three basic variants:

- the guillotine knife coulter closely coupled to the trash-cutting disc with a small vee-shaped guillotine attached to the knife, acting as a disc cleaner (the very small clearance is critical to performance and the size of the guillotine is smaller in heavier soils);
- a knife coulter some distance behind the trash-cutting disc following in the same furrow as the trash disc;
- offset double discs with different diameters receiving fertilizer in the gap between the discs.

Offset double discs should only be used when soils are well-structured (after 4–5 years of continuous ZT) and usually not for maize, cotton or sowing in desiccated pastures (see Plate 16). Since it is difficult to offset the seed disc from the fertilizer coulter, many farmers weld a small piece of chain, or wings, behind the coulter to improve the mix of fertilizer with soil and reduce the potential for seed burn from high K or N fertilizers. This problem can also be addressed by broadcasting most of these fertilizers after sowing, with potential gains in efficiency from reduced leaching and less down time for the planter. Normal fertilizer placement aims at a depth of 12–15 cm, usually directly below the seed. For irrigated phaseolus beans it has been advantageous to split the depth of fertilizer application, placing half at a shallower depth.

PLATE 16: A seed unit showing the double eccentric seed disc, adjustable depth control and furrow closing wheels – note that the units are offset to avoid clogging with surface residues.

Seed distribution mechanisms for planters are still dominated by the perforated disc, but pneumatic seeders are available at a higher price. Discs with a double row of perforations halve the disc rotation speed and improve distribution, allowing faster planter operation. A practical limit for planting speed is 6 km/hour, even for soybeans and pneumatic seeders (CAT Uberlândia, 2005). Uniformity of seed and fertilizer distribution is variable between planter-drill models and has become more crucial as different cultivars of maize and soybeans require different populations for top yields. Air seeders are not in general use in tropical Brazil and small grains are sown with the traditional drill mechanism or with multi-grain-size universal machines, most common on small farms in South Brazil.

Recent modifications have been: Increased trash disc diameters, pantographic suspensions for individual rows, independently hinged sections of the planter to allow better seed depth uniformity when planting in straight lines over the contour banks, folding planters for transport and easier manual adjustments. All tractor models use seed depth control wheels; the closer these are to the point where the seed enters the furrow, the better will be the uniformity of seed emergence. The principal types of furrow-closing wheels are:

(i) Paired slanting wheels whose angle and pressure are adjustable;
(ii) Single over-the-top rubber-covered press wheels; or
(iii) A single slanted metal press wheel.

The use of paired opposite discs for furrow closing has been discontinued, but some farmers have replaced the wheels with a section of looped chain. Farmers still make their own modifications to facilitate field adjustment; many of these have been adopted by manufacturers, e.g. the guillotine disc cleaner.

On soils of over 40 percent clay, planter adjustment is especially tricky. It requires some persistence to obtain satisfactory performance, but this has been achieved on soils varying from 5–60 percent clay.

In Plate 17 is a farmer modification to plant pasture seed after soybean harvest or coincidently with maize, using a pneumatic distributor to place the grass seed between the double seed discs – with the consequent in-row soil movement, most seed is covered by less than 2 cm of soil.

PHOTO: I. DOWICH

PLATE 17: Farmer modification to plant grass seed after soybean harvest (or for interplanting in young maize). The white boxes behind the planter are the pneumatic unit seed distributors – the delivery tube is inserted between the double seed discs.

Another farmer modification can be seen in Plate 18. In this case, an innovative farmer has attached a thick wooden pole to be dragged behind his planter. This modification is very helpful to assist with covering the seeds and redistributing the crop residue more evenly.

In Box 17 some specific points are given about using planting and drilling machines.

PHOTO: H. BARTZ

PLATE 18: Another farmer modification to improve seed and residue cover.

BOX 17. **Critical points: Planting and drilling**

(i) Planters and drills must be levelled along the planting line before work, so that fertilizer and seed can be adjusted to the desired depths;

(ii) "Hair-pinning" of residue below the trash disc often occurs with wet or wilted residues, or on very wet soils, and then planting must be suspended;

(iii) Always use a fertilizer boot, guillotine or narrow tine, for maize or cotton or for planting into desiccated pastures;

(iv) Check clearance of guillotine from trash disc according to manufacturer's specifications;

(v) Check for irregularities and sharpness of discs to prevent clogging;

(vi) Post-plant operations in the row must use the same number of rows as the planter and follow in its tracks.

SOIL FERTILITY CONSIDERATIONS

Liming. The effectiveness of broadcast lime application without incorporation has been long proven in ZT, as the lime enters the soil through old root holes and fauna-made galleries, more slowly through leaching of calcium and magnesium, and rapidly through translocation in the roots of black oats (Lopes, 2004; Bernardi *et al.*, 2003; Sá, 1993). Maintenance lime requirements are greatly reduced under zero, compared to conventional tillage, due to less anaerobic conditions for organic matter breakdown (Lopes, 2004). Farmers report going over 10 years without liming after adopting ZT, also due to earlier over-liming or large diameter lime particles taking longer to react. Care must be taken not to apply more than 0.5–1 tonne/ha (depending on soil texture and CEC), otherwise there can be an over-reaction at the soil surface, raising pH to above 7, when micronutrients, especially manganese, become less available. Manganese deficiency in soybeans shows as interveinal chlorosis and can easily be remedied by spraying nutrient solution containing Mn.

Excessive liming may also be responsible for cementation problems on silty sands (P. L. de Freitas, personal communication, 2005). Critical base saturation percentage (V percent) under ZT is 40; when it falls below this, apply lime to raise it to 50 percent (Sousa and Lobato, 2003). Sousa and Lobato (2003) also indicate that lime demand under ZT is reduced by 35–50 percent compared to conventional tillage; local recommendations for lime application often refer exclusively to the conventional situation and thus over-estimate the demand in ZT. There is increasing evidence that low base saturation levels are less limiting in soils with many years of ZT and consequently higher SOM and residue levels (L. Séguy, personal communication, 2004).

Planning the conversion of pasture to crops allows broadcast lime application one rainy season before planting the crop, ensuring longer reaction time and less likelihood of limitation to crop yield. In extreme cases, in-row applications of very finely ground lime ("filler") of 150–300 kg/ha can be made in the crop row, with a third hopper (Séguy *et al.*, 1998), where liming may not have been adequate; local calibration of this rate would be necessary.

Gypsum. This is applied broadcast in small quantities to supply soluble calcium to penetrate to the subsoil and correct deficiencies of that nutrient, or to reduce aluminium toxicity in the subsoil, or simply to correct sulphur deficiency throughout the root zone. According to Table 13, derived for latosols (Ferralsols), application levels rarely exceed 600 kg/ha.

TABLE 13: **RECOMMENDATIONS FOR GYPSUM APPLICATION TO CORRECT SULPHUR DEFICIENCY**

SULPHUR LEVEL IN SOIL	APPLICATION RATE (Kg/ha)
Low	10 x Clay %
Medium	5 x Clay %

Source: Sousa and Lobato (2003).

Higher application rates may be needed for in-depth correction of Ca deficiency and neutralization of subsoil Al. Gypsum may be applied with lime.

Phosphorus nutrition. Phosphate should not be broadcast together with surface application of lime in ZT since this causes reduced P availability due to a surface pH close to 7.0 (Sousa and Lobato, 2003).

Higher clay contents require increased P fertilization since a higher application rate is needed to shift the available P content.

Surface application of phosphatic fertilizer can only be made when the soil's P status is adequate to supply the needs of the present crop, the applied fertilizer being to maintain the system. Short cycle crops are more demanding in P than longer cycle ones, which have more time to extract it. Pasture grasses and legumes are more effective in extracting P from the soil than field crops: over seven years continuous cropping on a tropical latosol (Ferralsol), soybeans extracted 21 kg of P_2O_5/ha, while two years of soybeans followed by five of *B. humidicola* extracted 50 kg of P_2O_5/ha (Vilela *et al*., 2004).

Nitrogen nutrition. High organic matter and crop residue levels under ZT mean that more of the N in the system is sequestered. Therefore, higher N fertilizer applications are needed in the first years until an equilibrium is reached (Sá, 1993). For maize, an extra 25–30 percent of N is required; this also applies to other non-leguminous crops and phaseolus beans.

There is evidence that the enhanced biological activity of CA systems requires earlier N application than conventional tillage; in some soils this can be 100 percent pre-plant, but in years of exceptionally heavy rains this may not be an advantage (Lopes, 2004). Many farmers consider the reduction in the weight of fertilizer carried in the planter as a sufficient operational gain to justify pre-plant application of N. Local research is required on this point.

Urea should always be incorporated and not top-dressed, since crop residues liberate urease which breaks urea down rapidly and N is lost by volatilization as ammonia – in extreme cases (high temperatures and no rain) such losses may approach 70 percent (Lara Cabezas, 1998).

Potassium nutrition. There is a build-up of K in the top 10 cm of soil under ZT and little evidence of leaching. Since K fertilizers cause seed burn and it is not usually possible to place fertilizer to the side of the seed in ZT, half, or all, of the K fertilizer can be applied broadcast. Split applications may improve efficiency. Alternatively, the fertilizer boot can be modified to apply the fertilizer at two depths; this has been effective in heavily fertilized phaseolus beans under centre pivot irrigation.

Soil sampling. Brazilian practice in ZT is to sample at 0–10 and 10–20 cm, to take account of the high nutrient concentration at the soil surface, due to nutrient recycling through surface residues. Further sampling is advisable at 20–40 cm to determine if there is a calcium deficiency or toxic aluminium levels which will impede root development. In ZT, soil sampling needs to span the whole row width, with a specialized broad, flat (vertical) sampler, otherwise fertilizer concentrations in the row will distort results, (unless a very high number of random samples are taken).

CHAPTER 5

Technical and financial analysis of integrated crop–livestock zero tillage rotations

This chapter uses six case studies to illustrate the technical and financial aspects of ICLZT, compared to the situation prior to adoption of the technology. Results are conservative because the farms were all practising CA before adopting ICLZT and had an above-average management level, so the differences introduced by ICLZT were less marked than if the models had started with average management, using conventional tillage. Integrated crop–livestock zero tillage technology is new in the tropics (Broch *et al.,* 1997) and no farms were encountered which had gone straight from conventional tillage to ICLZT without an intermediate stage of CA crops without pastures. The first case study is described in some detail to show the steps in the farm system's evolution (see Box 18), while case studies 2–5 are summarized (Landers *et al.*, 2005). The sixth case study was included to illustrate its advanced management with a one-year ley.

CASE STUDY 1 – A FARM HISTORY OF THE ADOPTION OF CONSERVATION AGRICULTURE WITH ZERO TILLAGE

General description. The farm selected belongs to a traditional farmer in Vianópolis, Goiás state, who has modernized his operation from 1979, when he purchased a run-down cattle farm with degraded *B. decumbens* pastures, typical of the lower half of the 60 million ha of pastures today in the Cerrado region; he adopted a full ICLZT rotation in 1997.

The farm has 1 175 ha, including mandatory reserves of 280 ha (24 percent of total area), leaving 600 ha of crops (190 ha irrigated and 410 ha in rotation with pasture), 285 ha of pasture and 10 ha of other uses. Annual rainfall is 1 638 mm, latitude 16º 45' S, longitude 48º 30' W.

BOX 18. Phases of development in the adoption of CA with ZT

1979 Removal of erosion gullies with a crawler tractor for the large gully and deep ploughing for small ones and rills, followed by planting of *B. decumbens*, undersown in rice using limited fertilizer, incorporating 3 tonnes/ha of lime and re-making of contour banks for soil conservation.

1980 Fencing off of the river-edge gallery forest to allow self-regeneration.

1982 Production of 1 100 tonnes/yr of silage for dry-season supplement;

1980 - 1987 Conventional tillage with rainfed soybeans and maize, separate from the pasture area; pasture renovation with rice and undersowing of *Brachiaria brizantha*, initial pasture subdivision into 50 ha paddocks.

1987-1997 Gradual adoption of ZT.

1995 Introduction of improved pasture management with pigeon pea planted directly into pastures and installation of watering facilities for a beef fattening operation on grass;

1995 Installation of centre pivot irrigation on 190 ha;

1996 Introduction of an integrated crop–livestock rotation, with subdivision of pastures using electric fences into 1 and 2 ha units; rotational grazing on a 42-day basis.

2000 Conversion to a cow-calf (weaner) operation, with supplemental silage limited to 400 tonnes/yr for supplemental (creep) feeding of calves before weaning and for emergency drought reserve.

The investment model. This model represents the evolution of Cerrado biome farming from medium to high level technology in a mixed crop–pasture farm, which was originally solely pasture. The absentee owner lives 120 km away. The high management level is obtained through local professional consultants (veterinarian and agronomist). This is now common in the region.

The 20-year investment model considers the situation before the farmer decided to improve his management with ICLZT in 1995 and compares this with the results of ICLZT in 2004. Crop yields used for the "without project" situation correspond to the present day expectancy under the "without project" management and incorporate genetic yield improvements over the time-span between the "before" and "with" project situations on this farm. The use of historic yield data of ten years ago would have exaggerated the gains with ICLZT since there have been considerable gains in genetic potential of both soybeans and maize since then. Zero tillage adoption preceded the ICLZT technology on this farm, thus the comparison indicates the gains due to ICLZT alone, excluding the effect of conversion from conventional tillage to ZT. The "without project" situation, Scenario (i), represents approximately the situation of the middle third of producers in the Cerrado region and the "with project" Scenario (ii) situation, that of the upper ten percent. Since the farmer had changed his type of operation from a fattening to a breeding herd after adopting ICLZT, the equivalent herd parameters for a cow-calf operation under the "without project" management level, estimated by the farm veterinarian, were used in the comparison. The lack of good quality dry season feed in the "without project" situation affected calf weight at weaning; ICLZT allows earlier sales at the same weight, but no price increase was imputed in terms of quality, which would probably occur, also due to upgrading with pedigree bulls. Higher cow and calf mortality and lower calving and replacement indices occur in the "without project" situation.

Both scenarios are placed in the same time frame, with February 2004 farm gate prices – the price for irrigated maize was increased by 10 percent for out-of-season sale. In this model both rainfed and irrigated crops are assumed to be 100 percent under ZT in scenario (i), with the exception of conventional cultivation for pasture renovation. For purposes of comparison, the same cropping patterns were used for both scenarios; equipment only differed in heavy levelling disc harrow and plough for pasture renovation in scenario (i). In scenario (ii) a ZT planter with chisel-type furrow opener (Plates 26 and 27) for planting pigeon pea in pasture and electric fences for pasture subdivision were used.

Without project

A medium technology level was used, with the pastures for the cow-calf operation separate from the annual crops. Zero tillage was already used in both rainfed and irrigated areas, with pasture renovation using conventional tillage: the rainfed crop rotation was 3 yrs soybeans – 1 yr maize. The farmer had intensified part of the crop area (190 ha), using pivot irrigation. Irrigation is practiced on less than 5 percent of the crop area in the region. Pasture renovation was done every six years, using conventional land preparation and defraying the cost of establishment by undersowing *B. brizantha* in a crop of upland rice. Paddocks were about 50 ha of *B. decumbens* and more recently *B. brizantha.* Winter carrying capacity of pastures was low and offset by production of 1 100 tonnes of silage to feed the whole herd from August to October. The farm veterinary consultant's estimate of 220 cows plus followers was used for the "without situation" number of cows stocked, based on historical information. The pasture area was permanent and separate from the crops.

With ICLZT

The farmer directed his attention to improving the winter pasture situation for the cattle as the best route to improve profit. In 1996, he adopted a high-technology ICLZT rotation – annual rainfed ZT crops in rotation with pastures and irrigated ZT cropping separate. This was accompanied by more intensive grazing management through pasture subdivision with electric fences.

The original 220-cow herd was increased gradually by retaining replacement heifers until full carrying capacity under ICLZT was reached. Herd size used with ICLZT (380 cows plus followers) was actual, from farm records, and equal to the farmer's estimate of optimum pasture carrying capacity. Investment in higher pasture technology was stimulated by the adoption of ICLZT and improvements in performance were assisted by buying high quality bulls from progeny-tested sires.

Pasture stocking levels are considerably enhanced with ICLZT by:

(a) rotating with a crop phase;
(b) sowing pigeon pea into the pasture, with phosphate fertilizer and a band application of desiccant herbicide to check the pasture in the row;

(c) subdividing paddocks with electric fences; and
(d) oversowing millet into rainfed crops for winter stubble grazing.

The higher organic matter and the improved weed, pest and disease control from the pasture phase contribute to 10 percent higher yields for rainfed soybeans and maize, with the project. The crop budget-yield and costs of pasture maintenance were considered equal after planting for both scenarios. This is conservative, since the rotation of crops with pasture will also reduce the costs of weed, disease and pest control; records did not permit an accurate assessment of these aspects.

The pasture is renovated every four years, accompanying the crop rotation. Summer pasture is subdivided with electric fences into 2 ha paddocks, grazed intensively for seven days, with 35 days for recovery. All pasture in rotation with crops is planted with high digestibility *Panicum maximum* cultivars (Tanzânia and Mombaça), or with *Brachiaria brizantha*. *Paspalum atratum* cv. Pojuca, which is less palatable but tolerates poor drainage, is planted as permanent pasture in the bottomlands. Renovated pasture is planted with pigeon pea, which lasts about three years and acts as a winter protein supplement, increasing average protein content in the diet and maintaining good rumen throughput and hence weight gain. Three quarters of the soybean crop area is oversown broadcast with pearl millet (*Pennisetum americanum* cv. BN2) as the soybean is maturing. The cattle go onto the millet in soybean stover in May, and in June-July-August onto the maize stover. In late August, the whole herd goes back onto the upland *P. maximum* pasture sown with pigeon pea. With the first rains (mid-Oct.), the cattle are moved to the bottomlands, which give strategic grazing at this time, allowing the upland pastures to recover. About 30 ha of soybean stover sown to millet is left for seed and grazed after harvest. Fallen millet seed and weeds germinate with the first rains (Sept–Oct) and produce ground cover, which is desiccated in Nov–Dec for the next crop.

Irrigated crop management – with and without project

With and without ICLZT, the three centre pivots, covering 190 ha, receive identical management. Cropping intensity is 200 percent, preferred over higher intensity because of easier planting-harvest schedules. The rotation is: year 1 maize-for-grain/kidney beans; year 2 soybeans/wheat; year 3 maize-for-seed/kidney beans. Average irrigation period for beans is 90 days per crop; maize-for-grain receives an average of 35 days of supplemental irrigation between September and October; wheat consumes some 400 mm/crop in 100 days and soybeans are not irrigated. Irrigation is guided by tensiometers. Irrigated stovers are not grazed. Yields are equal with and without project, as this area is kept separate from the cattle/rainfed crops rotation.

Analysis of the Model Results

Herd performance improved after adoption of ICLZT and rotational grazing, as shown in the summary in Table 14. The number of cows increased from 220 to a steady 380 from year 9 onwards and stocking rate on the pasture increased from 1.0 to 1.76 AU/ha. Maize silage area was reduced from 22 ha to 8 ha with ICLZT, where it is only used as supplemental feed for unweaned stock and as a tactical drought reserve. Together with small increments in rainfed crop yields under ICLZT (10 percent) due to rotation with pasture, this gave IRR and NPV values as shown in Table 14.

For a modest incremental investment, a ZT planter and drill, electric fences, establishment of direct-seeded pigeon pea in pasture and watering facilities, IRR increases from 14.16 percent to 19.96 percent and average annual net profit (undiscounted) from R$229/ha to R$372/ha, a gain of 63 percent, making this investment in technology extremely attractive to the farmer who has the management capacity. If compared with average management levels in the region, this increase would be even higher.

Table 15 shows the results of three alternative scenarios applied to Case Study 1, compared with the “with project” situation, as Scenario (i). In this scenario, the rainfed crop enterprise shows a small deforestation mitigation potential (DMP)[4] of 0.11 ha of native vegetation preserved for each hectare under crops (due to small increments in maize and soybean yields with project). In addition, the cattle enterprise shows a gain of 0.76 ha/ha in total AU carrying capacity, giving a total mitigation potential (crops + pasture) of 0.87 ha/ha in ICLZT.

[4] Defined as the percentage capacity of expansion in production achievable by land use intensification within the existing area.

TABLE 14: **CASE STUDY 1 SUMMARY**

INPUT/OUTPUT DATA	WITH ICLZT	WITHOUT ICLZT	(%) DIFF.
Investment Yr 1 (R$ total)	1 290 363	1 268 581	1.72
New Investment Yrs 1–5 (R$/ha)	1 458	1 433	1.72
TOTAL INVESTMENT OVER 20 YRS			
IRR (%)	19.96%	14.16%	40.98
NPV (R$ ´000)	1 454 183	542 340	168.13
Annual output of grain (average) tonnes/ha	4.53	4.29	5.78
Net profit/ha/yr	372	229	62.64
Total area (ha)	1 175	1 175	0.00
Area in reserves (ha)	280	280	0.00
Area of rainfed crops yr 20 (ha)	410	410	0.00
Area of irrigated crops yr 20 (ha)	190	190	0.00
Area of pasture yr 20 (ha)	285	285	0.00
Percentage of pasture (exploited area)	32.20%	32.20%	0.00
No. of cows yr 0	220	220	0.00
No. of cows yr 20	380	220	72.73
Total Animal Units yr 20	501	299	67.59
AU/ha yr 20	1.76	1.05	67.59

Source: Expanded from Landers and Weiss (2005).

Scenarios (ii), (iii) and (iv) begin with the typical degraded pasture situation of a winter stocking rate at 0.5 AU/ha on the whole farm. In Scenario (ii) crop expansion of 600 ha generates 0.68 ha/ha, plus 0.11 ha/ha yield gain and 0.13 ha/ha for a 13% gain in carrying capacity, totalling 0.92ha/ha DMP.

Scenario (iii) shows renovating the pasture with lime and fertilizer, with no crops and in scenario (iv) there is a pasture/crop ratio of 1:1, with pasture renovation based on the residual fertility of the crop phase.

Both show greater mitigation potential (2.52 and 1.35 ha/ha respectively), than Scenario (ii) and Scenario (i), which was limited by the already high stocking rate of the “without project” situation, with above average pasture management of 1.0 AU/ha in winter. It is notable that, should fertilizer costs come down enough to make their use attractive (not the present case), in scenario (iii) the incremental carrying capacity of the land could reach 252 percent. Scenario (iv) shows an intermediate position of the more likely situation for adoption with equal areas of crops and pasture. This has considerable significance for the environmental aspects of livestock development, firstly in the potential to mitigate deforestation, but also in reduction of erosion losses from degraded pastures through improvement in soil cover.

TABLE 15: **CASE STUDY No.1 – IMPACTS OF DIFFERENT PROPORTIONS OF CROPS/PASTURES ON DEFORESTATION MITIGATION POTENTIAL**

PARAMETER	WITH PROJECT SCENARIO (i)	SCENARIO (ii)	SCENARIO (iii)	SCENARIO (iv)
Total exploitable area (ha)	885.00	885.00	885.00	885.00
Degraded pasture area *	285.00	885.00	885.00	885.00
Stocking rate w/out project AU/ha	1.00	0.50	0.50	0.50
AU/farm w/out project	285.00	442.50	442.50	442.50
Renovated pasture area	285.00	285.00	885.00	442.50
Renov. stocking rate AU/ha	1.76	1.76	1.76	1.76
AU/farm with project	501.60	501.60	1 557.60	778.80
Increase in AU/farm (fraction)	0.76	0.13	2.52	0.76
Hectares cropped	600.00	600.00	0.00	442.50
Increased crop yield	0.11	0.11	0.00	0.09
Crop area expansion	0.00	0.68	0.00	0.50
Mitigation potential (ha/ha)**	0.87	0.92	2.52	1.35

* Based on Case Study No. 1.
** Absorption of crop area is less efficient in mitigation than better pasture management including fertilization. Note; if highly producing maize/soybeans replace low-yielding upland rice there could be a yield gain of 100%.

Source: Expanded from Landers and Weiss (2005).

CASE STUDIES OF OTHER ICLZT TECHNOLOGIES

Below are short descriptions of case studies 2–6 and a summary table of their results.

Case study 2. A net area of 1 130 ha is farmed (not counting environmental reserves). A rainfed maize and soybean rotation is integrated with a cow/calf operation. ICLZT is introduced to rotate pasture with crops, and the crop stubble in grazed during the dry season, thus intensifying the cattle operation. After the summer crop, hay is taken from volunteer grass and millet, to supplement the permanent summer pasture, which becomes limiting in view of the ratio of 6.5:1 of stubble grazing to permanent pasture. An expansion scenario is also examined, using “without project” medium technology level and clearing new land. Initial low soil fertility, light scrub savannah vegetation and flat topography are typical of the Cerrado biome in this region bordering the drier Northeast “sertão”. Case study 2 is situated in Formoso do Rio Preto, West Bahia. Source: adapted from Landers and Weiss, 2005.

Case study 3. Weaned calves are brought in, reared on renovated and subdivided ZT pasture and sold as steers (for fattening to slaughter weight). A soybeans-soybeans-soybeans/maize arable phase follows the pasture, with 3 ICLZT rotations (2 rainfed and 1 rainfed + irrigated) on 3 200 ha, including environmental reserves. The “without project” situation uses a medium/high technology level without rotating crops and pasture, the latter with large 200 ha paddocks. Initial soil fertility, low, open scrub savannah vegetation, gently undulating topography, Cerrado biome. Location: Cristalina, GO.

Case study 4. Integrated breeding/rearing/fattening pasture operation on 1 000 cleared ha; ICLZT is introduced to renovate old pastures with mechanized crops, also providing dry season stubble grazing. The “without project” scenario represents the clearing cycle in traditional practice. Initial soil fertility moderate, originally heavy rainforest vegetation, Amazon biome. Marabá, PA.

Case study 5. Small intensive beef cow/calf operation on 261 ha rotates with ZT maize for silage and ZT pigeon pea in pastures. The latter and ZT adoption are the sole changes in the operation. Old cleared area (1940s), originally high soil fertility (old coffee land), Atlantic Forest biome, Poloni, SP.

Case study 6. Medium-sized mechanized operation on 800 ha (excluding reserves), with fattening of steers or heifers on a dark red clayey latosol (Ferralsol), originally forest vegetation, at Maracajú MS at approximately 20º S latitude. Cropping pattern is a 1 year pasture ley in rotation with 3 years of annual cropping: soybeans-cotton-maize. Stocking rate on this *P. maximum* pasture reaches 5 AU/ha, but if continued in the second year this would drop to 3 AU/ha. Winter grazing consists of finger or pearl millet and black oats, after soybeans; cotton is harvested late and is followed by winter fallow. The finger millet is also used as a nurse crop for the Panicum, to give early bite. No supplemental feed is used, except proteinized salt.

This system produces 3 hectares of arable crops and carries 5 AU per 4 hectares. To achieve the same production without integration of crops and livestock, 3 hectares would be needed for annual crops plus another 10 hectares to maintain 0.5 AU per hectare in the customary grazing system on degraded pasture cleared from forest. Four hectares of this intensive integrated crop–livestock system thus save 9 hectares of forest from clearance and land degradation. In short, 2.25 hectares of forest is saved per hectare used.

CONCLUSIONS FROM THE CASE STUDIES

From the case studies, it can be seen that the pasture phase (ley) after crops varies from 1 to 6 years, depending on the intensity of the system. A one-year ley, as in Case study 6, maximizes the carrying capacity of the pasture and also the proportion of crops in the rotation. Crop phases with ICLZT are between 3 and 4 years, allowing sufficient time for a significant build-up in fertility, which is exploited by the pasture phase, at zero cost. In return, the soil conditioning and breaking of pest, disease and weed cycles during the pasture phase results in reduced costs and higher yields for the crops. Under the traditional system of pasture establishment and renovation, undersowing in an upland rice crop with about 250 kg/ha of NPK fertilizer 4–14–8 for one year (maximum 2), generated far too little residual fertility, which is the reason why most Brazilian tropical pastures have fallen rapidly into degradation. The economic significance of the cropping phase in an ICLZT system is that it permits cheap establishment of high quality pasture and provides the mechanism to renovate it on a sustainable basis, besides improving annual crop performance.

The simplest ICLZT system is that of Case study 2, using winter grazing and haying of stubble to improve dry season carrying capacity. This can be improved, as in Case study 1, by oversowing pasture seed (usually in soya) or undersowing in maize or another nurse crop – these pastures can either be annual or perennial grasses (even the annual weed grass *B. plantaginea* could have application here). The former and *B. ruziziensis* are preferred for oversowing, because they come away faster. Case study 3 shows the greatest variety of rotations and uses *Brachiaria* spp. to suppress kidney bean diseases in the non-irrigated and irrigated rotations, and *B. ruziziensis* from seed as an annual catch crop for grazing in the irrigated area, in the window between maize harvest and bean planting. As shown in Case study 4, ICLZT has relevance for the Amazon biome, but will only have significant uptake when clearing new land becomes more expensive. Enriching permanent pastures with pigeon pea, as in Case studies 1 and 5, or other legumes, is a good means of improving their efficiency (alternatively, legume protein banks can be used, but these have not had significant uptake in Brazil). The most advanced system of grazing is that of the one-year ley in Case study 6, which maximizes pasture stocking rates and the percentage of total farm area in crops and hence, total farm income.

In Table 16 the results of economic analyses of the above case studies are summarised (except Case study 6, included as an example of the most intensive rotation possible).

The results of Table 16 indicate:

1. That the investment in intensifying to an ICLZT system is viable;
2. That investment levels are relatively modest;
3. That the highest impact of ICLZT is obtained with a high ratio of winter grazing (on stubble or second crop areas) to permanent pastures;
4. That the highest stocking rates are achieved with a one-year ley.

All ICLZT systems show clear financial benefits in terms of IRR and NPV, with the exception of Case study 4, where the inclusion of land sale value in the expansion in the "without project" scenario inflates the IRR when compared with the "with project" ICLZT scenarios, in which renting land to a crop farmer shows a lower return than planting with own machinery. However, these scenarios have attractive net returns and very adequate IRRs as well.

Also, there is a large variation in Deforestation Mitigation Potential (DMP), due to different proportions of crop to pasture and variations in incremental stocking rates, with two extremes: Case study 5 has the lowest proportion of crops and a high DMP of 2.52 ha/ha, but Case study 6 has 75 percent of annual crops and a DMP of 2.25 (see Table 17), due to the very high stocking rate allowed on a one-year ley. These systems, especially the latter, will be the trend for the future.

TABLE 16: **A SUMMARY OF THE RESULTS OF FINANCIAL ANALYSIS OF THE CASE STUDIES**

CASE STUDY DESCRIPTION	SYSTEM	CROPS + PASTURES (ha)	INVESTMT. YRS 1–4 (R$/ha)	IRR (%)	NET RET. R$/ha/yr	STOCK. RATE AU/ha
Study No. 1, Cerrado – cow/calf, annual rainfed/ irrigated crops on 1 175 ha. total area. Med. high mgt. – Goiás state.	ICLZT	885	1.458	19.96	372	1.76
Without ICLZT.	Without	885	1.433	14.16	229	1.05
Study No. 2, Cerrado – cow/calf, annual rainfed crops, 1 130 ha. Total area.	ICLZT	820	1.000	8.85	84	2.18
400 ha expansion – crops not rotated with pasture, cow/calf. Med. mgt. – Bahia state.	Expansion	1 220	1.340	5.38	83	0.52
Without expansion, without ICLZT.	Without	820	933	3.30	53	0.52
Study No. 3, Cerrado – rainfed crops x beef rearing high mgt. – Goiás state. 3 200 ha total area.	ICLZT Rot.1	2.400	2.598	19.63	187	1.49
Intensive grazing with electric fences.	ICLZT Rot.2	2.400	2.598	27.16	262	1.74
Irrigated crops.	ICLZT Rot.3	2.400	4.098	26.71	301	1.93
Without rotation with pasture.	Without	2.400	2.432	12.65	114	0.93
Study No. 4, Amazon – beef Itinerant 10 yr clearing cycle med. low mgt. – South of Pará state. 1 000 ha of pasture.	Clearing Scen.(i)	1 000	-559	35.7	37	0.98
Pasture renovation in situ med. mgt.	Renov. Scen.(ii)	1 000	805	9.72	203	1.22
ICLZT with rice/soybeans med. high mgt.	ICLZT Scen (iii)	1 000	698	11.68	310	1.60
Pasture renovation via renting 20% of pasture – med. low mgt.	ICLZT Scen.(iv)	800	742	6.48	173	1.58
Study No. 5, Atlantic – small farmer 261 ha. ZT + legumes in pasture – med. high mgt – São Paulo state.	ICLZT	261	1.552	6.41	138	1.79
Conventional tillage, no legumes.	Without	261	1.504	negative	16	1.20
Study No. 6	With Without	800 800	n. a. n. a.	n. a. n. a.	n. a. n. a.	5.0 0.5

Source: Expanded from Landers *et al.* (2005).

An analysis of DMP in Table 17 compares the effects of the best alternative management systems on this parameter (taking the best scenarios of those analysed). The land use intensification through increased stocking and absorption of crop expansion in areas of degraded pasture allows mitigation of land clearing on the scale of approximately 0.25 to 2.5 hectares for every hectare in ICLZT, depending on the system. It can be seen that the two most important variables are the increase in stocking rate in the pasture and the proportion of pasture to crops.

TABLE 17: **DEFORESTATION MITIGATION POTENTIAL OF THE BEST ALTERNATIVES IN THE MODELS**

PARAMETER	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6
Degraded pasture area* (ha)	885.00	980.00	2 400.00	1 000.00	252.00	800.00
AU/farm w/out project	442.50	490.00	1 200.00	500.00	126.00	400.00
Renovated pasture area (ha)	285.00	150.00	1 200.00	800.00	241.00	200.00
Renov. stocking rate AU/ha	1.76	1.96	2.03	1.22	1.82	5.00
AU/farm with project	501.60	294.00	2 436.00	780.80	439.00	1 000.00
Increase in AU/hectare	0.13	-0.40	1.03	0.56	2.48	1.5
Crop area (proportion)	0.68	0.85	0.50	0.20	0.04	0.75
Mitigation potential (ha/ha)**	0.81	0.45	1.53	0.76	2.52	2.25

* Assumes that the farm starts as 100% degraded pastures, with a stocking rate (winter) of 0.5 AU/ha.
** Crop yield increases (decreases) and reduced time to sale of animals were not considered and are much smaller effects. These factors are almost invariably positive, thus these assumptions are conservative.

Source: Landers *et al.* (2005).

CHAPTER 6

Sustainable agriculture and policy considerations

A sustainable approach to agriculture calls for a system that is not only environmentally friendly, but economically viable and socially responsible as well. Important allies for such an approach therefore include the CA farmers, but also the governments and societies that support these farmers. The environmental awareness of a CA farmer is considerably enhanced and his/her operation more profitable – mostly through ZT, and especially by increasing land use intensity (LUI) through ICLZT. However, societal investments in the transition to CA are important catalysts in the sustainable agriculture movement. It is important to recall that farmers worldwide have considerably reduced the cost of basic foods over the last decades (Vieira *et al*., 2001), and with the increased efficiency of ZT, a net transfer of value is generated to the consumer. In addition, food security, biodiversity conservation and the sustainable use of natural resources are common concerns for each member of society, so conversion investments to CA, ZT and ICLZT will be important agenda items for many national governments. Many of these governments need assistance with the promotion of conversion to such sustainable systems, which will result in economic gains for small farmers while increasing important environmental services for society as a whole. Therefore, funding by international donors and donor countries for programmes to extend CA, ZT and ICLZT in the tropics and subtropics will need to be continued and expanded, with technical support by international and national organizations such as CIMMYT, FAO, CIRAD[6], ANAE[7], EMBRAPA, FEBRAPDP and GTZ[8].

[6] A CIRAD project in the mountainous areas of Vietnam has promoted the inclusion of forage production in cropping systems as a means for adopting direct seeding systems that successfully integrate livestock. This project has contributed to increased food and feed system performance, soil improvement, and forest conservation (Husson *et al*., 2006).

[7] Direct seeding, mulch based cropping systems in the humid tropical east coast of Malagasy, supported by ANAE have contributed to soil conservation, fodder production, reduced forest clearing and the intensified sustainable production of annual crops, leading to improved socio-economic conditions for small farmers (Séguy *et al*., 2006).

[8] Besides medium and large farms, thousands of smallholders in Paraguay are practising conservation agriculture, with support from GTZ, which has resulted in improved incomes and labour savings; these tend to be reinvested in intensification and diversification of their production systems (Lange, 2005).

FARM-BASED ECONOMIC BENEFITS OF CA, ZT AND ICLZT

Conservation agriculture shows a clear trend in increased yields and reduced use of agricultural chemicals; and even if their amount would remain constant, their use per tonne of product would be reduced, thereby saving farmers money. In addition, CA farmers tend to have more time for their families and for professional training, and larger CA farmers generally train their personnel and pay higher wages.

The case studies on ICLZT systems in the Brazilian Amazon, Savannah and Atlantic Forest biomes described in chapter 5 were selected in order to determine what kinds of incentives might be necessary for the farmer to change his/her economic decision from land clearing to land intensification. Results showed that ICLZT technology would allow productive annual crops to be grown on a significant proportion of the approximately 80 million hectares of cultivated pastures present in the Amazon and Cerrado biomes today, of which 70–80 percent are classified as degraded (Sano *et al*., 1999; Vilela *et al*., 2004).

In twenty-year investment models, the study shows increased long-term financial returns to ICLZT (improved NPV, net return/ha and IRR), but incremental investments in the transition and new management skills are needed to achieve the best returns. The expression, “a farmer in the red cannot look after the green” is especially poignant here, since many small farmers are not able to make the needed one-time investments without some support. When farmers improve their levels of land stewardship, they merit environmental services payments, not just because of the extra costs involved in the transition, but also as a quid pro quo for the reduced off-farm impacts and consequent public savings generated.

FARM-BASED ENVIRONMENTAL BENEFITS OF CA, ZT AND ICLZT

Zero tillage substitutes for, or reduces the use of, many leachable herbicides used in conventional tillage, such as Trifluralin and Atrazine (a very soluble maize herbicide used widely in conventional tillage), that have recognized pollutant effects. Other chemicals used are the same as for conventional tillage, but the environmental conscience awakened in CA farmers increases the adoption of integrated pest management (IPM), ensuring reduced use and safer handling and application of these products. Most modern selective post-emergent herbicides are applied at very low dosages of active ingredients, (often only grams/ha) and these, along with all other agricultural chemicals, are subject to intense biological breakdown by the action of the bacteria and fungi which feed on the surface humus, besides being bound to soil organic matter and mineral surfaces. Zero tillage systems avoid Atrazine or reduce its use to post-emergence, thereby creating a ZT buffer effect, whereas pre-emergence herbicide use is the norm in most conventional systems.

Desiccant herbicides, whose use in ZT have given rise to some criticism, are either practically unleachable because they are bound to soil colloids within minutes of application (Prata *et al.*, 2000; Goellner 1989), which is the case of Glyphosate, or have a very short half-life due to biodegradability or instability, as for Ammonium Gluphosinate. Table 18 shows that the principal desiccants are alone in the least leachable category of the groundwater ubiquity score (GUS). For example, Glyphosate, by far the most widely used desiccant in ZT systems, is classified in the lowest toxicology rating in Brazil (Class IV, green stripe),

TABLE 18: **GROUNDWATER CONTAMINATION POTENTIAL OF DESICCANTS AND OTHER HERBICIDES**

HERBICIDE	Koc* (ml/g)	T (time in days)	GUS**	POTENTIAL FOR CONTAMINATION OF GROUNDWATER
Glyphosate	24.000	47	-0,6357	Very low
Ammonium Gluphosinate	100	7	1.6902	Low
Paraquat	1 000 000	1.000	-6.0000	Very low
Alachlor	124	21	2.5209	Medium
Atrazine	100	60	3.5563	High
Chlorimuron	110	40	3.1378	High
Cyanazine	190	14	1.9727	Medium
2,4-D DMA salt	20	10	2.6990	Medium
Diuron	480	90	2.5773	Medium
Fomesafen	60	100	4.4437	Very high
Metholachlor	200	118	3.5201	High
Nicosulfuron	30	21	3.3358	High

* Organic carbon partitioning coefficient (used for measuring how tightly bound a pesticide is).

** Groundwater ubiquity score: Calculated by the formula GUS = log T 1/2 x (4 – log Koc); values below 1.8 indicate low potential for groundwater contamination.

Source: Adapted from the Herbicide Handbook, SSA, 7th Edition (1994).

based on its very low toxicity to humans and non-leachability. This, however, does not mean that these products can be used carelessly. Farmers applying CA mainly use crop rotations, cover crops and mechanical means like the knife roller for weed management, and use desiccants and herbicides only if and as needed.

On CA farms, proof of enhanced biological activity abounds, principally the increased levels of soil fauna and flora, of which the mesofauna are the most evident, exemplified by earthworms and the burrows of scarab beetle larvae. Hayes *et al*. (2003) showed that concentrations of as little as 0.1 ppb of Atrazine have been shown to cause hermaphroditism and genital deformity in frogs on conventional farms, and although Atrazine-resistant populations are now appearing, amphibian population decline continues to be a serious global matter. According to the World Conservation Union (IUCN, 2001), agricultural lands continue to be an important focus for biodiversity conservation, and one of the keys to continued conservation is ecological education of decision-makers and farmers, which allows them to continue adopting more environmentally friendly farming methods. By limiting the amount of chemicals released into air, soil and water, CA farmers can continue to play a crucial role in biodiversity conservation by the protection of specific habitats.

In addition to the reduction of herbicides used, the increased environmental awareness of CA farmers in Brazil has led to a number of farmers' groups (Clubes Amigos da Terra) managing, or actively collaborating with, centres for the recycling of used agricultural chemical containers. In 2005 alone, Brazil recycled approximately 65 percent of these containers (INPEV, 2005).

Compared to conventional agriculture using ploughs and discs, ZT actually improves soil quality over time, reversing the loss of SOM. In the pampas of Argentina, which were originally fertile soils, top yields were produced without fertilizer, but SOM has declined from 6 percent a century ago to 2 percent today, as a result of exploitation with conventional land preparation, provoking continuous oxidation of organic matter, in order to mine soil fertility and generate agricultural exports. The pampas example further underlines the need for a sustainable approach to modern agriculture, such as through ZT and ICLZT.

SOCIAL BENEFITS OF ICLZT AND INCREASED LAND USE INTENSITY

The fundamental changes in soil behaviour and management, referred to in Chapter 1, bring a number of benefits to society, besides reducing on-farm production costs (Landers *et al*., 2001). Adjusting the approximate first estimate for Brazil (which requires revision, but used the most conservative data available at the time) for 50 percent versus 35 percent of adoption, the total gains with CA were estimated at US$ 1.9 billion in 2004/5. Besides the direct benefits to farmers (26 percent of the total), the principal indirect-use benefits constitute reductions in public spending. These derive from the value of the reduced clearing of native vegetation (57 percent of the total); reduced off-farm effects of soil erosion (silting, road maintenance and water treatment); lower emissions of greenhouse gases; carbon sequestration; and enhanced aquifer recharge (due to increased rainfall infiltration).

Besides these quantifiable benefits, a number of un-quantified benefits have been noted after the conversion to CA, usually increasing over time. Dust clouds from land preparation are eliminated in rural towns, as are the effects of residue burning on air quality; flood peaks are lower; and base flows of watercourses increase and springs have begun to flow again due to the 70 percent greater rainfall infiltration (De Maria, 1999). Also, the cost of reservoir silting may have been seriously underestimated, since another estimate (Carvalho *et al*., 2000) was 76 times higher than the conservative value chosen by Landers *et al*. (2001). These assumptions require more in-depth study, which may well increase the recognized benefits of converting to CA, ZT and ICLZT systems. It is implicit that not paying environmental services for preservation of native vegetation is a negative stimulus to conservation.

In many tropical and subtropical regions, land clearing is a response to increased demand for agricultural products. Land clearing, in turn, leads to loss of biodiversity, which is a growing concern in many societies. But without a value placed on the preservation of natural vegetation, land clearing will continue to be the cheapest route to increase food and fibre production. However, if environmental services payments were offered for increased LUI, deforestation could become economically less attractive.

Table 17 in Chapter 5 shows, in the bottom line, how many hectares of decreased demand for clearing native vegetation correspond to each hectare of LUI with ICLZT, starting from a base of degraded pasture. The realization of this mitigation potential depends on effective policy stimuli to ICLZT and constraints to clearing; the former implies a value put on each hectare of native vegetation spared, to use as a base for an environmental services payment to the farmer who intensifies the use of his land, thereby eliminating the need for frontier expansion. The latter implies tighter control of licensing to clear new land and effective policing of this, which will be enormously facilitated if farmers feel they are being fairly treated with incentives to LUI. With the right incentives it is possible to address this problem, as studies show that farmers respond logically to economic stimuli, thereby making LUI more attractive than clearing.

The mitigation potential of each system in Table 17 ranges from 2.52 ha of reduced demand for clearing new land for every hectare in the ICLZT system of Model No. 5, to 0.45 ha/ha in Model No. 2. The average of all models and their variants adopting ICLZT was 0.99 ha saved from clearing per ha converted to an intensified integrated crop–livestock ZT system. The differences are due to different proportions of annual crops to pastures (stubble grazing to permanent pasture) and different increases of stocking rates over the "without-project" situation. This shows considerable potential for policy actions to mitigate the loss of native vegetation, if society were willing to contribute to the transition costs of LUI and supply technical capacity-building and credit for the investments required. The largest of these is a relatively short-term increase in incremental working capital for purchase of additional animals to take advantage of the greater forage availability.

SOCIAL SUPPORT FOR CONVERSION INVESTMENTS IN ICLZT

As a result of minimizing erosion, increasing, or even maximizing, crop yields, soil biological activity and nutrient recycling, reducing market and climate risks and improving profits, farmers in Brazil are focusing on ICLZT, which intensifies land use and, consequently, mitigates the demand for further land clearing. This win-win-win situation merits the recognition of society, through a policy of both financial and non-financial incentives.

Farmers in other tropical and subtropical regions have also started focusing on ICLZT, but reliable support facilities to aid in the transition appear to be the key to conversion from conventional farming systems to intensive ZT systems, especially for small farmers. Without the appropriate incentives, training, or equipment, many small farmers may see conversion as too risky an undertaking.

Addressing the conversion needs of small farmers

In addition to training and up-to-date information on ICLZT systems, more tangible items such as cheap and simple equipment are considered the first step in addressing the needs of small farmers wishing to convert. Examples of simple and easily adaptable equipment, which can be used manually or drawn by animals, can be seen in Plates 19–27 on the following pages. Institutions or extension services can support small farmers by providing equipment or micro-loans needed to purchase the equipment, as well as the necessary training and information needed to begin.

Plates 19–27 were chosen from a photo gallery of FAO-supported projects to illustrate equipment that can be adapted for resource-poor farmers. Their use in different regions shows that CA, ZT and ICLZT systems are adaptable for a range of biophysical environments.

PLATE 19: Hand jab planter demonstrated for direct seeding by hand. Guantanamo, Cuba. October, 2006.

PLATE 20: Manual traction boom sprayer used for desiccation of degraded *Brachiaria* pasture as preparation for no-till maize planting. Goiania, Brazil. September, 2006.

PLATE 21: Animal traction no-till planter used for direct planting of maize into knife-rolled and desiccated spontaneous vegetation (weeds) used as soil cover. Posoltega, Nicaragua. June, 2005.

PLATE 22: Animal traction boom sprayer used for desiccation of cover crop. Posoltega, Nicaragua. June, 2005.

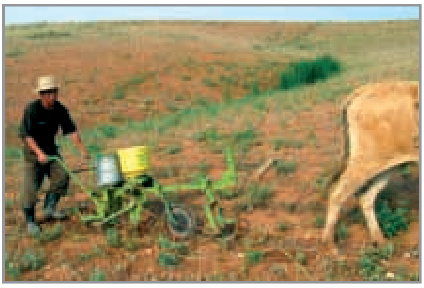


PLATE 23: Animal traction no-till planting of maize on degraded hill site. Jung San Up farm, Democratic Peoples Republic of Korea. June, 2004.

PLATE 24: Animal traction rolling punch planter made in Kenya for direct seeding into unprepared soil. Jinja, Uganda. May, 2002.

PLATE 25: Animal traction no-till planter used for planting beans into desiccated sorghum. Guantanamo, Cuba. October, 2006, (details in Plates 26 and 27).

PLATE 26: Chisel-type fertilizer boot (furrow opener) behind cutting disc; offset double-disc seed furrow opener at rear. Brazilian type animal traction no-till planter, used in various countries.

PLATE 27: Close-up view of the cutting disc, fertilizer boot and offset double-disc seed furrow opener (of a tractor-mounted ZT planter).

Equipment suitable for small farmers as illustrated in Plates 19–27, which should be easily adaptable for a wide range of biophysical conditions, is necessary for promoting ICLZT systems in the different tropical and subtropical regions of the world. The most important concept to keep in mind is that while the principles of CA, ZT and ICLZT are universal, the solutions are local and farmer-led (which crops to rotate, which equipment to use, access to inputs, etc.). Therefore, institutions or extension services supporting small farmers must inquire from the farmers themselves about the bottlenecks they are facing. They should assure availability and accessibility of low-cost equipment, facilitated and supported by local and national government actions and enabling policies. Technical solutions to local problems during the adoption phase have to be found in collaboration among farmers, extension technicians and scientists. The classic roles of technology development and transfer have proven not to work well for CA and to take too much time. The farmer him/herself is often the most creative developer when it comes to finding locally adapted solutions. Technical support from organizations such as FAO and CIMMYT, EMBRAPA and CIRAD, and funding from the World Bank, Regional Development Banks and donor countries are especially important to further encourage governments to facilitate the spread of ICLZT.

CONCLUSION AND POLICY RECOMMENDATIONS

In the drive to meet the demands of present-day society, without compromising the ability of future generations to meet their own needs, sustainable forms of agriculture are an essential element. Farmers are all too often caught in the cross-fire of differing societal demands for products that are cheap, yet produced in an environmentally friendly and socially responsible way. Since CA, ZT and ICLZT systems as described in this publication address some important societal needs such as food security, biodiversity preservation and natural resource conservation, they constitute a major step towards systems that can truly be called sustainable.

While the specific technologies vary depending on local conditions, the approaches toward sustainable intensification based on incorporation of pastures and livestock into ZT crop production are very promising. The biology of the approaches of what is found to work in Brazil will give useful insights on what farmers in other parts of the world, including smallholders in African savannahs, might consider when developing their own sustainable intensified production systems. This publication can therefore be used as a starting reference, benefiting not only farmers and consumers in tropical and subtropical regions, but possibly expanding into other regions as well, thus serving to benefit human society as a whole.

Policy recommendations for promoting ICLZT in tropical and subtropical regions

- Equipment lending, especially to small farmers
- Providing farmers with seed for cover crops, including through producer training and market development
- Support to the input supply sector to make suitable ZT equipment and inputs available and accessible to farmers in the long term
- Promotion and funding of farmers clubs
- Micro-loans enabling small farmers to convert to CA and diversify
- Reduced premiums on crop insurance
- Payments for environmental services performed (such as erosion control, carbon sequestration, forest/biodiversity preservation, watershed protection and habitat conservation)
- Increased cooperation among governments, agricultural extensionists and research institutes
- Increased information exchange networks between national and international research organizations, development organizations, private companies, producers and cooperatives, and donors
- Further funding of ICLZT projects by international donors and donor countries.

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Tropical crop–livestock systems in conservation agriculture
The Brazilian experience

This publication describes how pasture, fodder and livestock production have been integrated into conservation agriculture systems in Brazil's tropical zones. Vast areas of forest have been cleared in the tropical areas of Brazil for establishment of pastures that become unproductive once the native fertility of the soil is exhausted; this leads to yet more forest clearing.

Integrated crop–livestock zero tillage systems allow for the sustainable production of high-yielding pasture without further deforestation; in this system, grazing livestock convert both pastures and crop residues into cash. The ability of pasture to build up the fertility and biological activity of the topsoil is well known. The economics of the system are discussed and its very positive ecological effects are described at length.

This publication is geared towards agronomists, advanced farmers, extension workers and agricultural decision-makers throughout the tropics and subtropics. It is hoped that the many lessons learned and technologies developed in the Brazilian tropics can serve, with the necessary local adaptation, as a starting reference for other tropical (and subtropical) zones.

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