ADOPTION OF RESOURCE MANAGEMENT TECHNOLOGIES: LESSONS FROM THE BRAZILIAN SAVANNA

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INTRODUCTION

A major obstacle to achieving sustainable agricultural production systems, particularly in the developing world, has been the disappointing adoption of resource management technologies (Laing and Ashby, 1992).This paper documents and analyzes land use change among soybean producers in the Brazilian savanna (Cerrado) and draws out implications about the technological and institutional requirements for achieving more widespread adoption of environmentally sound technologies in the developing world. Results show that resource management technologies are best targeted to areas experiencing profound changes in economic circumstances. Under these circumstances farmers are more open to fundamental changes in their farming systems, which is often a requirement of resource management technologies. If the change in economic circumstances is a negative one, past opportunities for asset accumulation are a precondition for adoption. Thus the current productivity versus sustainability debate appears to be misconceived. Contrary to popular perception, long term benefits (including environmental improvement) can be the primary motive behind adoption, provided sacrifices in current income are not required and provided other attractive opportunities are not available. In areas with good access to markets, creative partnerships with the private sector can be a powerful means of achieving widespread technology diffusion.

Soybean production in the Cerrado is widely recognized as making a very substantial contribution to Brazil's economy. Brazil is the second largest exporter of soybean in the world. Soybean accounts for 8% of Brazil's exports (EIU, 1996) and 35% to 46% of Brazil's soybean is produced in the Cerrado (Mueller, et. al., 1992; Carvalho and Paludzyszyn 1993).Concerns about sustaining yields in these systems as well as their negative off-site effects are, however, becoming increasingly widespread (Goedert, 1987; Resek et. al., 1991; Klink et.al., 1993; da Silva, 1994; Spain et.al., 1996). In addition, the government's recent maroeconomic stabilization plan has led to a profound deterioration in the financial situation of crop farmers (de Melo, 1990; Goldin and Rezende, 1993; Ayarza et.al., 1993; Shiki, et.al., 1995; Smith et.al., 1996). Unfavorable economic conditions are usually believed to lead to environmental degradation (Cunha et.al., 1994;Barbier, 1990; World Bank, 1993; Ashby, 1985; Anderson and Thampapillai, 1990). In the Cerrado however, it appears to have stimulated moves towards certain sustainable practices, notably the adoption

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of no-till systems, although a number of serious environmental concerns remain. The reasons behind this unusual response are investigated, and implications for sustaining this trend are highlighted.

LAND USE CHANGE

The study's focus is on soybean based systems in the state of Minas Gerais in the south-eastern part of the cerrados. Typically in the Cerrado large scale mechanized crop systems are located primarily on extensive plateaus (chapadoes) with clay soils. Undulating sandy areas mainly have extensive cattle ranches, while small scale dairy farms are located downstream in riparian areas (Ayarza et.al., 1993). Thus crop practices on the chapadoes could have important off-site effects on systems further down the topo-sequence. For the purposes of this study we selected the chapadoes located within the watersheds of three rivers (Uberabinha, Santa Juliana and Bagage) in the municipalities of Uberlandia, Santa Juliana and Irai de Minas respectively. The first two watersheds are of particular strategic significance: the river Uberabinha is the main source of water for the city of Uberlandia with a population of 0.5 million; the chapadeo of Santa Juliana is upstream from the newly constructed dam of Nova Ponte. The Uberabinha watershed has also been the location for numerous geographical studies and on-farm trials have been carried out there since 1992.Rapid rural appraisals have been carried out in the study area in 1993 and 1995 (Ayarza et.al., 1993; Shiki et.al., 1995). In 1996 a survey of 36 randomly selected crop farmers in the selected chapadoes was carried out covering 23,332 ha. equivalent to 15% of the three watersheds.

Soils in the area are deep and well structured, with an inherently low fertility and high phosphorus fixation capacity. They are classified as dark red or red-yellow latosols (EMBRAPA, 1982). Soils on the chapadoes are predominantly clayey.Sandy to sandy-loamy to loamy-dark red latosols are found in the eastern part of the region towards the main rivers and purple latosols (basalt derived soils) run along the Aguari river. Climate is characterized by a bimodal rainfall distribution. Average annual rainfall is 1600 mm with a marked dry season of five months.More than 75% of the rain falls from November to March. The wet season is characterized by periods of high intensity rainfall interspersed by frequent drought spells of 10-15 days, known as veranicos.

Survey data on land use in the study area in 1996 show that unirrigated annual crops dominate, occupying 72% of farm area, with introduced pastures, the next common land use, being planted by about half the farmers but occupying only 11% of the area. Although it is mandatory to permanently preserve the natural vegetation in 20% of each farm, the area in reserves is only 7% of total farm area. Also noteworthy is that 14% of farmers have land that has lost its productive capacity, although these wastelands occupy only 1% of the area. Fifty-three percent of farmers have adopted direct planting or no-till, a system in which there is no preparatory cultivation and the seed is planted by a special drill in a narrow and shallow slit. Thirty-six percent of the study area is currently under no-till. The conventional land preparation method using the grader and disc plow is followed on the rest of the annual crop area. Soybean is the dominant crop in both systems occupying 80% of the annual crop area under conventional land preparation and 90% of the area under no-till. Over 70-88% of farmers claim that they rotate soybean (primarily with maize), the proportion of area in soybean indicating that rotation with maize as the principal crop occurs about every six years. In addition, rotation with cereals is practiced by about a quarter of farmers who double crop small areas, the second crop (safrinha) being predominantly maize and sorghum (Table 1).

The pattern of land use change extracted from the 1996 survey is depicted in Figure 1. Prior to 1987, native vegetation (Cerrado) was converted by 86% of farmers to annual crops (conventional system), with the first conversion by sample farmers dating back to 1978.Forty-four percent of today's annual crop area under the conventional system was planted by 1986.Cerrado was replaced with plantations (mainly eucalyptus and pine) by 25% of farmers, 99% of today's plantation area being planted before 1986.After 1986, 44% of farmers converted from the conventional system to no-till, 17% converted small areas of crop land to pasture and another 17% converted plantations to annual crops, with converted plantations now occupying 16% of the study area. Thirty-one percent of farmers converted Cerrado to planted pastures, with 97% of pasture area being planted after 1986. Thus annual cropping was well established, and there was a considerable number of plantations in the area by 1986. The most significant change in land use during the last ten years has been the shift from conventional to no-till crop systems, the replacement of plantations by annual crops and the introduction of cattle.

Current land use and patterns of change in land use are strikingly similar to remote sensing data for the Uberabinha watershed. These data confirm the current dominance of annual cropping (46% of area in 1994) and the minimal area in native vegetation and reserves (4.6% of area in 1994), the recent shift from plantations to annual crops (plantations declined from 21% in 1979 to 16% in 1994, while crops increased from 9% to 46% during the same period) and the recent increase in planted pastures which increased from 6% to 14% between 1979 and 1994. (Oliveira Schneider, 1996). The adoption of no-till, the decline in plantations and the increase in livestock are also consistent with rapid rural appraisals (Shiki et. al 1995; Ayarza et.al.1993).

ENVIRONMENTAL IMPACT OF LAND USE CHANGE

Overall the land use changes since 1986 represent a move towards more sustainable systems, although a number of serious environmental concerns remain. Evidence on the environmental impact of each change is given below.

From conventional tillage to no-till systems

There is extensive documentation of soil compaction resulting from conventional tillage using a grader and disk plow (Goedert, 1987; Mondardo and Dedecek, 1980; Alegre et.al., 1991).After ten years of intensive cropping in the Cerrado a five fold increase in compaction was found in the first 20 cm (Goedert, 1987).A compacted layer develops below the soil surface due to decreases in organic matter content, destruction of soil aggregates, frequent use of heavy machinery, and shallow tillage. This leads to root penetration problems thus severely reducing water infiltration and increasing runoff and erosion, which could have serious implications downstream, particularly on small-scale dairy farms. Farmers appear to be attempting to cure compaction: 65% of farmers practicing conventional tillage now use subsoilers as well as graders. This increases root depth and density (Alegre, et.al., 1991), but involves the use of heavy machinery.

No-till's ability to reduce erosion is amply documented. Soil losses were reduced from an annual average of 8 t/ha over 6 years for soybean under conventional tillage to 4.3 t/ha under no-till (Dedecek et.al., 1986). No-till with subsoiling reduced runoff and erosion by 34% (Alegre, et.al., 1991). Similar effects were quantified in other soils by Crosson (1981) and Lal (1976). Given the position of the chapadoes in the topography, adoption of no-till therefore could reduce off-site effects on the production systems of small scale dairy farms, with favorable equity implications. It could also improve water quality for urban consumers in the city of Uberlandia and reduce sedimentation in the Nova Ponte dam. No-till has also been shown to reduce evaporation and increase total water infiltration, thus leading to net reductions in water loss over the season (Peterson and Power, 1991). This could be particularly important in the cerrado given the high incidence of drought spells during the wet season (veranicos). The magnitude of the impact depends on the degree of soil cover, which is higher under the emerging practice of cereal safrinha crops (Seguy et.al., 1991). Other beneficial effects of no-till include higher amounts of organic matter in the surface layer (Fausey and Lal, 1992) and increased carbon sequestration (Campbell et.al., 1995).

On the negative side no-till provides an excellent environment for weeds, insects and pathogens (Amemiya, 1977; Griffith, 1977;
, Craig et.al., 1996;.Lal et.al. 1990; Araujo et.al., 1996). Use of agrochemicals is already high in the cerrados. Pesticide use is 1.8 kg. active ingredient (a.i.)/ha. of crops, equivalent to 9% of national consumption, compared to a national average of 0.75 kg. a.i./ha. (Da Silva, 1994). Survey data show that three highly toxic Category 1 (Farm Chemicals Handbook, 1995) broad spectrum insecticides (monocrotophos, endosulfan and methamidophos) are used by 74%, 48% and 9% of farmers respectively. Endosulfan in particular persists up to 30 years in the soil (Edwards, 1976) and its use is prohibited in Brazil except in emergencies. Endosulfan is also highly toxic in aquatic environments and kills fish even at very low dosages of 0.0009 ppm (Grande et.al., 1994). While residues of these insecticides have not been found in soil and water samples in the region (Oliveira Schneider, 1996), they build up insecticide resistance and destroy natural enemies (Metcalf and Luckmann, 1994).In

addition they pose toxicity risks to living creatures particularly as 23% of farmers do not obtain technical advice on handling insecticides and 42% rely on agrochemical salespersons for advice. Insecticides are handled without protective equipment such as masks and gloves on a third of the farms. Also 37% of farmers store empty insecticide containers presumably for reuse and 33% bury them, which could cause ground water contamination. On the positive side, 28% of farmers use only a low toxicity selective insecticide (Diflubenzuron) and 8% use a viral biological control agent. Thus, while clearly there is a need for ecologically sound and safer pest management practices, the adoption of no-till should have beneficial effects on soil and moisture conservation.

Introduction of livestock into crop based systems

Of the farmers that have cattle (approximately half the sample), 61% keep cattle for milk, and 68% for beef, thus indicating that most farmers keep both types of cattle. Thirtyeight percent keep dual purpose cattle. Cattle are predominantly grazed during the wet season. In the dry season almost half the farmers confine cattle at least partially. Silage, concentrates and cut and carry pasture are provided by all farmers in the dry season and by about half the farmers in the wet season.

Some evidence of crop-livestock integration is emerging. 14% of sample farmers apply cattle residues to their crop fields, 14% prepare silage from crop residues and 19% prepare feed concentrates using grain produced on the farm. Manure increases soil pH, soil organic matter and available P (Powell and Williams, 1993). In addition, fertilized crops improve the quality of concentrates and silage (Powell and Williams, 1993), resulting in better fed animals, which appears to reduce methane emissions(Minami et al., 1993).The introduction of livestock into crop-based systems also opens up new opportunities for developing sustainable systems. Livestock, for example, reinforce the importance of cereal crops such as maize and sorghum in the cropping system because of their use in silage and concentrates. The incorporation of cereals into soybean based systems should help to break soybean pest and disease cycles. Also, cereal residues provide better soil cover than soybean. While soybean residues cover only 16% of the soil surface 60 days after the start of the rainy season , maize residues are able to keep 54% of the soil covered after the same period, thus preventing runoff and improving water retention (Seguy, et.al., 1991).The introduction of livestock also opens up opportunities for introducing forage cover crops with superior ground cover characteristics into soybean based systems. Currently only 6% of farmers use planted cover crops in crop fields.

Six percent of sample farmers have recently started practicing ley farming which, compared to monocropping, has been shown to increase earthworm biomass, microbial N and P and large soil aggregates, thus improving water retention and aeration (CIAT, 1995). Widespread adoption of ley farming is however unlikely because two-thirds of farmers planted pasture on areas they consider unsuitable for crops.

Introduction of pastures may also be leading to certain deleterious environmental effects. In spite of pastures having moved into the area only in the last ten years, almost half the farmers with livestock already have degraded pastures, which can result in runoff and erosion, particularly given the undulating topography on which pastures have been planted. Thus while clearly there is a need for preventing pasture degradation, diversification into livestock appears to be a move towards more sustainable systems.

From plantations to annual crops

On-farm trials investigating the environmental impact of this land use change are currently underway. Preliminary results of a comparison with native vegetation indicate that pine plantations result in a 50% reduction in the large macro aggregates in the soil (between 2 to 8mm in size), and a 25% reduction in microbial biomass and microbial activity. These differences are however minimal between plantations and annual crops (Lilienfein, 1996). Traces of the insecticide Mirex, used in plantation activities have also been found in soil and water samples in the study area (Oliveira Schneider, 1996).On the other hand there are certain positive impacts of plantations relative to annual crops under the conventional system, such as reduced tillage and erosion. The shift from plantations to annual crops could also have negative implications for green house gas emissions. Winograd and Perez (1991) estimate that the above ground standing biomass of plantations in Latin America store around 80 tC/ha. and sequester around 7 tC/ha/year during the first ten years of rapid growth. While clearly these figures are only rough estimates because data on parameters affecting carbon fluxes, such as growth rates, age at harvest and final use are not available, these figures indicate that the replacement of plantations by annual crops is likely to have increased net carbon emissions. Thus the limited information available indicate that if plantations are replaced by annual crops under the no-till system, the most significant environmental impact appears to be increased carbon emissions.

DETERMINANTS OF LAND USE CHANGE

Financial stress

The above land use changes appear to have occurred during a period of severe deterioration in the economic circumstances of crop producers. Net returns to soybean production under the conventional system are given in Table 2.Costs are based on a detailed budget for soybean production in the cerrado (Cunha et.al., 1994) adapted to reflect current real interest rates of around 12.5% for short term financing of production inputs and 10% for longer term capital outlays (EIU, 1996). Yield is based on agricultural census data for the three study municipalities of Uberlandia, Santa

Juliana and Irai de Minas (IBGE, 1980-1992) in which average annual yields over the 1987-1992 period are 1.9 t/ha. for the first two municipalities and slightly higher (2.2 t/ha) for the third. These yields are comparable to average yield for conventional systems in the survey (2.1 t/ha). Gross revenue is calculated at soybean prices of $163/t and $175/t representing the range of market prices in Goiania during normal years (Cunha et.al., 1994). Results show that with the current cost structure soybean production is unprofitable. These results are consistent with perceptions of sample farmers, 75% of whom consider annual crop production to be no longer profitable. Almost all gave reasons connected with economic factors such as low output prices, high interest rates and high production costs. Thirty percent of farmers mentioned low yields as an additional factor. Among farmers who claimed that annual crops were profitable, the reason given by 90% was high yield.

Almost all farmers (83%) claimed that annual crops were more profitable in the 1980s. This does not appear to be related to higher yields in the past. Census data in fact show that average yields in the three municipalities during 1980-1986 were equal or somewhat lower (1.9t/ha, 1.7 t/ha. and 1.4 t/ha.) than today. The decline in profitability is more likely to be related to increases in interest rates. A large rise in interest rates reduces the optimal degree of financial leverage, and thus creates financial problems for farmers in highly leveraged positions, particularly if accompanied by falling output and land prices (Melichar and Irwin, 1985). This is very similar to what happened in Brazil. Real interest rates during 1980-1986 averaged -22% p.a. In 1987 they changed abruptly to 7% p.a. and continued increasing from then on. Real output prices received by producers were 38% higher during 1980-1986 than in 1987-1991 and real land prices were 36% higher (Goldin and Rezende, 1993). The extent to which farmers are leveraged is not known, but survey data show that 86% of sample farmers had loans in 1996, and 68% claimed that they had problems with loan repayment. The dependance on loans is not surprising considering the high cost of soybean production($260,068 for the average sized farm of 823 ha). Table 2 shows that with output prices and interest rates adjusted to the level of the early 1980s soybean production would be profitable even at the lower prevailing yield levels. Thus the land use changes described above appear to have taken place during a sharp decline in profitability.

Strategies for responding to financial stress

In-depth discussions revealed that the fight to maintain profitability is being waged on two fronts. On the one hand the powerful coalition of soybean farmers and agroindustrialists is engaged in intense lobbying to obtain credit concessions and reductions in the "custo Brazil" (the high level of taxes and the high cost of infrastructure). On the other front farmers revealed that the profound change in economic circumstances had driven home the need for fundamental changes in their production systems. This realization is particularly relevant to resource management technologies which, unlike technologies such as new crop varieties, often require a major reorganization of the production system. Survey data reflect the recognition of the need for fundamental change. When asked for strategies to improve their economic situation, introduction or expansion of no-till was most frequently mentioned, both among farmers who said that economic circumstances were currently unfavorable (40%), as well as among the entire sample (44%). Introduction or expansion of beef enterprises was another strategy mentioned by about about 25% of farmers in both groups. New ideas, not yet implemented, include irrigated crops (around a third of farmers) and poultry or piggeries (around a quarter of farmers). Less than 10% of farmers mentioned marginal changes such as new crop varieties and improved fertilization practices. Also notable is the resilience of sample farmers and their commitment to crop farming. Of those farmers facing economic difficulties, less than 5% had no ideas on improving their situation, or planned to give up farming or wanted to reduce annual crop area (Table 3).

Livestock and Plantations

In situations of financial stress farmers tend to substitute purchased inputs by internally generated inputs and to shift towards liquid assets (Boehlje and Eidman, 1893). Livestock activities appear to be consistent with the above strategy. In established breeding/fattening enterprises farmers claim that proceeds from cattle sales can be rolled over to finance replacement cattle and pay for variable costs, thus reducing cash requirements (Cunha et.al., 1994). Variable cash costs are particularly low when feed is produced on-farm (as is the case with most sample farmers). Also, cattle can be more easily liquidated than machinery, particularly under duress. These factors apparently compensate for the modest returns to capital provided by breeding/fattening enterprises, estimated to be 3% p.a. (Cunha, et.al., 1994). This is consistent with farmers' stated reasons for introducing livestock activities. Sixty-nine percent mentioned that pastures enabled them to use land which had been lying idle because it was unsuitable for crops. Thus pastures increase total farm income (23% of farmers). Fifty-four percent also introduced livestock to diversify their activities. Thus livestock is a complement to, rather than a substitute for, cropping activities, adopted because it modestly increases total income, requires little cash (once established) and provides liquidity during times of financial stress.

The shift from plantations to annual crops also appears to be driven by economic reasons. Plantations were established in response to generous tax concessions given during the 1970s with the objective of turning Brazil into a major exporter of paper and cellulose. In Cerrado areas where producers are linked to processing industries, plantations are reported to be still attractive to farmers. In the study area, however, processing industries failed to materialize. In addition, financial incentives were reduced substantially in 1988.As a result, the net present value of eucalyptus plantations is estimated to be -$958/ha. even under a low interest rate of 3% p.a.(Cunha et.al., 1994).

No-till

The case of no-till is more complex and provides interesting insights into the adoption of resource management technologies. The most notable feature is that although no-till is the most frequently mentioned strategy for improving their financial situation, a comparative assessment by farmers of no-till and conventional systems indicates little or no economic benefit in the short run. Table 4 shows that there is no clear agreement among farmers that no-till reduces the variable cost of production. While 44% say that conventional tillage is more expensive, 31% believe there is no major difference in cost. While most farmers believe that, no-till reduces land preparation fuel and labor costs , over two thirds also say that herbicide costs are higher, while 31% say there is no difference in expenditure on herbicide. This appears to indicate that there are considerable differences in practices among farmers. Estimates of savings achieved with no-till under a variety of production practices are presented in Table 5. Results show that the savings in variable cost can range from negligible to as much as 20% of variable cost depending on the practices followed. If we assume practices similar to those followed by the majority of sample farmers, i.e. occasional subsoiling by farmers practicing conventional tillage and substantially higher herbicide cost under no-till, savings in variable costs amount to 7% (Table 5, Row 3). Survey data show that about half the farmers purchase no-till planters, while the rest adapt planters used for conventional tillage. Table 5 shows that savings in total machinery and equipment costs are less than 10% in either case. Thus under the practices most commonly followed by sample farmers, no-till provides only modest savings in costs. Turning next to yield, farmers appear to see no significant difference in yield in the first year of no-till. When asked about the last harvest, while 38% of farmers said they got higher yields from no-till plots, another 31% indicated that there were no clear differences in yield (Table 4).This is consistent with data on farmers' yields for the last harvest. While average yield was somewhat higher for no-till plots compared to conventional systems (2.4 t/ha. versus 2.1 t/ha), the difference was not statistically different ($t = 1.7$, $df = 35$). It should be noted that these yields refer to the first few years of no-till, because 91% of the area had been in no-till for 3 years or less. The lack of significant yield increases in the short term is also consistent with data reported by Plantio Direto (1996), in which the yield advantage of no-till over conventional systems averaged 8% over a four year period. Thus no-till appears to offer little or no significant increases in income in the short term.

Farmers appear to be well informed about the environmental impact of no-till systems. Table 4 shows that farmers perceive clear benefits of no-till in terms of erosion control which should lead to higher yield in the long run. Another widely perceived difference is no-till's ability to conserve soil moisture and lower the risk of drought. Twelve to nineteen drought spells (veranicos) were found to have occurred in the study area during the the rainiest month, January, over a period of 20 years (Cunha, 1994). If veranicos occur at the seed filling stage yields can be reduced by about 30% to 50%.Thus this advantage of no-till could considerably reduce downside risk and result in higher average yield in the long run. Farmers also overwhelmingly believe that no-till is easier to manage. Discussions revealed that conventional soil preparation often leads to delayed planting and thus exposes crops to end of season drought. Delayed planting can reduce yield by 11% to 30%. Earlier planting also makes double cropping (safrinha) more feasible. Seguy et.al. (1994) show that no-till with safrinha can give substantially higher gross margins than conventional systems without safrinha. Their calculations, however, are from an area (Mato Grosso) with a longer wet season. In our study area, the adoption of safrinha remains minimal, with adoption only slightly higher in no-till than in conventional systems (Table 1).Thus it appears that when farmers mention no-till as a strategy for improving their economic circumstances they are referring to expected long term improvements in yield. This is consistent with discussions with farmers in which they repeatedly emphasized no-till's ability to "prolong the life of the soil". The implication is that, contrary to popular perception, long term benefits of conservation technologies can be the principal motive behind adoption, provided that sacrifices in short term incomes are not required. This is consistent with data from the corn belt in the US, where half the farmers indicated that reduction of soil loss was the main motivation for adopting reduced tillage and a quarter adopted the technology to decrease field time requirements at critical periods (Rahm and Huffman, 1984).

A critical factor determining the adoption of sustainable technologies which offer minimal short term gains is the absence of competing opportunities. In the study area, as was shown earlier, the other widely adopted strategy of incorporating cattle appears to be more a complement than a substitute for crop production and offers low returns to capital. While irrigated crops were frequently mentioned, no farmer had recently installed irrigation, and several mentioned the high cost of accessing water as a limitation to the area that could be irrigated, particularly given the high interest rates. Rapidly increasing land prices can make land speculation more attractive than investment in sustainable technologies (Smith, et.al., in press). However, in Brazil, real land prices had stabilized in the early 1990s to levels below the early 1980s (Goldin and Rezende, 1994).Thus, the adoption of no-till may have been made easier because of the unfavorable environment characterized by few competing alternatives. In this context it is worth pointing out that the adoption of no-till systems in the Cerrado is not confined to the study area. The system has also been recently widely adopted in frontier soybean growing areas in Mato Grosso state (Franz and Pimienta de Aguiar, 1994).

Explaining the resilience of soybean farmers

Adoption of sustainable production systems has been shown to occur with the emergence of new market opportunities (Tiffen and Mortimore, 1992). Resource management technologies often require considerable investment and new market opportunities provide the capacity to finance investments. Of the changes in land use systems in our study area no-till systems probably require least investment. While planting equipment can be adapted, half the adopters bought new seed drills which are worth about $40,000 for a farm of 550 ha. (Cunha et.al., 1994).Cattle breeding/fattening enterprises require $600/ha. for initial cattle purchases and pasture establishment (Cunha, et.al., 1994).Conversion of plantations to annual crop land also requires substantial investment for uprooting trees and for soil amendments. Farmers were obviously able to make these investments inspite of a severe deterioration in profitability.

The resilience of soybean farmers is explained by the opportunities for asset accumulation during the early 1980s. A veritable explosion of soybean production took place in the Cerrado during the early 1980s resulting in a major redistribution of soybean cultivation from traditional growing areas in the south of Brazil to the Cerrado. Census data from our study area (IBGE, 1980-1986) shows that soybean area in the municipalities of Uberlandia, Santa Juliana and Irai de Minas increased by 8, 17 and 4 times, respectively, between 1980 and 1986. This is attributed to major technological advances achieved by the national agricultural research system (EMBRAPA), which developed soybean varieties adapted to the Cerrado and technologies for the managing Cerrado soils for annual crop production (Goldin and Rezende, 1993; Muller et.al., 1992). Reflecting this, yield increased by about 33% in Santa Juliana and Irai de Minas between 1980 and 1986, and by 11% in Uberlandia (IBGE, 1980-1986). Topography and soils in the Cerrado were also highly suitable for the mechanized, high input soybean technologies produced by EMBRAPA (Goldin and Rezende, 1993). Another very significant factor was a government development program for the Cerrado (POLOCENTRO), which provided highly subsidized credit, infrastructure, research, technical assistance and storage facilities and explored for deposits of lime (without which soybean production is not possible in the Cerrado). A Japanese-Brazilian non- governmental program (PRODECER) also promoted settlement, in the Cerrado, of experienced, medium sized farmers from southern Brazil (Muller et.al, 1992; Shiki, et.al., 1995). An additional development was the increase in land prices, which enabled farmers to leverage increases in land holdings and build up assets. Between 1981 and 1986 land prices were on average 23% higher in real terms than in 1980.During the same period rents were averagely 9% higher than in 1980, thus indicating that factors other than agricultural productivity, such as inflation and interest rates, accounted for the bulk of the increase in land prices (Goldin and Rezende, 1993). The combination of all these factors enabled farmers to accumulate substantial assets. In 1996, farmers averagely owned 701 ha. within the study area and an average of 839 ha. in other areas. Seventy-five percent owned their homes and 94% availed of private health care facilities. In spite of a steady erosion in profitability and a decline in land price increases over the last ten years, 67% of farmers augmented their land holdings, 78% bought vehicles and 86% and 75% invested in machinery and infrastructure respectively, over this period. While 22% of farmers had sold land during the last ten years, the amounts sold were only 14% of the amounts purchased. Thus policies during the late 1970s and early 1980s provided farmers with the means to invest in sustainable technologies during a period of negative profits. Without this history of asset accumulation, the likely response would have been soil mining and the disposal of productive assets. While some of the policies that supported asset accumulation are highly inefficient (examples being negative real interest rates and hyper inflation), the Brazilian soybean case demonstrates that policies which increase the profitability of farming, such as infrastructure and productivity increasing technologies, have a key role to play in inducing the adoption of resource management technologies. Thus the productivity versus sustainability debate appears to be misconceived.

The role of the private sector

The private sector (agroindustry, farmers' organizations) has always been a potent force in soybean production in Brazil (Coy, 1992; Pompemeyer, 1984; Salazar Pessoa, 1983; Shiki, 1995).The interest of agroindustry in the fortunes of soybean producers is not surprising given that 45% of the total cost of soybean production consists of agrochemicals, and $258,000 of machinery and equipment are required for a 550 ha. farm (Cunha et.al., 1994).In addition soybeans are mainly exported in a processed form: exports of processed soybean products were almost five times more than soybean grain exports in 1991 (Carvalho and Paludzyszyn, 1993). Farmers' associations have played a powerful role in lobbying the government for favorable policies, promoting vertical integration between producers and processors, building infrastructure and setting up private colonization programs (Pompemeyer, 1984; Franz and Pimenta de Aguiar, 1994).

Our survey data reveals that the private sector played a major role in the diffusion of no-till systems. As shown earlier, information about the environmental benefits of no-till appears to have assisted adoption. The most important sources of information about no-till were agroindustry (69% farmers), other farmers (69%) and farmers' associations and cooperatives (25%). Only 19% obtained information from the government extension agency. Thus one of the few successes in the adoption of resource management technologies relied heavily on private sector diffusion. Clearly this occurred because no-till provides opportunities for increasing sales of private sector products, such as seed drills and herbicides. The example of no-till implies, however, that in the case of resource management technologies, which are essentially new systems of production, there is considerable scope for public sector research to develop a complementary relationship with the private sector by focusing on the ecological and off-site impact of agrochemicals and farm machinery. In the case of no-till for example there is a need for integrated pest management (including human health aspects) and technologies for obtaining better soil cover. While clearly there may be conflicts of interest with the private sector (an example being herbicide use in no-till systems), certain environmentally sound technologies, such as commercial biocontrol, can also provide opportunities for agroindustry to increase product sales. Others, such as pest management practices, could be positioned as integral parts of the package of practices making up the no-till system, and could thus benefit from private sector diffusion. A strategy of capitalizing on private sector interests need not be limited to areas of large scale farming. Even in West Africa, where food production prognostics have been so pessimistic for so long, purchased inputs, such as fertilizer and improved seed are now widely used by small scale farmers in areas of good infrastructure (Smith et.al., 1994). Thus a creative approach to a collaborative relationship with the private sector, in areas of good infrastructure, could be a powerful mechanism for improving the adoption of resource management technologies, even among small scale farmers.

REINFORCING THE TREND TOWARDS SUSTAINABILITY

While soybean systems appear to be moving towards greater sustainability, a number of serious environmental concerns remain. Results show that pest management practices, in particular, pose serious dangers to human health. Thus a major effort on integrated past management is required. In addition there are a number of opportunities for increasing the environmental benefits of the recent changes in production systems. Soil cover in no-till systems appears to be inadequate as most farmers use soybean residues. Farmers' recent diversification into livestock and the plans some of them have to introduce poultry and piggeries reinforces the attractions of rotation with crops such as maize and sorghum, whose residues provide better soil cover. Livestock also provide opportunities for exploiting the benefits of crop-livestock interactions, such as introducing forage cover crops. Pasture renovation technologies are required as pasture degradation appears to be widespread. Ley farming, which has been proposed as a pasture renovation technology, is however unlikely to be widely adopted as farmers appear to be sowing pastures on land unsuitable for crops. Although farmers invest heavily in crop production, pastures appear to be a subsidiary activity, primarily for using less productive land. Thus intensive pasture management technologies are unlikely to be adopted. A number of farmers mentioned plans for introducing irrigated crops. The ecological implications require careful consideration, particularly as satellite images already show substantial declines in hydromorphic areas (Oliveira Schneider, 1996). Government regulations on preserving areas of natural vegetation are clearly being flouted. In addition to threatening savanna biodiversity, the conversion of riparian forests to crops could eliminate their buffering function resulting in alterations in the hydrological cycle. Policy requirements include macro stabilization which should prevent speculative increases in land prices and lower interest rates, tax reform and infrastructure improvements to reduce the "custo Brazil", sustained funding for resource management research and environmental policies, such as pollution taxes to reduce undesirable off-site effects (Smith et.al., 1996).

CONCLUSIONS

During a time of acute financial stress soybean farmers in the Cerrado appear to have moved towards more sustainable production systems: no-till systems and crop-livestock interactions. Because of the strategic location of the study area, the widespread adoption of no-till systems, in particular, should in the long run not only improve soil and moisture conservation in soybean-based systems, but also reduce the undesirable off-site effects of soil erosion on small scale dairy farms, improve water quality for urban consumers and reduce sedimentation in dams. No-till systems do not appear to offer substantial economic advantages in the short run. This shows that adoption can be primarily driven by expected long term improvements in yield, provided that sacrifices in current income are not required, and provided that competing alternatives are absent. Faced with a major deterioration in economic circumstances, farmers recognized the need for fundamental changes in their production systems. Thus resource management technologies, which generally require substantial changes in production practices, may be best targeted to farmers undergoing major changes in economic circumstances. Results also show that past government policies had enabled farmers to accumulate substantial assets and this allowed them to embark on profound changes in their production systems during a period of financial stress, instead of the more usual response of soil mining and depletion of productive assets. While many of the policies that promoted asset accumulation were inefficient, this case demonstrates that policies which increase the profitability of farming, such as infrastructure and productivity increasing technologies, have a key role to play in inducing the adoption of resource management technologies. Thus the current productivity versus sustainability debate appears to be misconceived. The results also show that the private sector played a key role in the diffusion of no-till systems. While there is a danger of the private sector promoting environmentally undesirable inputs, creative technology development by the public research system, in collaboration with the private sector, can provide opportunities for benefiting from the private sector's capacity for effective technology diffusion. This is particularly useful for resource management technologies given that their adoption usually requires the diffusion of information about their long term benefits. While a discernible move towards sustainable systems is occurring, serious environmental concerns remain. Technological and policy requirements for overcoming these problems have been highlighted in this paper.

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Table 1. Land use in soybean based systems, Minas Gerais, Brazil: Survey data 1996.[1]

	% farmers	% area
Unirrigated annual crops	100	72
Planted pastures	53	11
Reserves	53	7
Plantations	14	5
Coffee	11	1
Irrigated crops	6	1
Unproductive land	14	1
Unirrigated annual crops		
Conventional land preparation	72	64
No-till	53	36
Soybean (% conventional)	61	80
Soybean (% no-till)	81	90
Maize (% conventional)	30	17
Maize (% no-till)	13	7
Double cropping (% conventional)	22	2
Double cropping (% no-till)	31	7

Table 2. Returns to soybean, production in the Cerrado (conventional system)[1].

	Early 1990s	Early 1980[2]
Gross revenue	309 to 385[3]	315 to 459[4]
Variable cost	216	316[5]
Fixed cost	118	125[5]
Interest	115[6]	-135[7]
Total cost	449	306
Net return	-140 to -64	9 to 153

1 Adapted from Cunha et al., 1994
2 Real prices (early 1990s)
3 Yield = 1.9 t/ha to 2.2 t/ha
Output price = $163/t to $175/t
4 Yield = 1.4 t/ha to 1.9 t/ha
Output price = 38% higher than in early 1990s
5 Adjusted according to real input price indices (Goldin and Rezende, 1993)
6 Real interest rate = 12.5% p.a. for variable costs, 10% p.a. for capital outlays
7 Real interest rate = -22%p.a.

Table 3. Farmers' reported strategies for improving economic circumstances, Minas Gerais, Brazil: Survey data, 1996.

	Current circumstances unfavorable	All farmers
	% farmers	
No till	40	44
Beef production	23	25
Irrigated crops	30	36
Poultry/piggery	27	22
Fish farming	11	25
Milk production	0	6
New crops/better fertilization	7	6
Reduce beef production	4	3
Reduce annual crops	4	3
Give up farming	4	3
No changes	4	8

Table 4. Farmers' assessment of major differences between no-till and conventional tillage, Minas Gerais, Brazil: Survey data, 1996.

Characteristics	Farmers' assessment (% farmers)		
	No-til	Conventional tillage	No difference
Greater fuel consumption	0	100	0
Higher labor cost	0	88	12
Higher herbicide cost	69	0	31
Higher total variable cost	19	44	31
Higher yield in first no-till year	19	19	50
Higher yield in 1995	38	0	31
Better soil moisture	100	0	0
More soil erosion	0	94	0
More compaction	13	69	13
Greater risk of drought	0	88	12
Easier to manage	88	5	5
More nematodes	19	25	6
More weeds	69	6	25
More stem gall	0	31	13

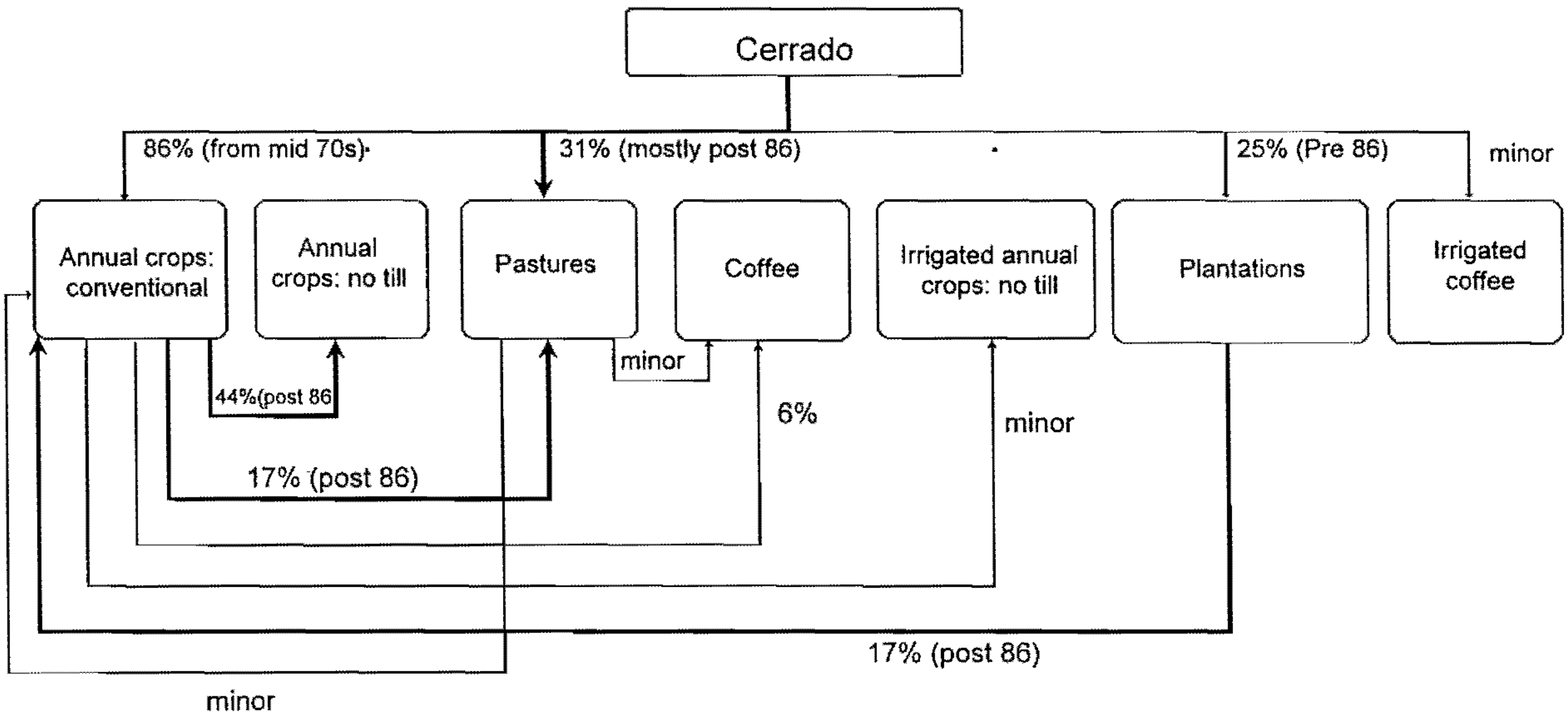
Table 5. Estimates of savings achieved by changing from conventional land preparation no-till systems: soybean production in the Brazilian cerrado[1].

Management Practices	Savings in Variable Costs[2]	
	$/ha	%
Conventional: No subsoiling No-till: Herbicide cost $32/ha	2	1
Conventional: Subsoiling every 4 years No-till: Herbicide cost $19/ha	41	20
Conventional: Subsoiling every 4 years No till: Herbicide cost $25/ha	20	7
Changes in Machinery	**Savings in machinery and equipment (550 ha/farm)[3]**	
	$	%
Replacement of graders and conventional planters by no-till planters	15,200	7
No graders. Conventional planters adapted at negligible cost	19,400	8

[1] Source: Plantío Direto (1995).
[2] Assuming variable costs of $205/ha (Plantío Direto, 1995).
[3] Assuming total machinery and equipment costs of $258,000 (Cunha et al., 1994).

1. C:\wpdocs\jsmith\soybean1.tab

Figure 1. Land Use Change: Survey data: plateaus of Minas Gerais, Brazilian Cerrado - 1996.



Percentages refer to proportions of sample farmers.
Significant recent changes are highlighted.