LAND SPECULATION AND INTENSIFICATION AT THE FRONTIER: A SEEMING PARADOX IN THE COLOMBIAN SAVANNA

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ABSTRACT

Frontier areas in Latin America have been characterized by land speculation, abandonment and exploitation. This paper analyzes a frontier cattle ranching area in the savanna where intensification has occurred in spite of land speculation. A whole farm livestock production model is used to quantify the determinants of intensification. Results show that land speculation has simultaneously increased the profitability of cattle ranching while slowing down intensification and impeding the adoption of sustainable practices. Intensification occurred because the production gains offered by improved pastures over native grasses were large enough to overcome the negative effect of land speculation on intensification. By contrast, in the Amazon, improved technologies have to overcome the high fertility of newly deforested land. Thus, technology, land speculation and characteristics of the resource base interact in a complex way to determine the speed and nature of intensification.

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INTRODUCTION

The sustainable management of frontier areas is of increasing importance in a world characterized by growing populations and increasing pressure on the natural resource base. Latin America, in particular, has turned increasingly to its frontier areas to provide food, export earnings and employment. Examples abound however, of Latin American frontier occupation being characterized by massive resource degradation, with minimal compensating contributions to agricultural production, (World Bank, 1993; Aramburu, 1984; Hecht, 1988). This paper analyzes a frontier cattle ranching region in the Colombian savanna, where substantial increases in agricultural productivity have occurred. While intensification has undoubtedly been accompanied by resource degradation, the compensating increases in production and carrying capacity imply that this is a frontier that offers the possibility of sustainable increases in production. The paper analyzes the determinants of intensification in the savanna, and draws implications about the lack of intensification in the Amazon. The results reveal that speculative land price increases, technology, and the nature of the resource base in the savanna have been key determinants of the pace and nature of intensification. While land speculation in the Amazon has led to mining of the native soil fertility, the poor production potential of native vegetation in the savanna largely precludes land mining. This, combined with improved pastures which provide strikingly better returns than native savanna grasses, has induced intensification instead of land exploitation. Also, while in the Amazon penetration roads increased the supply of new land, in the savanna infrastructure improvement occurred within areas that were already accessible. Speculative land price increases have been a double edged sword in the savanna, on the one hand contributing substantially to the profitability of cattle ranching, and on the other hand slowing down the intensification process, and impeding the adoption of sustainable technologies.

The process of intensification in the savanna is particularly interesting because the neotropical savannas of Latin America are recognized as one of the last significant agricultural frontiers in the world. As a result, their potential for contributing to world food supply is now widely acknowledged (Borlaug and Dowsdell, 1994, Macedo, 1994). It has also been argued that development of the savanna could alleviate pressure on the Amazon rain forest (CIAT, 1991a). Recently, there has also been more awareness about the ecological implications of intensification in the savannas (Solbrig, 1993; Macedo, 1994; Smith, et al. in press), particularly biodiversity losses from degradation of native savanna grasses and gallery forests (Klink, et. al., 1993; Rippstein and Girard, 1994), and siltation and pollution of watercourses and neighboring wetlands (Alho, et. al., 1988). Thus, a sound understanding of the driving forces behind intensification is required if the savanna is to fulfill its agricultural potential, while simultaneously protecting the environment.

LAND USE CHANGE IN THE COLOMBIAN SAVANNA

The study area covers the municipalities of Puerto Lopez and Puerto Gaitan, an area of 2364 sq. km. in the department of Meta, in the Colombian savanna (Figure 1). The region is characterized by highly acidic soils (pH 3.8 - 5), with high levels of aluminum (>80%). Annual rainfall is 1700 - 2500 mm., with a dry season of 3 - 4 months. The vegetation consists primarily of native savanna grasses, with clumps of woody areas. Small water courses are found throughout the region, along the banks of which are gallery forests.

The analysis of land use change presented in this paper, draws on a rich data set. In 1995 the authors carried out a survey of 98 randomly selected farmers, which had been preceded by earlier surveys in 1979, 1989, and 1992. Bio-physical case studies of small samples of farms were carried out in 1977-1979, and in 1988 -1991. In addition on-station and on-farm trials have been on-going in the area since the early 1970s.

In the 1970s, the region was still a frontier area, i.e. the natural ecosystem was just beginning to be brought under human intervention. Although the native savanna grasses were grazed, the number of animals per ha. (0.09) was too low to alter the natural vegetation.The majority of holdings lacked official land titles and physical boundaries, and the native savanna grasses were open to communal grazing (Tamayo, 1975). Rivers were the main form of transport, the dirt tracks running through the area being virtually impassable during the wet season (Sere and Estrada, 1985).

Major changes in land use have taken place in the last fifteen years, the most notable being the shift from extensive cattle ranching on native savanna grasses, to semi-extensive cattle ranching, in which a small but increasing proportion of the farm is planted to improved pasture (Table 1). Survey data from 111 farms in the municipalities of Puerto Lopez and Puerto Gaitan show that there was virtually no planted pasture in 1979 (Sere and Estrada, 1985). Adoption increased steadily to 9% of the total area in 1989, 17% in 1992 (Cadavid, 1995), and reached 20% in 1995. During this period the number of animals per ha. tripled and fertilizer users increased from 3% to 53% of farmers. Accompanying this intensification in land use, has been a decline in the average farm size from over 5000 ha. to under 2000 ha. in 1995.A dramatic increase in land prices has also taken place during this period. In the 1995 survey, farmers were asked to value land in native savanna,in the vicinity of their farms, at current market prices. Comparing these values to estimates for 1979 (Sere and Estrada, 1985) shows that land prices increased at an annual rate of approximately 15% in real terms. In 1995, land in improved pasture was reported to be selling at 2.5 to 5 times the price of native savanna. A very active land market has accompanied these changes: only 9% of sample farmers in 1995 inherited their land. The rest purchased their farms, fifty four percent having acquired them within the last 12 years. Presumably these new owners purchased land because they had better access to capital or management skills, and could therefore get higher returns from the land than previous owners. Considerable progress in the legalization of land titles has also occurred: in 1995 88% of farms had legal title deeds. In spite of the intensification, cattle ranching remains the dominant enterprise, with a few farmers (15%) having small plots of annual or perennial crops, the most dominant among these being watermelon.

Although improved pastures occupy only a small part of the area, they appear to have resulted in significant increases in land productivity and carrying capacity. Production data from on-farm sources show that beef production is around 12 kg/ha on native savanna (Kleinheisterkamp and Häbich, 1985), and increases to around 200 kg/ha on improved grass pastures under farmers' management (CIAT, 1994). Weighting this data by the reported extent of improved pasture implies that beef production/ha. has more than tripled between 1979 and 1995. Data from the intensive case studies carried out in the late 1970s (Sere and Estrada, 1985) indicate also that with 20% of the area converted to improved pasture, and the current stocking rate on improved pasture of about 1 AU/ha. (Hoyos et al., 1992), the potential herd size has increased by 80% (Table 1). Consistent with this, the cattle inventory of sample farmers increased at an annual rate of 2.9% between 1979 and 1989 (Cadavid, et. al., 1991), which is considerably higher than the increase in the national inventory of 0.93% over the same period (Lorente, 1994).

EXPLAINING LAND USE CHANGE: HYPOTHESES

The key role played by land values in inducing land use intensification is widely accepted. Intensification increases the returns per hectare of land, but requires investment in farm infrastructure and/or inputs.Farmers may prefer therefore to practice unintensified techniques, and use the foregone investment to acquire more land. This may give a higher total income if land is cheap relative to capital and labor. Thus intensification increases with land values. While some authors have related this phenomenon to population pressure, which increases the scarcity and therefore the value of land (Boserup, 1965; Binswanger and McIntire, 1987), others have emphasized transport infrastructure and distance from market centers (Binswanger and McIntire, 1987, Smith et. al, 1994, Katzman, 1974). Improved access to markets lowers input/output price ratios, and thus increases the discounted present value of expected future returns from the land.

In frontier areas a number of authors (World Bank, 1993; Kaimowitz, 1994) have pointed out that intensification is unlikely as long as the frontier is open, i.e. as long as construction of penetration roads exposes previously inaccessible public land to private occupation, thus increasing the supply of economically usable land and exerting a downward pressure on land values. Another impediment to intensification particularly in frontier areas, is the lack of government law and order services, particularly poor enforcement of property rights, leading to illegal encroachment and violence (World Bank, 1993).

Thus a considerable literature linking high land values to intensification exists. Very little is known however about the impact of land price appreciation on intensification. Recently a number of authors have hypothesized that land speculation is an impediment to intensification, particularly in frontier areas (World Bank, 1993; Brandao and Rezende, 1992; Kaimowitz, 1994; Smith et. al., in press). Where credit and risk markets are incomplete, or macroeconomic instability exists, land values exceed the present value of capitalized agricultural profits. In frontier areas when infrastructure improves and land prices increase rapidly, this speculative component gains importance relative to productive use. Available capital is therefore likely to be used more for increasing land holdings, than for intensification (Lowenberg - DeBoer and Boehije, 1986).

Technological advances also interact with incentives to intensify (Smith et. al., 1994). If a new technology results in a major increase in land productivity, farmers may obtain a higher total income by changing to the new technology on their current land holding, rather than augmenting their land holding with the old technology. The lower the land price the larger will be the extra land that can be acquired if the new technology is not adopted. Thus only a very major technological advance induces intensification when land prices are low. Conversely, the greater the technological advance, the lower the land price at which intensification occurs.

High interest rate regimes in Brazil have been blamed for the current pattern of land use in the Amazon, in which new land is opened up after existing land is "mined" and abandoned (World Bank, 1993). The logic behind this is that high interest rates increase the preference for current income relative to future income. Thus land is exploited for high initial incomes, with minimal investment in inputs for sustaining future productive capacity. The extent to which this argument is valid will depend on biophysical conditions which determine the scope for land mining. As pointed out earlier this may be much higher in the Amazon (where native fertility after deforestation is high), compared to the savanna where possibilities for short term exploitation are severely limited by the poor quality of native grasses. It should be also be recognized that high interest rates increase the cost of acquiring new land, and thus have the opposite effect of discouraging extensification. This aspect may be less important in the Amazon where penetration roads lower the cost of land acquisition, but is likely to hold more weight in the savanna, where the frontier is closed.

We now carry out a descriptive analysis of data from the Colombian savanna, in order to develop hypothesis about the relative importance of the various factors which may have induced intensification. Intensification in this area appears to be related closely to land values. The smallest farms, with the highest proportion of area in improved pasture and with the highest stocking rates are located in parts of the savanna where land values are highest (over $500/ha.) (Table 2). This is an area which is electrified, located relatively close (100 km) to the capital of Meta (Villavicencio), and connected to it with a paved road. In addition it has a flat topography which permits mechanization, thus making it more economically feasible to sow improved pasture. By contrast, plains with poor infrastructure, have a significantly lower degree of land use change, with 19% of the area in improved pasture, and land values under $300/ha. Intensification is even lower in remote areas with an undulating topography.

Considerable improvements in infrastructure have occurred, starting in the early 1980s. Currently about 45% of the road between Villavicencio and Carimagua is paved, and the road between Puerto Gaitan and Carimagua is passable for most of the year. The road between Villavicencio and the nation's capital (Santafé de Bogotá) is also being significantly improved. Major oil discoveries in the eastern part of this region, which have more than doubled Colombia's oil reserves, are expected to lead to further improvements in infrastructure. Thus improvements in infrastructure appear to have stimulated an increase in land prices, which in turn have induced intensification. The role of infrastructure in the savanna has been very different from its role in the Amazon, where penetration roads made new land available for human intervention, ie the frontier was 'open'. By contrast, land in the savanna had long been accessible. Infrastructure improvements increased the viability of economic activity, rather than increasing the supply of land as in the Amazon. Thus infrastructure stimulated intensification in the savanna, and impeded it in the Amazon.

Improvements in infrastructure undoubtedly increased the profitability of cattle ranching by permitting producers to take advantage of seasonal differences in cattle prices. However, the extremely high degree of land price appreciation (15% p.a. over the last 15 years) makes it likely that land is also being acquired as a speculative financial asset. Macroeconomic developments since the mid 1980s have favored the attractiveness of land as a financial asset. During the latter part of the 1980s a severe structural adjustment program led to a rapid increase in inflation (from 20% in 1980 to 32% in 1990; IMF, 1995). During this period there were few investment opportunities other than land that could keep up with inflation. The 1990s have been characterized by high levels of capital inflows averaging $1.7 billion during 1991-1993

(E.I.U., 1995). This was due both to high levels of foreign direct investment in the oil sector, and to the repatriation of profits from the illegal drug trade, which increased the demand for land. Although the recent political crisis and crackdown on the drug trade has led to currency depreciation, and an uncertain outlook for land prices, it is likely, in the medium term, that land will continue to be regarded as a trusted financial asset. Thus, expected appreciations in land values are likely to play a part in the intensification decision. This is borne out by the reported objectives of ranchers. The majority of farmers (52%) claim that they hold land both because of its productive capacity, and because of expected increases in land values. Twenty eight percent of farmers are interested primarily in the land's productive value, while the rest (20%) claim they are holding land primarily as a financial asset.

Turning next to technology, the productivity of the traditional technology of grazing animals on native savanna grasses is severely limited by the inherent nature of the forage on offer, characterized by low levels of dry matter yield (which enforce low stocking rates), and poor digestibility which limits liveweight gains per animal (Fisher, et. al., 1992). Thus in the savanna, expanding to a new area with traditional technology gives a very minor increase in benefit. In this situation improved grass pastures are able to offer spectacular increases in land productivity, with more than 16 fold increases in beef production per ha, as shown earlier. By contrast in the Amazon, cultivation with traditional technology on newly deforested land gives high returns for a few years. Improved technologies have to significantly surpass these returns in the first few years in order to be adopted (World Bank, 1993). Thus the poor production potential of native vegetation in the savanna made it easier for technology to contribute to intensification.

Price changes appear to have resulted in a high degree of variability in the ratio of output to input prices, without displaying any clear trend. Cadavid (1995) shows that during the 1978-1992 period cyclical changes in cattle prices were accompanied by a high degree of variability in a weighted composite of input prices. Real interest rates however increased steeply from 5% p.a. in the early 1980s to 13% p.a. during 1985-1994 (IMF, 1995). Thus intensification occurred during a period of unstable prices and high and increasing interest rates.

Turning finally to population pressure, the colombian savanna is clearly a manifestation of intensification occurring in a land abundant area. In 1985, population density was as low as 3.5 persons/ sq. km in Puerto Lopez, and even lower (0.46 persons/sq. km) in Puerto Gaitan (DANE, 1989).

Summing up therefore, the descriptive analysis leads to the hypotheses that the most significant factors driving the process of intensification decision have been technology, land price appreciation, and the nature of the natural resource base. These factors are incorporated in the quantitative analysis given below.

QUANTIFYING THE DETERMINANTS OF INTENSIFICATION

Let the returns to cattle ranching on native savanna be

$$E = - L_o + R_1' + L_1' \quad \text{...(1)}$$

and the returns to cattle ranching on a combination of improved pasture and native savanna be

$$I = - L_o + R_2' + L_2' \quad \text{...(2)}$$

where: L_o = initial investment for purchase of land in native savanna

R'_j = discounted net cash flow from beef production

L'_j = discounted proceeds from the sale of the initial land holding plus sale of cattle inventory and salvage value of infrastructure at the end of the planning period.

j = 1 refers to native savanna

j = 2 refers to a combination of improved pasture and native savanna

$$R_j' = \sum_{i=1}^{t} \frac{R_{i_j}}{(1 + r)^i} \quad \text{...(3)}$$

and i = 1...t refers to the time period, with t being the time horizon

r = the discount rate

$$L_1^t = \frac{L_o\,(1 + v)^t + W_t + S_t}{(1 + r)^t} \quad \text{.......................................(4)}$$

and

$$L_2^t = \frac{k\,L_o\,(1 + v)^t + m\,(1-k)\,L_o\,(1 + v)^t + W_t + S_t}{(1 + r)^t} \quad \text{.....(5)}$$

where v = annual rate of land price appreciation in real terms

k = proportion of land in native savanna in period t

m = price premium for land in improved pasture

W = value of cattle inventory

S = salvage value of infrastructure including fences

and R_{ij} = net cash flow from beef production

$$R_{ij} = y_{ij} - c_{ij} - g_{ij} - h_{ij} - f_{i2} - p_{i2} - l_{ij} \quad \text{..................(6)}$$

where y = proceeds from cattle sales net of freight

c = cattle purchases net of freight

g = inputs purchased for beef production, such as salt, minerals, animal health services

h = expenditure on construction and maintenance of infrastructure such as corrals, drinking toughs, wind mills for pumping water

f = expenditure on construction and maintenance of fences for paddocks of improved pasture

p = expenditure on establishment, maintenance and renovation of improved pastures, including machinery services.

l = expenditure on labor for cattle herding and administration

Let Z_j = discounted value of total expenditures required for beef production

= discounted value of

$$(\sum_i R_{ij} - \sum_i y_{ij})$$

Then

$$X = (Z_2 - Z_1)/L_o \qquad (7)$$

= extra land that can be acquired if incremental expenditure required for improved pasture is foregone

Therefore intensification occurs if

$$I > E\ (1 + X) \qquad (8)$$

or

$$I/E > 1 + X \qquad (9)$$

where the *LHS* of equation 8 is the discounted returns to an intensification strategy based on improved pasture, and the *RHS* of equation 9 is the discounted returns to an extensification strategy based on native savanna in which the foregone expenditure on improved pasture is used to acquire additional land.

I/E (equation 9) is the incremental discounted income from improved pasture. Thus the more profitable the current technology relative to current practices, and the higher the land price, the greater will be the degree of intensification. Since I and E are also functions of v, intensification is determined by the interplay between technology, land price, the rate of land price appreciation, and the resource base. The relative importance of these factors will be quantified in the empirical analysis.

A whole farm livestock production model is used to simulate annual changes in beef production over the planning period, resulting from cumulative changes over time in the establishment of improved pasture. The structure of the livestock production model is based on Gittinger's (1982) herd projection model which has long been in use at the Centro Internacional de Agricultura Tropical (CIAT), after being adapted to Colombian conditions. For this analysis the model was adapted to the Colombian savanna. Starting with a typical breeding herd grazed on native savanna in the 1970s the model simulates changes in herd size and composition based on typical reproduction, mortality and culling rates, for each age and sex category, derived from the intensive farm monitoring study carried out in the 1970s (Kleinheisterkamp and Häbich, 1985). As the area in improved pasture increases, certain key technical coefficients are changed in accordance with trial results, synthesized in Botero (1989). With 50% in improved pasture, for example, the calving rate increases from 46% to

70% (Kleinheisterkamp and Häbich, 1895), and the calf mortality rate falls from 12% to 7% (Botero, 1989). The breeding enterprise also progressively includes a fattening component starting with 8% of the herd, when 20% of the area is planted to improved pasture. Typical stocking rates on improved pasture and native savanna are achieved via cattle purchases and sales as required. Data on year by year LWG per animal on native savanna and improved pasture is obtained from a long term trial carried out over 16 years and summarized by Lascano and Euclides (1994).

We begin by quantifying the nature of the relationship between intensification and its determinants.Taking the case of a rancher who purchases 500 ha. in native savanna in time period 0, we simulate the returns to intensification and extensification over a time horizon of 15 years, at the end of which period the capital gains on land are realized by disposing of the farm. Farm size remains constant at 500 ha. throughout the planning period under the intensification strategy, but is augmented under the extensification strategy by purchasing land with the foregone expenditure required for intensification. The discount rate is taken as 5% (equivalent to the real interest rate in the early 1980s), and improved pasture is assumed to sell for 2.5 times the price of native savanna. Land price is varied from $10/ha. to $200/ha., and the rate of land price appreciation from 0% p.a. to 15% p.a. in real terms.

The case of extensification is represented by a farm containing only native savanna. Given that adoption of improved pasture occurred very slowly in the early 1980s, the intensification strategy is represented by a farm that converts 10% of the area to improved pasture by the end of the planning period. Figure 2 shows how the value of equation 8 changes with land price and the rate of land price appreciation. INT represents the intensification strategy (LHS of equation 8). EXT represents the extensification strategy (RHS of equation 8). The numerical suffixes after INT and EXT indicate the assumed rate of land price appreciation. Results show that net present values (NPV) of strategies based only on native savanna are negative for all land values, unless land appreciates in real terms by at least 10% p.a. This is consistent with results from the early 1980s (Sere and Estrada, 1985). INT15 and EXT15, representing land appreciation rates of 15% p.a. (which is the situation prevailing during the last 15 years) intersect at a threshold land price (T15) just below $100/ha. This indicates that intensification is unlikely unless land prices are at least $100/ha. Figure 2 also shows that with land appreciation held constant at 15%, the incentive for intensification (ie the positive difference between INT15 and EXT15), increases with the price of land. This is consistent with the positive relation between pasture adoption and land price shown in Table 2. In 1995 average land prices were above the threshold level for intensification in all parts of the study area. Therefore it is not surprising that 93% of farmers had at least a part of their farms in improved pasture, and that the proportion of improved pasture averaged 10% or greater in all parts of the study area (Table 2). Figure 2 also shows that if improved pastures had been about 30% less productive, causing INT15 to shift downwards to INT'15, the threshold land price for intensification would have risen to T'15 (just under $200/ha.). Thus the dramatically higher productivity of improved pastures over native savanna appears to have induced earlier intensification.

Figure 3 analyzes the impact of land price appreciation on intensification.Given the negative returns to native savanna, the strategy of extensification is represented in the rest of the paper as a slow rate of adoption of improved pasture, resulting in 10% of the farm being converted to planted pastures by the end of the planning period. Intensification is represented as a more rapid adoption, resulting in 50% of the farm being converted by the end of the planning period. As before, the foregone expenditure required for intensification, is used to acquire additional land in the extensification strategy. Figure 3 shows that when land prices appreciate at 15%, the threshold intensification price (T15) is >\$150/ha. If the expectation of land appreciation drops to 5%, intensification occurs at T5, ie at land prices >\$50. Thus a high rate of land price appreciation slows down the process of intensification. This occurs because when land prices appreciate rapidly, capital gains dominate income gains from intensification. Therefore farmers with relatively cheap land are better off purchasing more land in order to capture capital gains, rather than investing in intensification. At higher land prices less land can be acquired by foregoing intensification, and therefore the opportunity for capturing capital gains on additional land declines.The higher the rate of land price appreciation, the slower the rate at which this phenomenon occurs. This quantifies the negative effect of land speculation on intensification, and shows that the high rate of land price appreciation in the study area explains why intensification has progressed relatively slowly. Intensification can be expected to progress slowly as long as expectations about land appreciation remain high.

Figure 4 holds land appreciation constant at 15% and varies the discount rate. At a higher discount rate of 10%, the intensification threshold (T*15) is around $75/ha., which is lower than at a discount rate of 5% (T15). Both the INT and EXT curves shift downwards at higher discount rates, but the downward shift in EXT is greater than that for INT particularly at lowland prices, because EXT involves buying more land, an expenditure that is incurred *at the beginning* of the planning period, and therefore penalized when discount rates are high.

Figure 4 indicates how sensitive NPVs are to discount rates. In fact Figure 5 shows that with interest rates at 15% in real terms, even 50% in improved pasture is barely viable, if land appreciation drops below 10% (INT**5 and INT**0). Thus, in a climate of high interest rates, speculative land price increases have made a key contribution to the viability of cattle ranching. Moreover as shown earlier, increases in land prices have attracted new, more capitalized owners, for whom intensification may have been easier. Thus land speculation has both aided and hindered intensification. Currently in Colombia interest rates are around the 20% level in real terms. Moreover political instability has clouded land price prospects, and increased insecurity in cattle ranching areas.These developments seriously threaten the viability of cattle ranching in the savanna, at least while the current situation continues.

RESOURCE DEGRADATION, INTENSIFICATION AND LAND SPECULATION

Intensification in the savanna appears to have had both positive and negative effects on the environment. On the positive side, Fisher et. al (1994) show that improved pastures sequester substantially more carbon than native savanna grasses. On the negative side, farmers and scientists report considerable resource degradation, some aspects of which appear to be systematically related to intensification. In the sample as a whole a little over 60% of farmers report degradation of native savanna, which results in changes in plant communities, and threatens biodiversity (Rippstein and Girard, 1994). Table 3 compares reported degradation between areas of moderate and poor infrastructure in the plains. Reported degradation of native savanna appears to be significantly lower in areas of moderately good infrastructure where 50% of the area is in improved pasture, compared to areas where improved pastures occupy only 19%. Native savanna degrades because the common practice for coaxing higher productivity out of native grasses is frequent burning, and continuous grazing of young regrowth after burning. The lower incidence of native savanna degradation in intensified areas implies that when farms increase the area in improved pasture, the pressure to produce more from native savanna declines.To the extent that land speculation slows down intensification, it prolongs the pressure on native savanna. On the other hand, intensification may ultimately lead to only small pockets of native savanna remaining. Thus it is important to study the spatial variability in plant communities in native savanna, in order to identify suitable protected areas as intensification proceeds.

Other widely reported ecological changes include degradation of gallery forests reported by 60% of farmers, and declines in bird, animal and fish species each reported by around half the farmers. Gallery forests appear to be under greater threat in the more intensified areas (Table 3). 90% of farms that report degradation of gallery forests relate this to the extraction of species for fencing paddocks of improved pasture.27% of farmers had also cut down gallery forests in order to plant improved pastures. Thus the adoption of improved pastures appears to threaten gallery forests. Thirty five percent of farmers report that logs are extracted for sale from gallery forests. This is likely to be more prevalent in intensified areas because infrastructure is better, and therefore the cost of getting logs to market is lower. Table 3 shows that while fish species and supplies have declined uniformly in all areas, birds and animals are under greater threat in areas of better infrastructure. Farmers relate this to uncontrolled hunting and fishing, and degradation of gallery forests, both of which appear to be more prevalent where infrastructure is more developed.

A little over 60% of farmers report degradation of improved pastures, mainly loss of ground cover, which could result in wind and water induced soil loss. Pasture degradation also results in significant declines in animal production. Data from trials on two farms, under farmers' management show that beef production per ha. declined by a third within three years on one farm, and declined to a negative value in the other farm (CIAT, 1994). An intensive monitoring of pasture management practices indicates that overgrazing may partially account for the degree of pasture degradation. Improved pastures are grazed for about 67% of the year, with grazing pressures particularly high during the dry season, when instantaneous stocking rates are about 0.8 to 1.6

AU/ha. (Hoyos, et al, 1992). Unlike in the Amazon rain forest however, degraded pastures are not abandoned. Forty four to sixty percent of paddocks are renovated at least every four years. Sixty six percent of farmers renovate by harrowing, with or without the application of small quantities of P fertilizer, while 5% use fertilizer alone. Seventy eight percent of paddocks were reported to have been attacked by spittle bug which is commonly controlled through overgrazing followed by mechanical renovation (CIAT, 1991b). Thus overgrazing, nutrient deficiencies (particularly N), and pest problems appear to contribute to pasture degradation. Rotation with annual crops has been proposed as a means of renovating degraded pastures, the cost of renovation fertilizer being paid out of crop sale proceeds (Vera, et. al., 1992). However only 2% of the pasture area is renovated with this technology.

Technologies for preventing pasture degradation include mixed grass-legume pastures which maintain soil N levels (Thomas, 1992), and increase soil carbon in sand fractions (Guggenberger et. al., 1995) and earthworm populations (Decaens et. al., 1994). Adoption however remains disappointing. Only 2% of the pasture area contains legumes, and 88% of farmers who plant legumes report that legumes fail to persist under farmers' grazing pressures.

The relative profitability of pure grass, and grass-legume pastures is compared in Table 4. As before we simulate the case of a rancher who purchases 500 ha. in native savanna, progressively converts a part of it to improved pasture, and disposes of the farm at the end of the planning period of 15 years. Land price appreciation is assumed to be 15% p.a. in real terms, and improved pasture (whether pure grass or grass-legume) sells for 2.5 times the price of native savanna. The first two rows of Table 4 present results based on data from on-farm trials under farmers' management. In the first trial LWG was lower on the grass-legume pasture than in the pure grass pasture. In the second LWG was 30% higher on grass-legumes. In both trials legumes effectively disappeared after 3 years, and had to be resown, while the grass persisted. Results show that the Internal Rate of Return (IRR) for grass-legumes was at best only marginally higher than for pure grass. Thus there is clearly a need to improve the performance of currently available legumes under farmers' management. In the third row of Table 4 a controlled trial with best practices is analyzed, in which the legume persisted for 16 years. Here the LWG on grass-legumes was 34% higher than on grasses, and no expenditure on replanting legumes was required. Even in this trial however IRR was only 8% higher than for grass pastures. The fourth row simulates a further 30% increase in LWG for grass-legume pastures compared to the data in the third row, giving a total increase of 74% over pure grass pastures. Under these conditions a considerable increase of 20% in the IRR is achieved. In the last row LWG remains at the level of the third row, but the rate of land price appreciation declines to 5%. The results show that in this situation the inclusion of legumes can increase IRR by 23%. Thus when land appreciates rapidly, the productivity gains of improved technology are overwhelmed by the capital gains from land sales, which dominate the IRR. Thus technologies have to offer spectacular increases in productivity before they are adopted. Recent data indicate that a newly released legume, *Arachis pintoi*, offers significant gains in productivity while persisting under farmers' management (Lascano, 1994). However adequate data are not yet available to quantify whether it is sufficiently productive to make a significant impact on profitability, under high rates of land price appreciation. Thus land speculation may impede the adoption of technologies which have the potential to prevent resource degradation.

TOWARDS A DEVELOPMENT PATH FOR FRONTIER AREAS

The above results indicate that technology, land speculation and biophysical conditions have all been key determinants of the process of intensification in the savanna. These results are used to take a first step towards formulating a tentative development path for frontier cattle ranching areas in the savanna (Thomas, et. al., in press). In emerging frontier areas when land price is stagnant at very low levels, extensive production systems based on native savanna grasses are likely to prevail. With very low stocking rates and minimal infrastructure resource degradation is unlikely. This is similar to the situation prevailing in the Colombian savanna in the 1970s, and is depicted as phase I in Figure 6. As infrastructure improves land prices may increase very rapidly if conditions in the larger economy encourage speculative land purchases. In this situation capital gains on land investment dominate profitability, and overwhelm technological advances which offer but moderate production increases. Thus only technologies which lead to spectacular increases in productivity are likely to be able to induce intensification. Thus the speculative motive slows down the pace of intensification and technology adoption. On the other hand it may support the productive use of land by maintaining the viability of cattle ranching under unfavorable economic conditions.This scenario is similar to the current situation in the Colombian savanna (phase II in Figure 6), in which the dramatic production increases obtained with grass pastures has stimulated their adoption, and consequent intensification. Sustainable technologies, such as grass-legume pastures have not however been adopted, resulting in widespread pasture degradation. In this situation farmers demand highly productive grass pastures capable of withstanding severe grazing pressures, or technologies which recuperate degraded grass pastures. Our results also indicate that once the frontier matures, and land prices plateau at high levels (phase III), farmers may be more open to technological advances even if the production gains are not dramatic. Sustainable technologies such as ley farming systems and grass-legume pastures may be better targeted at this phase. However native savanna and gallery forests may be threatened with extinction in this phase. Carefully designated protected areas may be required, or market-based institutional mechanisms which internalize the environmental services of these resources (Smith et al., in press).

Frontier areas in Latin America have been rife with land speculation, abandonment and exploitation. Intensification has been an elusive commodity. Our analysis indicates that intensification can occur even in frontier areas. Intensification occurred in the savanna because improved pastures offered spectacular production increases over native grasses, the gains being large enough to overcome the negative effect of land speculation on intensification. The implication is that biophysical conditions may be one factor contributing to the lack of intensification in the Amazon. Improved technologies in the Amazon have to out perform the high native fertility of newly deforested land. Also, in the Amazon the supply of new land has been progressively augmented by the construction of penetration roads, while in the savanna infrastructure has increased the economic viability of already accessible land. Thus technology, land speculation and characteristics of the resource base interact in a complex way to determine the nature and speed of the intensification process. These crucial elements should be taken into consideration in the development of *sustainable land use strategies and in the design of medium and long term research* strategies, particularly in frontier areas.

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Table 1. Changes in land use 1979-1995, municipalities of Puerto López and Puerto Gaitán, Colombian savanna : survey data.

	1979[1]	1995[2]
% farm in improved pasture	2	20
Animals/ha	0.09	0.28
Fertilizer users (% farmers)	3	53
Average farm size (ha)	5162	1857
Estimated beef production (kg/ha)[3]	16	50
Estimated carrying capacity (000 heads)[4]	959	1726

[1] Survey data (111 farmers): Seré and Estrada (1985)

[2] Unpublished survey data (98 farmers)

[3] Based on degree of pasture adoption and production data from on-farm trials

[4] Potential herd size in well drained savanna (4.8 m ha) based on degree of pasture adoption and stocking rate (Seré and Estrada, 1985).

Table 2. Characteristics of farms in Puerto López and Puerto Gaitán (Colombian savanna), by infrastructure and topography: survey data, 1995.

	All farms	Infrastructure			
		Moderate		Poor	
		Plains	Undulating	Plains	Undulating
Number of sample farms	98	11	26	29	32
Average land price ($/ha)	289	543	385	293	137
% farm in improved pasture[1]	20	50[a]	35[b]	19[c]	10[c]
Animals/ha[1]	0.28	0.6[a]	0.3[b]	0.3[b]	0.2[b]
Farm size[1]	1857	418[c]	915[bc]	1998[ab]	2989[a]

[1] Differences in letters indicate significant differences (5% level), Duncan's Multiple Range Test.

Table 3. Reported resource degradation in the plains of the Colombian savanna: municipalities of Puerto Lopez and Puerto Gaitan: survey data, 1995.

	Infrastructure	
	Moderate	Poor
% area in improved pasture	50	19
Reported Degradation	% farmers	
Native savanna	37	83
Gallery forest	89	52
Improved pasture	67	52
Animals (species/supply)	89	66
Birds (species/supply)	78	59
Fish (species/supply)	63	57

Table 4. Internal Rate of Return: pure grass vs. grass-legume pastures: simulation results, Colombian savanna[1].

	Grass	Grass-legume
On-farm trial (undulating topography, fragile soil)[2, 3]	19.5	18.3
On-farm trial (sandy soil)[2, 3]	17.6	18.9
Well managed long term trial (well drained plain)[2, 4]	19.4	21.0
Well managed long term trial (well drained plain) (+ 30% production for grass-legume)[2, 4]	19.4	23.3
Well managed long term trial (land price appreciation 5%)[4]	11.8	14.5

[1] Farm size 500 ha, time horizon 15 years, 50% in improved pasture

[2] Land price appreciation 15%

[3] Live weight gain data from CIAT (1994)

[4] Liveweight gain data from Lascano and Euclides (1994).

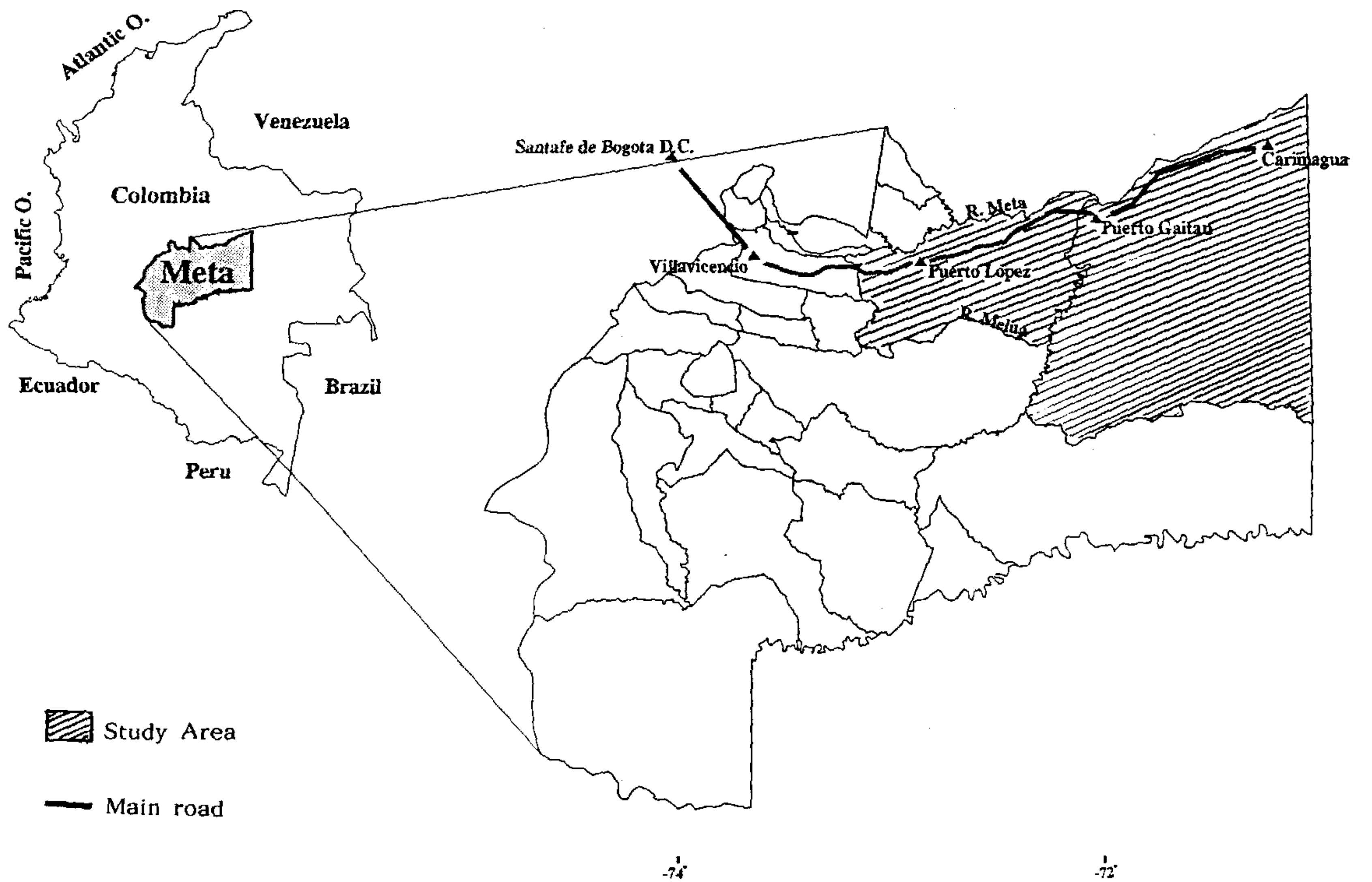
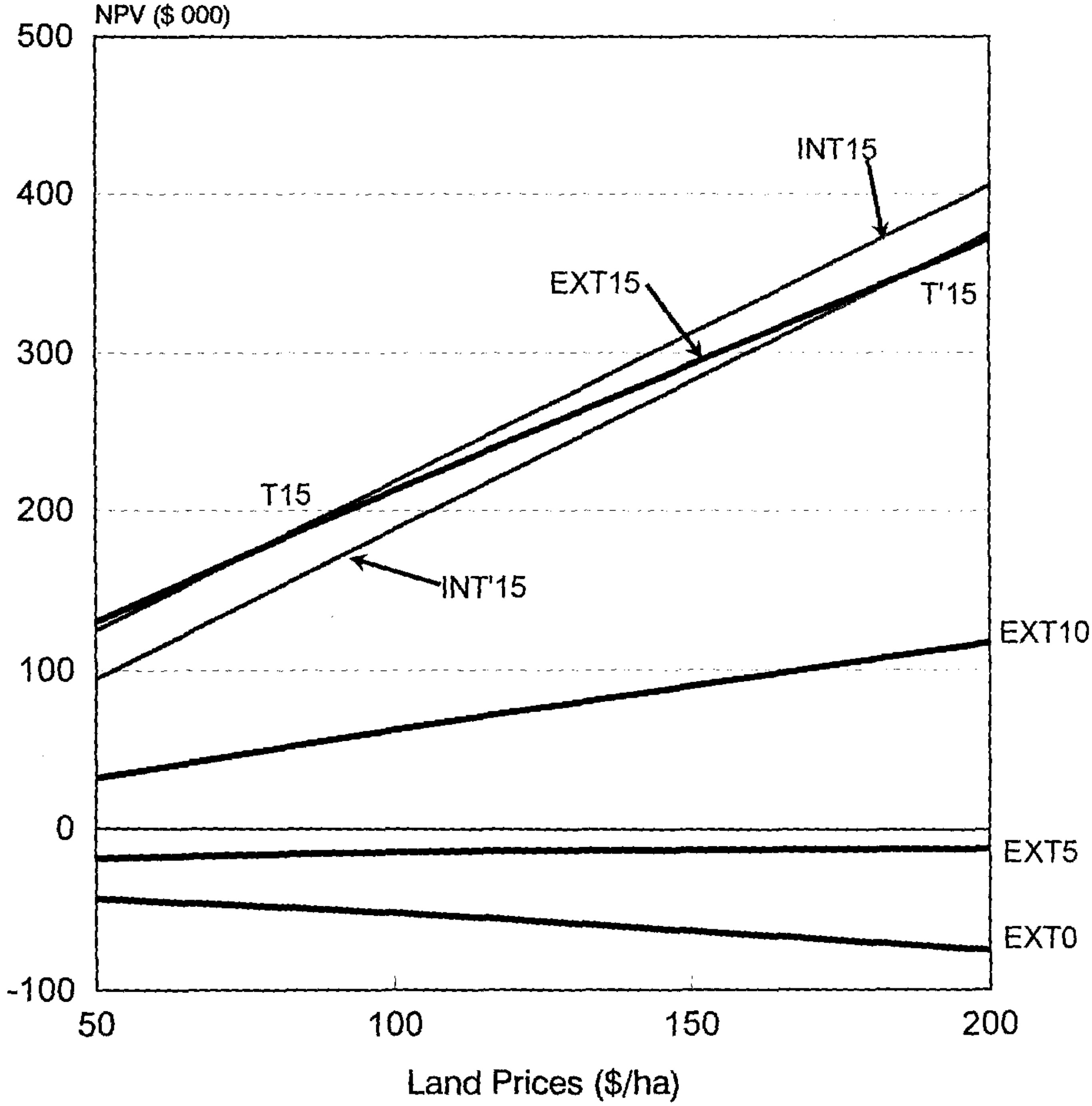


Figure 1: Study area in Department of Meta, Colombian savanna

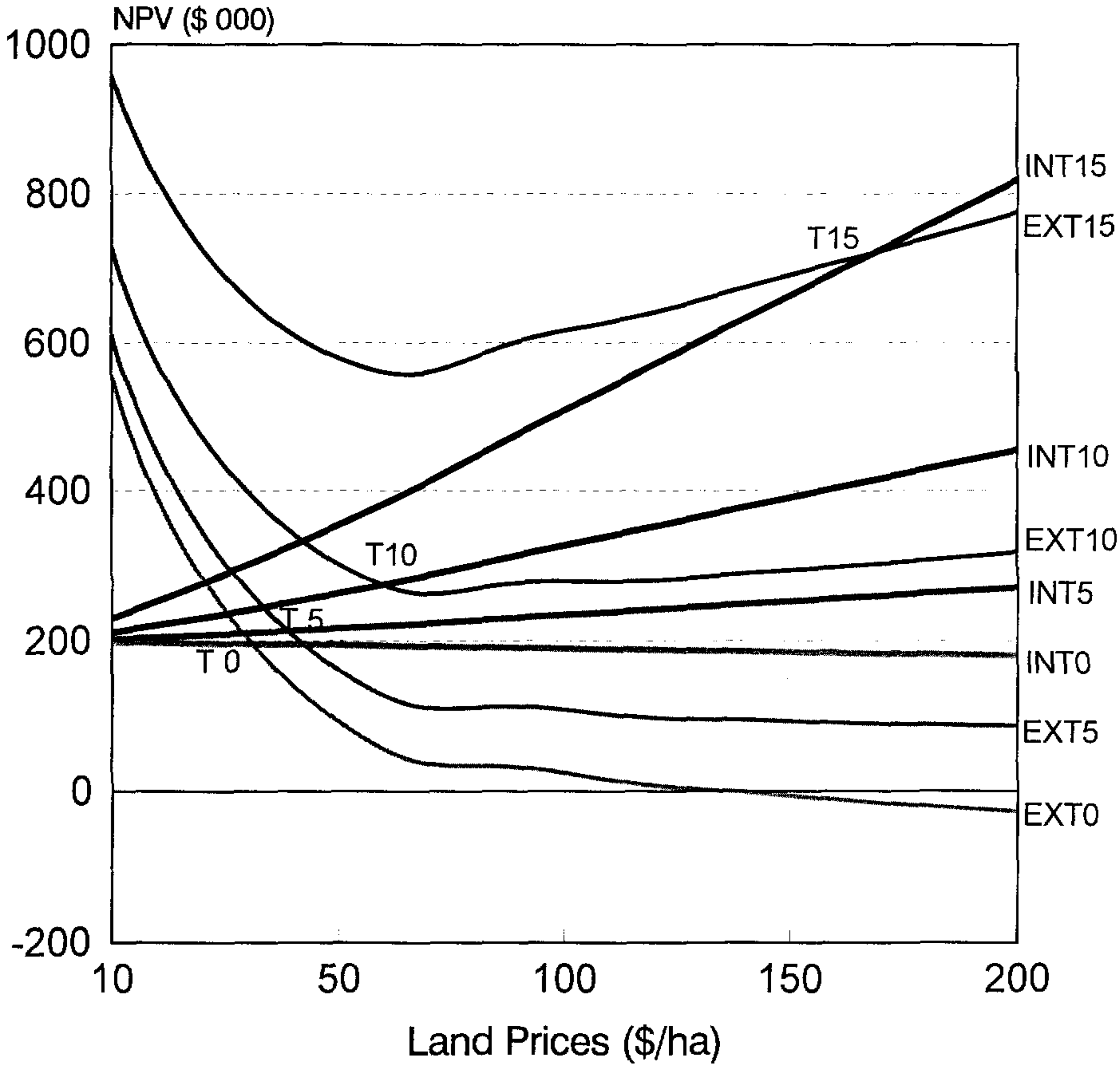
CIAT
GIS-Lab

Figure 2. Effect of technology on intensification: Threshold land prices: Simulation results, Colombian savanna



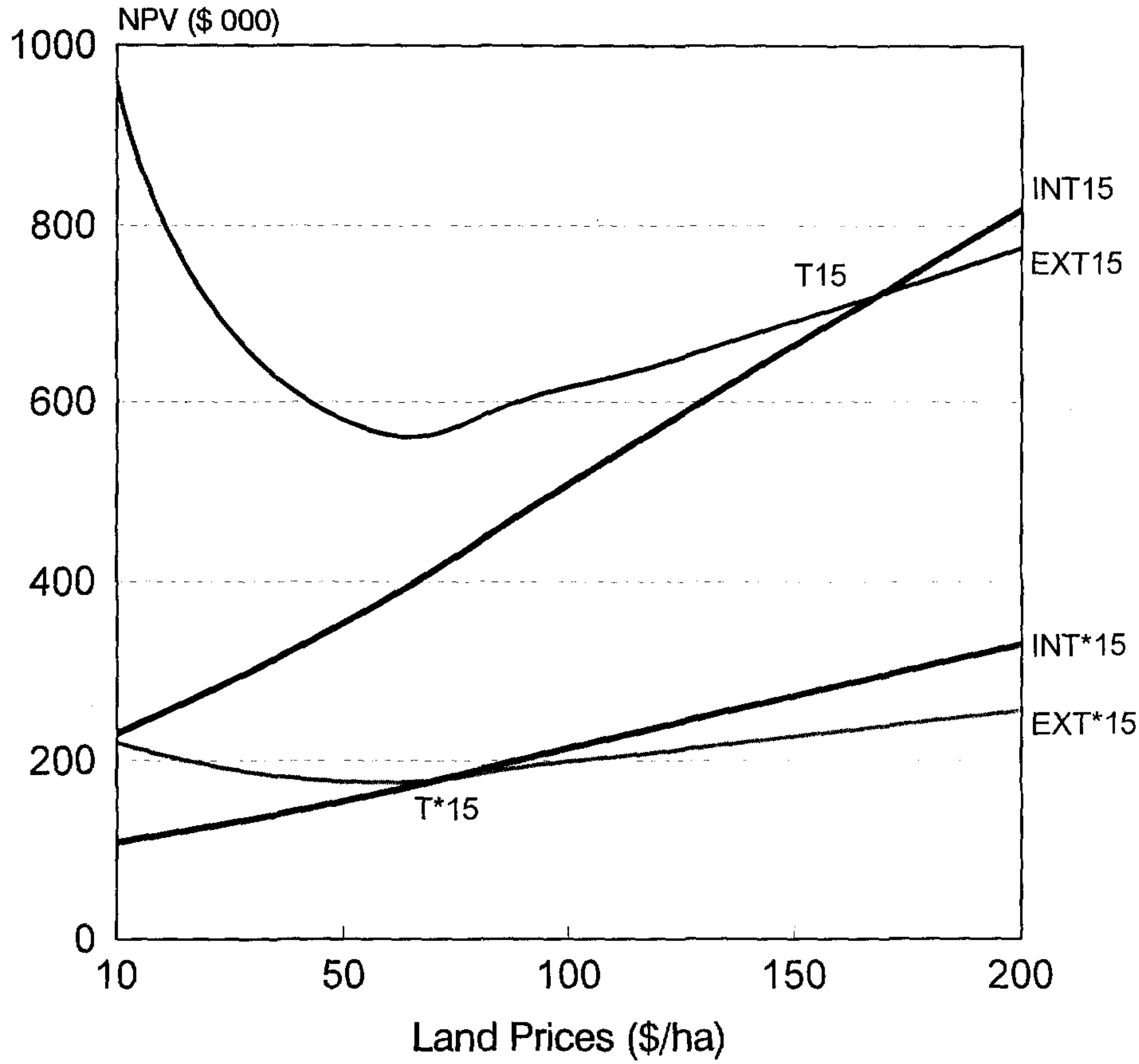
Farm size: 500 ha, Time horizon: 15 years,
INT=10% in improved pasture
EXT=0% in improved pasture,
Discount rate= 5%,
Live weight gain data form: Lascano and Euclides (1994),
Suffixes for INT and EXT refer to land price appreciation.

Figure 3. Effect of land price appreciation on intensification: Threshold land price: Simulation results, Colombian savanna.



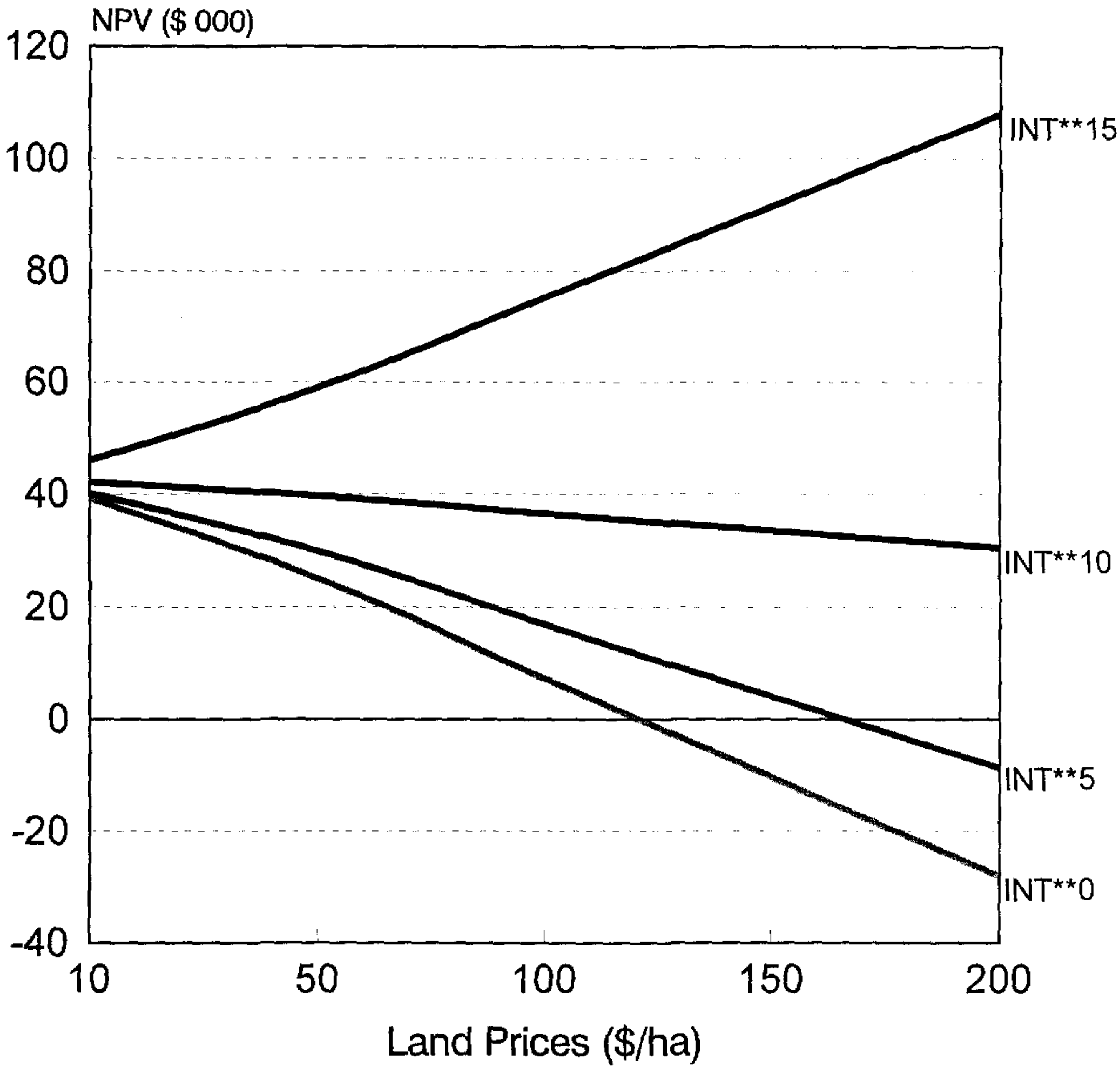
Farm size: 500 ha
Time horizon: 15 years
INT=50% in improved pasture
EXT=10% in improved pasture
Discount rate= 5%
Live weight gain data from Lascano and Euclides (1994)
Suffixes for INT and EXT refer to land price appreciation.

Figure 4. Effect of discount rate on intensification: Threshold land prices: Simulation results, Colombian savanna.



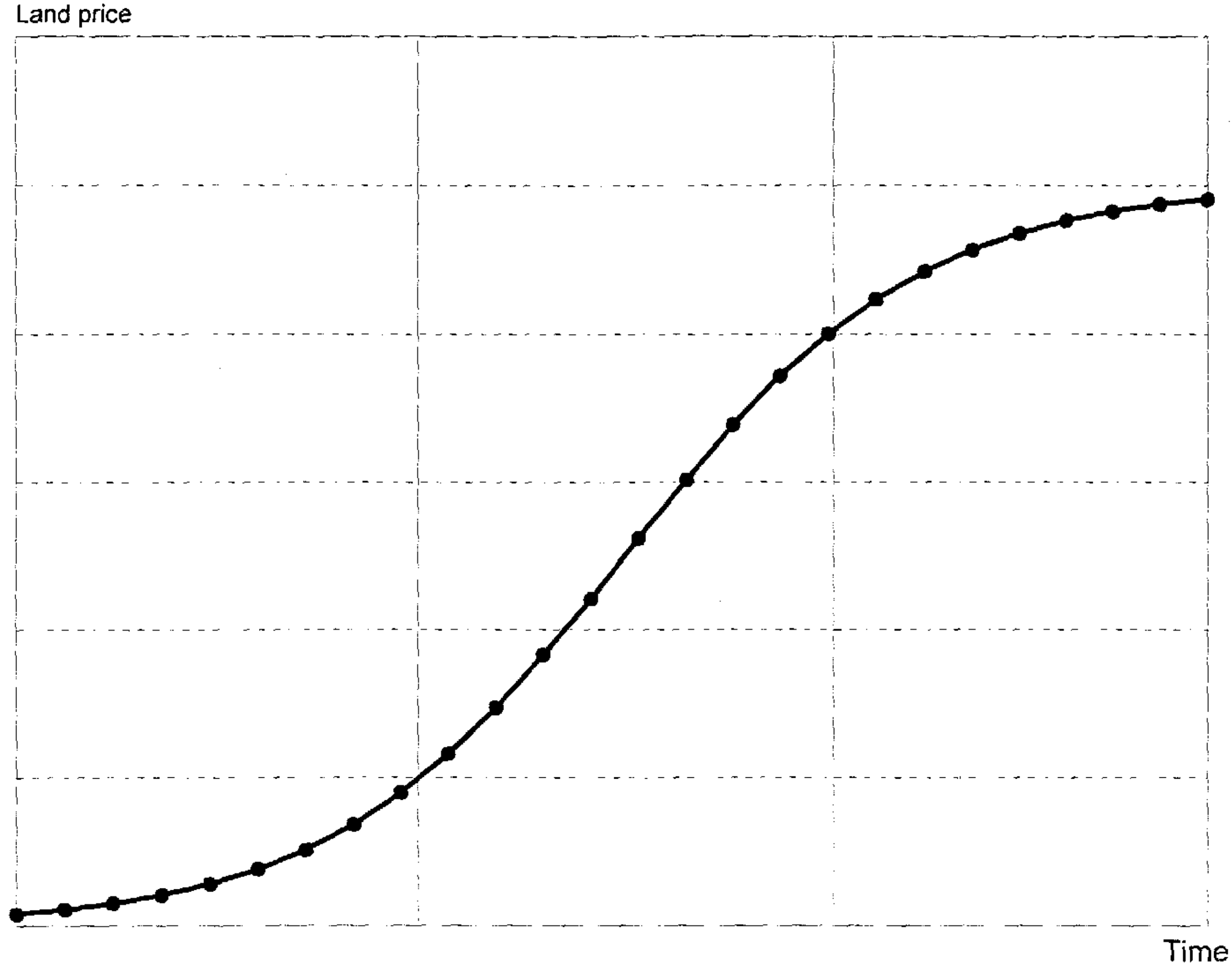
Farm size: 500 ha
Time horizon: 15 years
INT=50% in improved pasture
EXT=10% in improved pasture
Discount rate= 5% for INT15 and EXT15
Discount rate = 10% for INT*15 and EXT*15.
Land price appreciation = 15%p.a.
Live weight gain data from Lascano and Euclides (1994)

Figure 5. Effect of land price appreciation on viability of cattle ranching (discount rate=15%): Simulation results, Colombian savanna.



Farm size: 500 ha
Time horizon: 15 years
INT=50% in improved pasture.
Live weight gain data from Lascano and Euclides (1994)
Suffixes for INT and EXT refer to land price appreciation

Figure 6. Stages of Intensification in Frontier Cattle Ranching Areas in the Savanna.



Phase I

Extensive Ranching
Minimal resource degradation

Phase II
Slow increase in intensification:
gradual adoption of improved grass pastures.
Adoption of legumes unlikely.
Degradation of improved pasture, gallery forest.

Phase III
Rapid increase in intensification.
Legumes? Crops?
Ley-farming?
Native savanna, gallery forest threatened with extinction.