EVOLUTION OF THE CORN YIELD

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ABSTRACT - In some of Brazil there are two distinct periods for corn production. The first and largest corn crop is planted at the beginning of the rainy season, and a much smaller crop is planted after the first crop is harvested. This paper deals only with the first period, when corn has to compete for land with soybeans. As a consequence of this crop competition, the corn crop has to offer a return to capital at least equivalent to that of soybeans. Modern crop production has large fixed costs per hectare. The impact of fixed costs on total cost is reduced by increasing the yield. Pressed by fixed costs and international competition, the yield of Brazilian soybeans is close to that found in more advanced countries. Hence, corn production becomes feasible in areas where both crops can be cultivated, only if the corn yield is high. Therefore, it is expected that soybeans are the driving force behind the modernization of corn production. This paper provides several evidences that support this hypothesis, one of them being that it was not rejected by the econometric model contrived to test it.

Key words: Corn, soybeans, yield, econometric model.

INTRODUCTION

Corn provides a challenging field for research. The information available to Brazilian corn producers is close to that found in more

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advanced countries, but the technologies that farmers employ vary from primitive to sophisticated. In this heterogeneous group of growers, some farms use only labor and land as inputs, while others boost production using science, modern technology, and machinery, with strong links with all markets, including the financial and international markets.

Over the period under study, 1995-97, great dispersion was found in the levels of corn yield (kg/ha). The level was 800 in Brazil's Northeast, 3000 in the South, it reached 3900 in the state of Goiás; and 3500 in the Center-West. The Brazilian average was 2500, while that of the advanced countries is over 7000. When smaller aggregates are considered, such as the IBGE geographical micro-regions, several of them, mainly in the Northeast, are below the 1000 level. On the other hand, there are micro-regions with corn yields near those of the advanced countries, such as the irrigated corn crop from Barreiras, in the state of Bahia.

As all traditional crops, corn was spread throughout the country using a primitive production strategy that took advantage of the soil's natural fertility in newly accessible, recently deforested areas. Using this very low level of technology, it became an important Brazilian crop whose growers had very low productivity levels. Corn yields were congruous with the endowment, where land and labor were not scarce factors[2]. Hybrid corn was not introduced until the 1950s; machinery, equipment, and fertilizers didn't become became important until the 1970s.

The growth and diversification of domestic labor, inputs, and products markets, rapid urbanization induced by industrialization, and the increase of competition brought about by the recent trade policies dramatically changed the technological requirements of Brazilian agriculture to a pattern more based on science. This new, agricultural, production pattern tended toward intensive use of the land and minimum use of labor.

The change of a technological pattern demands time, even in the presence of vigorous international competition. Modern technology implies a much higher expenditure per hectare than traditional production techniques. Through use of different sharecropping systems, traditional

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[2] Human capital requirement was very low and its level in conformity with illiterate people.

farmers sought to share the risks of both market fluctuations and weather with labor; this also implies smaller expenditures per hectare.

With modern agriculture's higher costs per hectare, come the chance of considerable economic loss; therefore, modern agriculture avoids high-risk areas, be it market or climatic risks[3]. In Brazil, modern agriculture is associated with mechanization and, consequently, develops over flatter lands. It demands human capital and farmer ability to support economic losses without going into bankruptcy. In summary, it excludes regions and farmers. The farmers excluded by modern technology do not always quit farming. They can keep farming with low productivity levels and maintain a low standard of living. Hence, the transformation from traditional to modern agriculture need not extend to all farmers and regions. However, for the crop technologies that shift the production function upwards in its relevant domain, farmers will have to adopt the new technologies or change their crop mix[4].

In the case of crops that have been cultivated over a long period of time, it is natural that farmers with low levels of productivity live next to those with high yields. These low productivity levels bring down the national and regional averages if they represent a substantial share of the total production. Therefore, a significant change of national and regional yield averages may take a long time, as it depends on the replacement of the low-yield farmers by high-yield ones.

There are important forces at the macro level that are driving agriculture—in particular the corn crop—out of its traditional patterns. Among them are industrialization and the urbanization that comes with it, labor laws, more liberal trade policies, the larger and more diversified product and input markets, and the increase of public investments in science and technology. Together with these macro forces, the increase in cropland devoted to the soybean crop has had an important role in the improvement in corn productivity per hectare.

The soybean crop competes with the corn crop for the use of

[3] Irrigated technology is rarely used in corn and soybean. It does not reduce all climatic risk such as high temperatures, excess of rain, hail, and frost.
[4] If the production function is linearly homogeneous only one technology will prevail.

the same lands. Soybeans were recently introduced into Brazil; and soybean growers have adopted a modern, completely mechanized, production system, similar to the technological pattern found in the United States. Some Brazilian states are near to or have reached American productivity levels. Soybeans are planted on 12 million hectares in Brazil and yields reach 2300 kg/ha. American yields are about 2600 kg/ha, equivalent to the yield reached in the Brazilian state of Paraná and smaller than that in the state of Mato Grosso.

Crop rotation is desirable, both from the agronomic and the economic standpoints; this is especially true for soybeans and corn. It is possible to plant corn and soybeans in the same year on the same land. In this case, the corn planted in the second period becomes very important (Garcia, 1997). Since soybean producers prefer using modern technology, they also use it in corn production because of the high opportunity cost of their human and physical capital. They want to receive at least the same return from their corn crop as from their soybean crop.

In summary, since corn competes with soybean, on the country's best land corn producers must adopt production technologies in line with the machinery and equipment they have to bring an adequate return for the invested capital. This requires a much higher return than that required by the farmer using traditional farming techniques. Corn cultivation can compete with soybeans cultivation only if corn yields are equivalent to those found in the advanced countries. Otherwise, corn cultivation will be moved from fertile to marginal lands and traditional farming techniques will be the technology of choice.

The paper will sustain the thesis that soybean productivity explains corn productivity if the macro forces are taken into consideration. If perfect competition prevails, economic theory establishes that the rates of return of crops that compete for the same area must be equal. Since the soybean producer uses modern technology, he has a high fixed cost per hectare. Hence, high corn productivity per hectare is required when corn is cultivated, in order to obtain a rate of return equivalent to that of soybeans. Furthermore, soybean technology provides an example to corn producers, even if they do not cultivate soybeans. It is in this sense that soybeans explain the evolution of the corn crop, and, hence, economic logic points out that soybean yields can be used as a proxy for the modernization of the corn crop. If, for agronomic reasons, rotation is needed, the choice will fall on a crop that can offer a return near or higher than that of soybeans; if corn was chosen it is because it satisfied this condition. Therefore, there are good economic reasons to believe that the soybean crop is the force that drives up corn productivity per hectare.

Several authors present yield growth rates for Brazilian grains (e.g., Marques and Souza, 1998); however, no reference was found that explains the influence of soybeans on the modernization of corn crop production techniques. This paper is divided into the following sections: Growth Rates, Corn Imports, Econometric Model, Spatial Distribution of Productivity, and Policy Implications.

GROWTH RATES

The first step we employed to explain the influence of the soybean crop on corn production was to build a series of three-year moving averages for the period from 1975 to 1997. The derived series covered corn production, area under cultivation, and yield at the state level. In the second step, we obtained corn production growth rates. Starting with the equations $P_n = P_0(1+p)^n$, $A_n = A_0(1+a)^n$, and $R_n = R_0(1+r)^n$ where P_t, A_t, and R_t respectively represent production, area, and yield in year *t*, the geometric growth rates were calculated for each separate period. In each case, only the values for the initial year (*0*) and the terminal year (*n*) were used, as pointed out by the equations. Considering the identity $P_t = A_t R_t$, which is true for any year t, after canceling out the relation $P_0(1+p)^n = A_0(1+a)^n R_0(1+r)^n$, the formula $p = a + r + ar$ is obtained. Table 1 shows the calculated values for *p*, *a*, and *r*. The value of *ar*, which is very small in absolute terms when compared to *a* and *r*, can be obtained by difference and was not include in the Table.

The values found in Table 1 support the following conclusion: the production increases are basically explained by yield growth. This is less noticeable over the first ten years and dramatically evident over the last ten years. Up until the 1950s, the growth in area under corn cultivation was able to explain most, if not all, of the corn production increase. Since then this has changed, and increasing yield per hectare has became the dominant reason for production increases.

In the Northeast, the growth of area under cultivation is the same for the two sub-periods. But, in recent years, corn cultivation has been moving toward lands which are more suited for the use of modern technology; consequently, the increase in yield explains most of the production increment.

In the Center-West, area and yield grow at the same pace and at high rates. It is the region where corn production has had the largest increase and where the adoption of modern technology is the most prominent engine of growth.

Over last ten years, the Southeast has not been able to achieve the corn yield growth found in Brazil's other regions. A more detailed analysis of the data showed that, among the four states of that region, Minas Gerais was responsible for the poor performance in the Southeast. In Minas Gerais, yield increased 3.6% in the first period and 2.4% in the second. In the state of São Paulo, the two periods were very similar with respect to yield growth; and soybeans and corn have yielded to sugar-cane and citrus fruits in the fight for the best lands.

In the South, cultivated area did not explain the change in corn production over the last period. In this respect, the South and the Southeast are very similar. But notice, yield became the dominant force impelling the South's production growth in the last period.

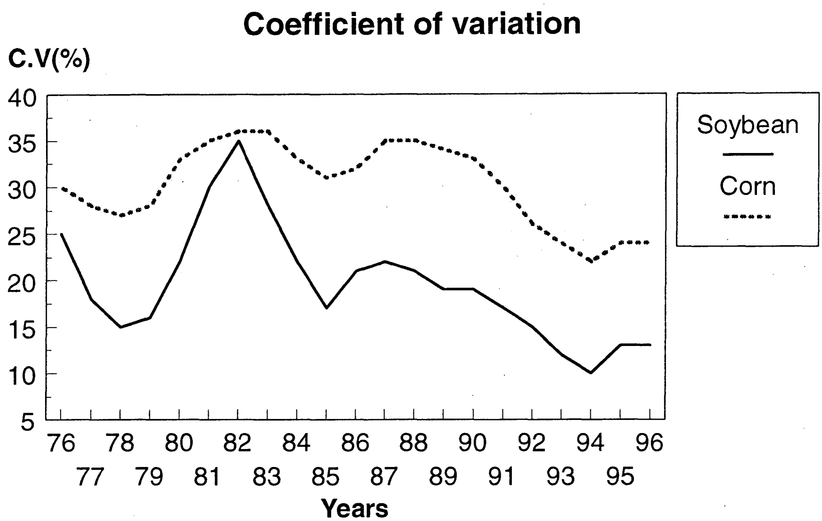
Table 1 - Annual geometric rates of growth in the period 1976-1996

Geographical entity / period		Production	Area	Yield
Brazil	Period: 1976-1996	3.36	0.98	2.36
	First ten years	2.66	1.13	1.51
	Last ten years	4.06	0.84	3.21
Northeast	Period: 1976-1996	3.02	1.32	1.72
	First ten years	-0.50	1.32	-1.70
	Last ten years	6.65	1.33	5.25
Southeast	Period: 1976-1996	2.14	-0.64	2.81
	First ten years	2.70	-0.37	3.08
	Last ten years	1.59	-0.91	2.52
Center-West	Period: 1976-1996	7.06	3.54	3.40
	First ten years	6.98	3.74	3.13
	Last ten years	7.14	3.34	3.68
South	Period: 1976-1996	2.78	0.58	2.18
	First ten years	1.87	1.03	0.83
	Last ten years	3.69	0.13	3.56

Source: MA/SPA/DEPLAN.

The annual coefficient of yield variation (in %) was calculated for soybeans and corn from 1976 on. The data came from eight Brazilian states that produced both crops during the period from 1976 to 1996: Bahia, Mato Grosso, Goiás, Minas Gerais, São Paulo, Paraná, Santa Catarina, and Rio Grande do Sul. For the newly introduced soybean crop, cultivated by commercial farmers pressed by international competition and eager for new agricultural information, showed a convergence of yield values. The differences in soybean yield between the states are much less influenced by technology than is the case of a traditional crop. In other words, the differences in yields are quickly eliminated, as far as possible, with the passage of time. In a traditional crop, such as corn, the convergence of yields is much slower. It depends on the modern producers becoming responsible for the major share of production, and this may take a long period. This phenomenon is illustrated by Graph 1.

Graph 1 – Coefficient of variation of the yields of corn and soybeans



The soybean coefficient of variation increased until 1982 when the soybean crop occupied a great part of the area in which it is cultivated today. From 1982 onwards, the coefficient of variation started to decrease. It may have now reached a level that corresponds to state peculiarities that cannot be altered through the diffusion of technology. The corn story is quite different; it reflects a production mosaic of different technologies and environments, favoring both high and low yields. There has not been enough time for corn to move onto the favorable lands and leave the unfit ones. Consequently, the variation coefficients of corn are larger than those of soybean; the coefficients have stayed stable for many years and started to decrease only in the 1990s.

We carried out another exercise with the purpose of estimating the production growth rate by yield class. The micro-regions were classified by yield classes, and the productivity per hectare for each class was obtained for the period from 1976 to 1994. The data cover all geographical micro-regions for all the years in the series, with the exception of the four micro-regions which did not produce any corn in the years

1993, '94, and '95. The original series covered the period 1975-1995. This series was transformed into another one using a three-year moving average transformation, covering the period 1976 - 1994. The year 1994 of the transformed series was used to define the yield classes. The growth rates were estimated for each yield class using the transformed series and fitting exponential functions. Table 2 contains the growth rates in the last column. In the first column, (a,b] the lower bound (**a**) does not belong to the class and the upper bound (**b**) does. The table's other columns are self-explanatory.

The first class's average yield is very low, 963 kg/ha. This yield characterizes traditional agriculture on poor lands. The yield growth rate is very low, 0.93. This class is found in 56% of the geographical micro-regions, accounts for 29% of the harvested area, and only 11% of total production. The Brazilian yield average is not in this class. If this class is excluded, the average yield of the micro-regions changes from 2497 to 3127 kg/ha.

Table 2 – Number of geographical micro-regions, mean values of corn production, harvested area, and yield in the period 1993-1995, and geometric growth rate of yield in the period 1976-1994, by yield class and for the country

Yield class	Geographical microregions		Production (1000 ton)		Harvested area (1000 ha)		Average Yield	Growth rate
(kg/ha)	No.	%	Amount	%	Amount	%	(kg/ha)	(%)
(0, 2000]	310	55.96	3696	11.22	3837	29.09	963	0.93
(2000, 3000]	156	28.16	11173	33.92	4343	32.93	2573	2.00
(3000, 3500]	51	9.21	8973	27.24	2713	20.57	3308	2.37
(3500, 4000]	26	4.69	6010	18.25	1617	12.26	3717	3.47
(4000, 4500]	7	1.26	2139	6.49	496	3.76	4312	4.43
> 4500	4	0.72	945	2.87	183	1.39	5164	7.09
Total	554	100.00	32937	100.00	13188	100.00	2497	2.51

Source: IBGE and AGROTEC (Garagorry & Rego, 1997).

The (2000,3000] class contains the national average. It is found in a large number of micro-regions, about 28%. Its shares of total area and production are 33% and 34% respectively. Its yield grows at a yearly rate of 2%, much higher than the rate of the first class. The average yield of all the remaining classes is above 3000 kg/ha. Their share in total output is 55% and they cover 38% of the harvested area. Of the 554 micro-regions, 88 are in this group. Each one of these classes has a high growth rate and, hence, their share in total production will increase more rapidly than that of the low yield classes.

The growth dynamic shows a very interesting feature: the growth rates substantially increases when moving to an upper yield class. This unbalanced growth indicates a concentration of the more sophisticated systems of production in a few areas of the Brazilian territory. The impact of these areas on the national average will become more noticeable than it is today, as they account for a larger share of total production. As already pointed out, the more liberal trade policies and the competition with soybeans and other dynamic crops in environmentally favorable areas are strong forces driving the corn yield up. The low yield corn crops, significantly the corn crops of most Northeast micro-regions, will be driven out of the favorable growing regions and into the climatic high-risk zones, loosing importance in the national production total. Corn grown in the high-yield regions will support the demand of all other regions and the international market. Corn production will be located in a few corn belt; however, each one of them will be much smaller than the American corn belt.

CORN IMPORTS

This paper will not analyze the external corn market in detail, though a few words are in order. In the period from 1985-1997, corn was always imported. From year to year, the data point out a huge variation in imports, both in absolute terms and in relation to domestic production. The largest amount of corn was imported in 1985/86, 2.4 million tons, and the smallest amount was15 thousand tons in 1987/88. The series does not show any definite pattern relating imports to domestic production. The same is true for the series in quantity. The average import of corn in the period was 800 thousand tons and the variation coefficient reached 80%.

There is a very large and dynamic international market for corn in Brazil. The country is a large exporter of processed poultry and swine and needs competitively priced corn in order to maintain or increase both meat products' export shares. As trade policies become more liberal this international market will dictate internal corn prices, and Brazilian producers will face stronger competition in both internal and external markets. Brazilian corn producers will first have to win in the internal market if they want to become large corn exporters Pressed by the poultry and swine agroindustries, which have a strong political base, the government will not protect the national corn producers by erecting corn import barriers. The external corn market, as does soybean farming, acts to strongly influence corn yield.

ECONOMETRIC MODEL

It was argued that for producers to produce corn in areas that can be cultivated with both crops, corn must offer a return to investment at least equivalent to soybean's. In this section, two groups of farmers will be considered: those that cultivate soybeans and corn, and those that only cultivate corn. In general, the second group does not mechanically harvest and other crop operations may not be mechanized[5].

The group of producers that cultivate soybeans and corn has a high fixed cost per hectare. Consequently, it is pressed to increase the yield of both crops. Since Brazilian soybean producers attain yields similar to those found in advanced countries; corn yield should converge toward that yield level. Soybean production therefore facilitates the modernization of corn production. By this logic, corn yield is a function of soybean yield for this group of farmers.

There is the other group of farmers that cultivate corn but not soybeans on lands which are fit for both crops. They face restrictions on human capital and credit necessary to adopt modern technology. In this

[5]The two groups are in areas that fit to both soybean and corn.

case, there is a lag in the influence of soybean production on corn crop productivity. Hence, the effect of soybean production on corn yields takes more time to occur. Since the opportunity cost of land, labor, and capital grows with the development of soybean and other crops, the traditional farmers are pressed to change. But their transformation into modern farmers may take time.

In order to capture the effects of opportunity cost, international competition, technology, relative price change, and general Brazilian economic development time variable T is added. Its value is 1 for the first year of the series, 2 for the second, and so on.

It is clear that yields are influenced by the amount and distribution of rain and other climatic factors. To smooth the effects of these factors, the original series were transformed. The model is estimated with data from a three-year moving average of the original series for corn and soybean yields, covering the 1975-1997 period. Hence, they cover the period from 1976-96, 21 years. The original data are for the following eight states: Bahia (the Northeast), Minas Gerais and São Paulo (the Southeast), Mato Grosso and Goiás (the Center-West), and finally Rio Grande do Sul, Santa Catarina and Paraná (the South).

According to the description of the background conditions, the statistical model combines the time series and the states. It is represented by the equation

$$y_{it} = \sum_{k=1}^{24} X_{itk} \beta_k + u_{it}$$

where i=8 (number of states), t=1,2,...,21(size of the time series).The covariables X_{itk}, considered as explanatory of the Corn response (yield of corn, y_{it}), are Soybean (yield of soybean), time T, the indicative variables D2, D3, D4, D5, D6, D7 and D8 that correspond to the states of São Paulo, Minas Gerais, Paraná, Santa Catarina, Rio Grande do Sul, Mato Grosso and Goiás, respectively, the interactions F2, F3, F4, F5, F6, F7 and F8 of the variables Di with Soybean, the interactions H2, H3, H4, H5, H6, H7 and H8 of the variables Di with time, T, and the intercept. The model assumes one coefficient of time for each state, distinct linear coefficients for each state, and distinct responses by state to the soybean crop yield. The state of Bahia is the basis, and its response is given in the model by the intercept and by the variables time T and Soybean. The response of any other state is obtained by adding the coefficients for Bahia to the values of Di, Fi and Hi for that state. The residual structure assumes contemporaneous correlations (between states) and serial correlation. Specifically, it is assumed that

$$u_{it} = \rho_i u_{i,t-1} + \varepsilon_{it}$$

where the residuals u_{it} are heteroskedastic, for each i=1,...,8, with variance σ_{ii} for all t, and are contemporaneously correlated with covariance σ_{ij} for each t. The noises, ε_{it}, are uncorrelated for each i and satisfy $E(\varepsilon_{it})=0$, $E(u_{i,t-1}\varepsilon_{jt})=0$ and $E(\varepsilon_{it}\varepsilon_{jt'})=\phi_{ij}$. Additionally, it is assumed that $E(u_{i0})=0$ and $E(u_{i0}\, u_{j0})=0$. This structure was originally proposed by Parks (1967). It is important to stress that some assumptions adopted by the econometric model are different from those which are standard in SUR ("Seemingly Unrelated Regression"). This paper models the situation with a structure that requires the specification of a time series in combination with a cross-section. The adequate estimation method for this formulation uses generalized least squares. The differences between these two methods are discussed by Greene (1997). Generalized least squares is used after obtaining consistent estimates of the s_{ii} parameters. These are obtained through a two-step procedure, with the use of ordinary least squares and the necessary transformation to correct first-order autocorrelation. More details on the procedure can be found in SAS (1993, p. 882-884). The TSCSREG procedure, with the Parks option, of SAS (Statistical Analysis System) was used to obtain the estimates. The results are in Table 3.

Table 3 – Estimates of the statistical model's parameters

Variable	GL	Parameter (*)	Deviation (*)	t	Prob > t
Intercept	1	63.97	153.07	0.417921	0.6766
Soybean	1	0.38	0.07	5.307380	0.0001
T	1	23.28	10.88	2.138480	0.0342
H2	1	4.20	12.62	0.332759	0.7398
H3	1	14.62	10.41	1.403897	0.1625
H4	1	14.60	9.94	1.468346	0.1442
H5	1	-35.70	12.30	-2.902257	0.0043
H6	1	17.26	11.40	1.514028	0.1322
H8	1	54.54	15.37	3.548475	0.0005
H9	1	49.38	11.65	4.236757	0.0001
F2	1	0.46	0.12	3.756540	0.0002
F3	1	0.13	0.12	1.074004	0.2846
F4	1	0.49	0.11	4.537459	0.0001
F5	1	0.91	0.12	7.337008	0.0001
F6	1	0.80	0.10	7.760670	0.0001
F8	1	-0.53	0.21	-2.519325	0.0128
F9	1	0.52	0.18	2.972086	0.0035
D2	1	552.37	231.91	2.381803	0.0185
D3	1	645.88	167.78	3.849464	0.0002
D4	1	156.17	201.18	0.776267	0.4389
D5	1	690.76	184.75	3.738902	0.0003
D6	1	-320.90	188.41	-1.703205	0.0907
D8	1	1440.37	316.30	4.553841	0.0001
D9	1	186.04	252.57	0.736596	0.4626

Source: MA/SPA/DEPLAN. (*) Values were rounded to two decimals.

The correlation coefficient between observed and predicted values is 0.9854, which indicates that the model is attuned to reality and that the indicator variables and their interactions with Soybean and time T are statistically significant. It is interesting to note that even a model without time and the corresponding interactions demonstrates good forecasting power, with a 0.946 correlation between observed and predicted values. This finding shows the importance of soybean yield in the statistical model. Table 3 stresses this point, as it indicates the dominant effect of the Soybean variable. The soybean effect varies from state to state and is stronger in Rio Grande do Sul and Santa Catarina. Mato Grosso is the only state where the effect of soybean is not statistically different from zero. Nonetheless, in 1994, a rank correlation of 63% between yields of soybeans and corn was found at the micro-regional level; this is statistically significant at the 3% level. This result suggests an evolution in which Mato Grosso's soybean crop will become an important variable affecting the state's corn yield.[6]

SPATIAL DISTRIBUTION OF PRODUCTIVITY

Two maps, made up of the Brazilian South, Southeast, and Center-West regions, and the state of Bahia, were prepared; they are shown at the end of the paper. Map 1 shows the distribution of corn productivity by yield class. The same criterion was followed for soybeans in Map 2. The area covered by the maps accounts for more than 90% of the output of the two crops. Both maps are based on the three-year average for the period 1993-95, for each IBGE micro-region. The GMAP procedure of SAS was used to produce the maps. A visual comparison of the two maps provides additional evidence for the strong association between soybean and corn yields, and suggests the following comments:

1. Areas without soybeans or with a low soybean yield correspond to areas of low corn yields. They are shown in black.
2. Areas with high productivity of corn are inside of, or near to, areas of high soybean yield. These areas are shown in white.
3. It is important to note that the four micro-regions in Table 2, with corn yield above 4500 kg/ha, are Barreiras (BA), with 5226 kg/ha, Ponta Grossa (PR), with 5234 kg/ha, Cassilândia (MS), with 5066 kg/ha, and Não-me-toque (RS), with 4971 kg/ha. They deserve the attention of research to determine which factors explain these regions superior performance: producers factors or environmental factors. One needs ask, can these regions become engines of growth? are they suitable for the dissemination of modern technology?

[6] In the paper, yield and productivity are used as synonymous.

POLICY IMPLICATIONS

This paper shows that in regions where soybeans are cultivated with success, corn yields grow at higher rates and corn production facilities are more intensively modernized. It was found that the country's corn belts are tending to concentrate and that corn production outside these areas of concentration, especially in most of the northeastern micro-regions, does not show any sign of modernization. This may be due to the regional environment's unsuitability for the application of modern agricultural inputs.

The many biological programs supporting corn production need to take into account the heterogeneous nature of the corn belts, both from the physical and economic point of view. Public and private sectors are aware of the diversity and are responding with high-yield materials, such as simple and triple hybrid corn, both of which are more specific to the local conditions than is the double hybrid. Hence, there is a great potential for the small-size firm collaborating with public research institutions and for the large firms exploring methodology adapted to different growth environments.

Brazil's Northeast is the great importer of Argentine corn. In the Northeast's irrigated cropland, corn cannot compete with fruits and vegetables. Corn production should move into the micro-climatic zones that favor both corn and soybeans, as in Barreiras. The states of Maranhão and Piauí offer good productive conditions; unfortunately, the road and communications infrastructure in Piauí is in disarray and needs to be improved. The state of Tocantins is another good alternative. These regions can become large corn exporters as their shipping costs to Europe and Asia are lower than those of the other regions, due to the efficient functioning of the port in São Luís and the North-South railroad. Private firms and public researchers must develop hybrid corn varieties for these regions; for to neglect their potential is to ignore the European and Asian corn markets' potential. In this area, soybean genetic research technologies are opening the doors for corn researchers.

A few questions deserve some consideration. What can be done to assist farmers cultivating in the regions best suited for modern corn production who are unable to adopt advanced technology because of financial and human capital constraints? They cannot survive without this technology; intermediary technology is insufficient. We recommend an economic policy that will remove the obstacles to modern technology from these farmers paths: credit restriction and credit discrimination, restricted access to machinery and equipment, and a deficient extension service. The growing evidence of positive return from increasing grain production cannot be neglected. This imposes another set of limitations on small producers, unless they are able to associate.

What is to be done in environmentally unfavorable regions? What are the probabilities that research will be able to develop corn hybrids and open pollinated varieties that can overcome environmental restrictions and give yields that can compete with those of good land ? Or, should public research invest money on this type of genetic material? Another question needs to be answered: do the migration trends indicate that the regions unfavorable to corn cultivation are loosing rural population at a high rate? If the answer is affirmative, then why invest money on this type of research? If not, which is doubtful, the cost of the science and probability of success must be investigated. Why not explore crop alternatives, such as sorghum and millet?

Research is being undertaken by EMBRAPA which may lead to the production of genetic corn materials adapted to multiple stresses, with an ability to quickly respond to environment improvements. The best examples of these new genetic materials are the "cerrados" hybrids. Genetic materials with extreme adaptive power have exhibited some problems. Those already developed are also resistant to yield increases. It cannot be forgotten that even a plant with great genetic plasticity, like corn, has adaptation limits.

The corn belts are heterogeneous with respect to yield growth rates; it is important to know the reason for this. If the rationale for this heterogeneity is linked with stable factors whose effects prevail in the short and long run, they deserve special attention from both researchers and economic policy makers seeking to improve production. Geoprocessing techniques can be used to discover the special conditions that promote yield increases; why does production and yield increase more rapidly in some regions rather than others?

REFERENCES

GARAGORRY, F.L.; REGO, A.M. **AGROTEC**: base relacional de dados estatísticos. Estrutura de dados. Versão 1.0. Brasília: EMBRAPA, 1997. 20p. Mimeo.

GARCIA, J.C. Evolução da área e produtividade do milho "safrinha" por estado. In: IAC/CDV. **IV seminário sobre a cultura do milho safrinha**. Campinas: 1997. p.11-14.

GREENE, W.H. **Econometric Analysis**. 3 ed. New York: Prentice-Hall, 1997.

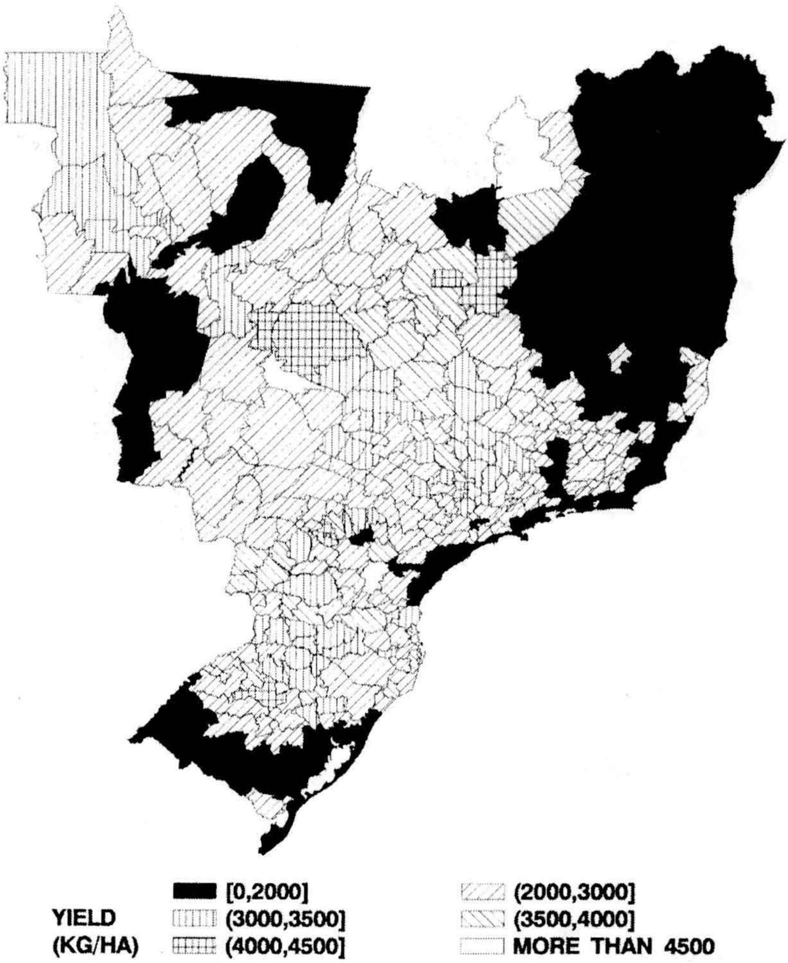
MARQUES, P.V.; SOUZA, E.L.L. de. Cenários dos sistemas agroindustriais de grãos no Brasil e novas formas de comercialização. In: AGUIAR, D.R.D.; PINHO, J.B. (Eds.). **Agronegócio brasileiro**: desafios e perspectivas. Brasília: SOBER, 1998. V.I, p.209-222.

PARKS, R.W. Efficient Estimation of a System of Regression Equations when Disturbances are both Serially and Contemporaneously Correlated. **Journal of the American Statistical Association**, Alexandria, v.62, p. 500-509, 1967.

SAS Institute. **SAS/GRAPH Software**: Usage. Version 6. Cary, NC: 1991.

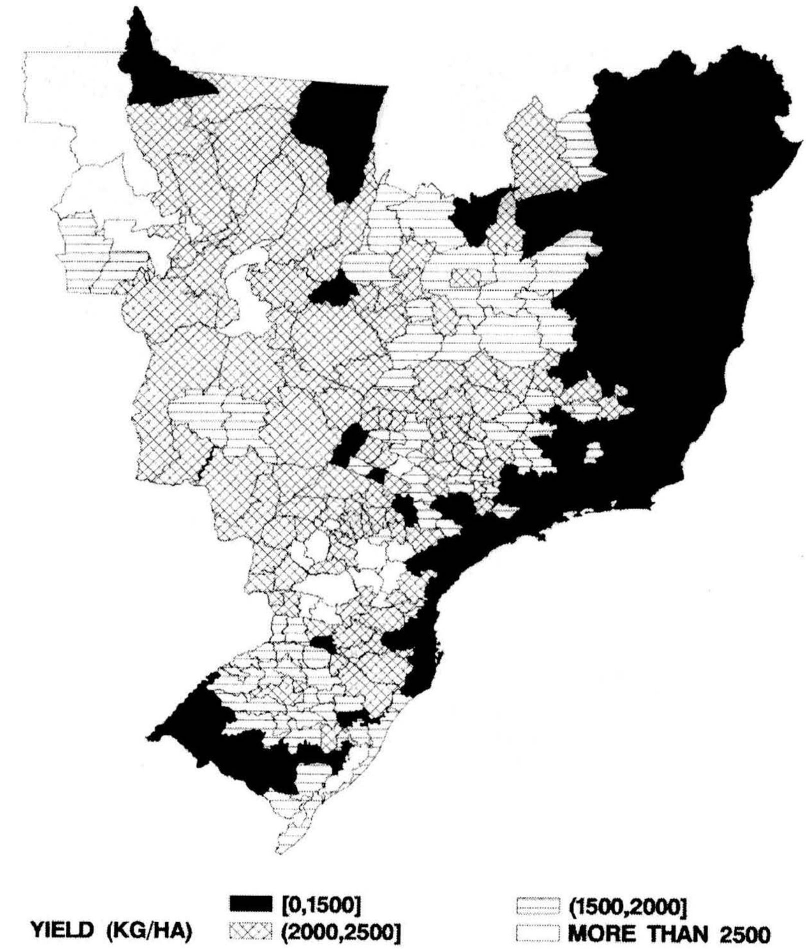
SAS Institute. **SAS/ETS User's Guide**. Version 6. Cary, NC: 1993.

MAP 1 – YIELD OF CORN MEAN IN THE PERIOD 1993–95



SOURCE: DATA FROM IBGE IN THE AGROTEC DATABASE, SEA/EMBRAPA.

MAP 2 – YIELD OF SOYBEAN
MEAN IN THE PERIOD 1993–95



SOURCE: DATA FROM IBGE IN THE AGROTEC DATABASE, SEA/EMBRAPA.