Chapter 5

Use of Technology to Increase the Productivity of Corn in Brazil

Wilian Henrique Diniz Buso and
Luciana Borges e Silva

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Abstract

Brazil is one of the world's principal producers of corn, and over the past few decades, a range of new technologies have been incorporated to guarantee advances in the productivity of this crop. Initially, genetic enhancement was achieved through the production of hybrid seed that was more productive than freely pollinated cultivars. Subsequent adjustments to cultivation practices, such as the reduction in row spacing, balanced fertilisation and direct planting, have contributed to a progressive increase in productivity. The authorisation of the marketing of transgenic seed, providing resistance to insect pests and herbicides, contributed further to productivity by reducing losses to pests (*Spodoptera frugiperda*) and competition with weeds. Together, all these technological advances have contributed to ever increasing gains in the productivity of Brazilian corn crops.

Keywords: biotechnology, management, research, *Zea mays*

1. Introduction

Brazil covers a total area of 8,511,996 km^2, divided into five geographic regions characterised by major climatic and economic differences [1]. The equatorial northern region has a rainy climate, and is covered by the world's largest area of pristine tropical rainforest, while the Northeast is mostly semi-arid with some irrigated areas. The Midwest, Southeast and South are the principal grain-producing regions.

Corn (*Zea mays*) is the grain cultivated in the largest volume worldwide, with the United States, China and Brazil being the principal producers. In Brazil, 15,922.5 million hectares were planted with corn in the 2015–2016 season, with a mean productivity of 4178 kg ha^{-1}, rising to 16,772 million hectares in 2016–2017, with an expected mean productivity of 5305 kg ha^{-1}, with a total harvest of 88,969.40 million tons [2].

The technological advances in the production of corn in Brazil involved the correction of the soil (acidity, neutralisation of aluminium and increase in base saturation). Over the subsequent years, direct planting was adopted as a strategy for the protection of the soil, using corn stover as a way of increasing the amount of organic matter in the soil. Subsequent research tested the reduction of the spacing of the rows from 0.90 to 0.45–0.50 m to optimise the performance of seeding machines and improve the density of plantations, leading to an improvement in the absorption of soil nutrients by the roots of the plants.

The reduction in spacing also contributed to an improvement in the control of weeds, through the more rapid formation of ground cover and shading of the soil, in addition to an increase in the efficiency of fertilisers. Subsequently, the introduction of genetically modified organisms for the control of the fall armyworm (*Spodoptera frugiperda*), the principal insect pest of corn plantations, also resulted in gains in productivity.

Recent advances in biotechnology have included the incorporation of a number of proteins derived from the bacterium *Bacillus thuringiensis* to control of a range of insect pests (*Elasmopalpus lignosellus*, *Agrotis ipsilon*, *S. frugiperda*, *Diatraeia saccharalis* and *Helicoverpa zea*), reducing damage to the plants, and improving productivity. The subsequent introduction of hybrids resistant to insects and herbicides (glyphosate and ammonium glufosinate) has further reduced the costs of the control of insect pests and weeds. The combination of these technologies has brought significant gains in the productivity of corn, both in Brazil, and the rest of the world.

2. Technologies adopted to increase productivity

2.1. Brazilian research in corn production

In Brazil, the corn seed industry involves a number of national and multinational corporations, as well as public entities that are all working to develop new cultivars and technologies [3]. In recent years, these enterprises have marketed cultivars that target specific productive sectors, which rely on high, medium and low levels of technology. The former two sectors use hybrids, while the low technology sector still relies on many freely pollinated varieties.

Araújo et al. [4] investigated the collaborative public networks of corn research in Brazil between 2006 and 2010, and found close ties between the institutions involved in the enhancement of cultivars and those working on the development of technology for the improvement of productivity (**Figure 1**). Research efforts are concentrated in Southeast Brazil, where the Brazilian Public Agricultural Research Corporation (EMBRAPA) and São Paulo State University (UNESP) have close links with a number of other research institutions, developing collaborative research projects for the divulgation of new technologies for corn production.

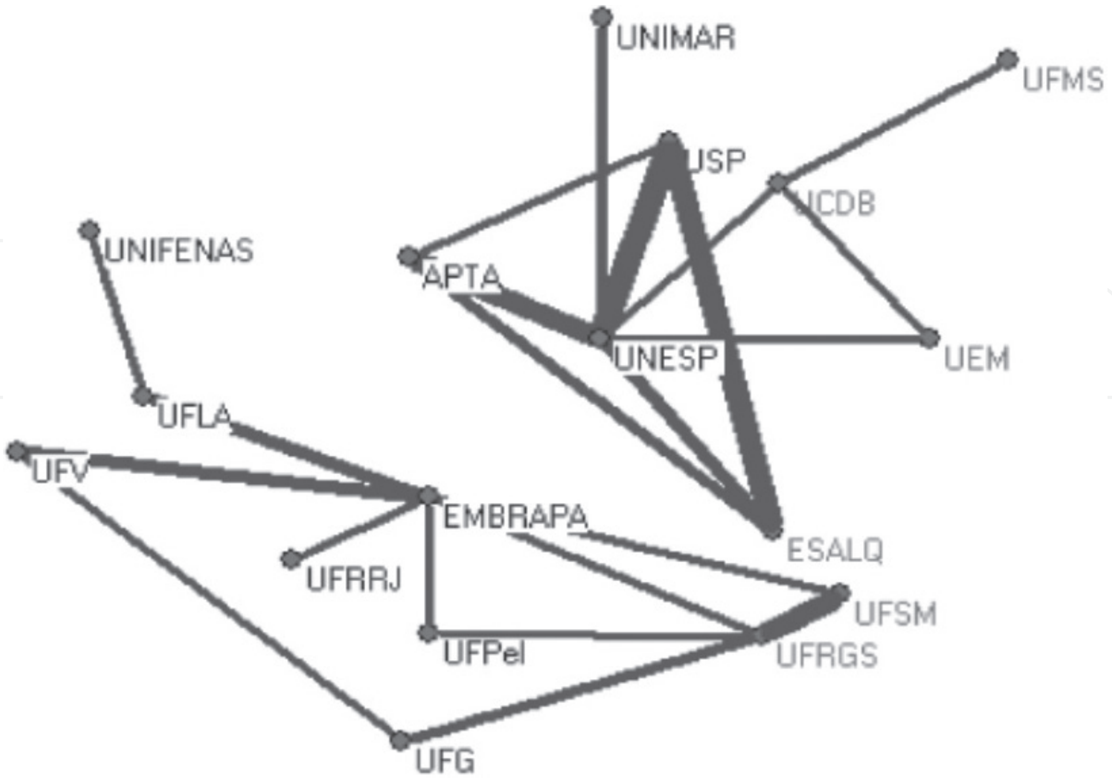

Figure 1. Nucleus of the collaborative public corn research network in Brazil (2006–2010). Source: Araújo et al. [4].

Galvão et al. [5] evaluated the advances in the production of corn in Brazil since the 1940s and found that technology has contributed to an increase in productivity of 379% over the past 70 years. Research institutions have contributed to this increase in productivity through the development of research, cultivars and technologies, the training of specialised personnel, and the communication of information to farmers. This technological development has resulted in Brazil reaching third place in the world ranking of corn producers and exporters, with total production increasing from 5.6 million tons in 1944 to more than 89 million tons in 2017.

2.2. Use of biotechnology

The Brazilian National Technical Commission for Biosecurity (NTCBIO) was created by federal decree number 1520/95. This organ is responsible for the development of legal norms on the biosecurity of genetically modified organisms (GMOs) and the classification of their potential risks. The commission was initially responsible for the authorisation of experiments on transgenic plants in Brazil. The cultivation of genetically modified plants in Brazil began in the 1990s with the illegal introduction of the Roundup Read (RR) soybean, which is resistant to the herbicide glyphosate, in the state of Rio Grande do Sul.

In the specific case of transgenic corn, the importation of seed from Argentina was first authorised in 2005, in an attempt to overcome the poor harvest of this year. Eventually, in May 2007, the NTCBIO authorised the sale of transgenic corn in Brazil. Currently, most areas planted with corn in Brazil involve some transgenic variety, and the vast majority of hybrids are now resistant to insects (lepidopterans) and herbicides (glyphosate and ammonium glufosinate). In 2007, the NTCBIO authorised the planting of *Bt* corn, which contains the protein cry1fAb for the control of *S. frugiperda* and *Diatraeia saccharalles*, and in 2008, it permitted the sale of RR corn seed, which is resistant to glyphosate-based herbicides, as an alternative for the management of weeds, due to the ample spectrum of control of these plants.

In the most recent Brazilian harvest (2016–2017), transgenic corn, resistant to insects and/or herbicides, should account for 82% of the summer crop and 92% of the second planting, with transgenic hybrids thus being planted in more than 88% of the total area cultivated.

2.3. Use of hybrids to increase productivity

Tollenaar and Lee [6] concluded that the productivity of corn is dependent on the specific genetic characteristics of the hybrid planted, favourable environmental conditions and the adoption of adequate farming technology. The potential for the production of grain will be influenced by the interaction between the hybrid and the cultivation conditions, with the same hybrid responding differently to distinct conditions, depending on the ambient temperatures, the incidence of sunlight and the availability of water.

Each year, a number of new hybrids are marketed, following extensive testing in the principal corn-producing regions of the country to determine the conditions to which the hybrid is best adapted. In a study of 22 hybrids at 14 different sites, Cardoso et al. [7] observed varying responses, with some cultivars being well-adapted to a wide range of conditions, in which they maintain their productivity, whereas others are better adapted to certain specific conditions.

In a study of 10 hybrids during 3 different planting periods (18/11/2011, 31/01/2012 and 20/02/2012), Buso and Arnhold [8] recorded variation in the performance of the cultivars under different seasonal conditions. In this analysis (**Figure 2**), the hybrid AGN 30A77H performed better than all the other hybrids in the first two periods (18/11/2011 and 31/01/2012), whereas the third period (20/02/2012) was found to be unfavourable due to water stress.

Sousa et al. [9] evaluated 36 corn hybrids cultivated under water stress and found that the performance of these cultivars varied according to the humidity of the soil, with some hybrids performing much better than others under these extreme conditions. The testing of these hybrids contributed to the identification of the cultivars best adapted to the second planting in Brazil, principally under conditions of water stress, in the different Brazilian regions. The interim harvest is planted between January and March. Silva et al. [10] noted that, due to the precocity of the hybrids, the interim crop is favoured by the fact that the flowering period coincides with the rainy season, when more groundwater is available, contributing to productivity.

2.4. Changes in production management

In addition to genetic enhancement and the use of biotechnology, other agricultural practices contributed to the increase in corn productivity, such as nutrient management, the reduction

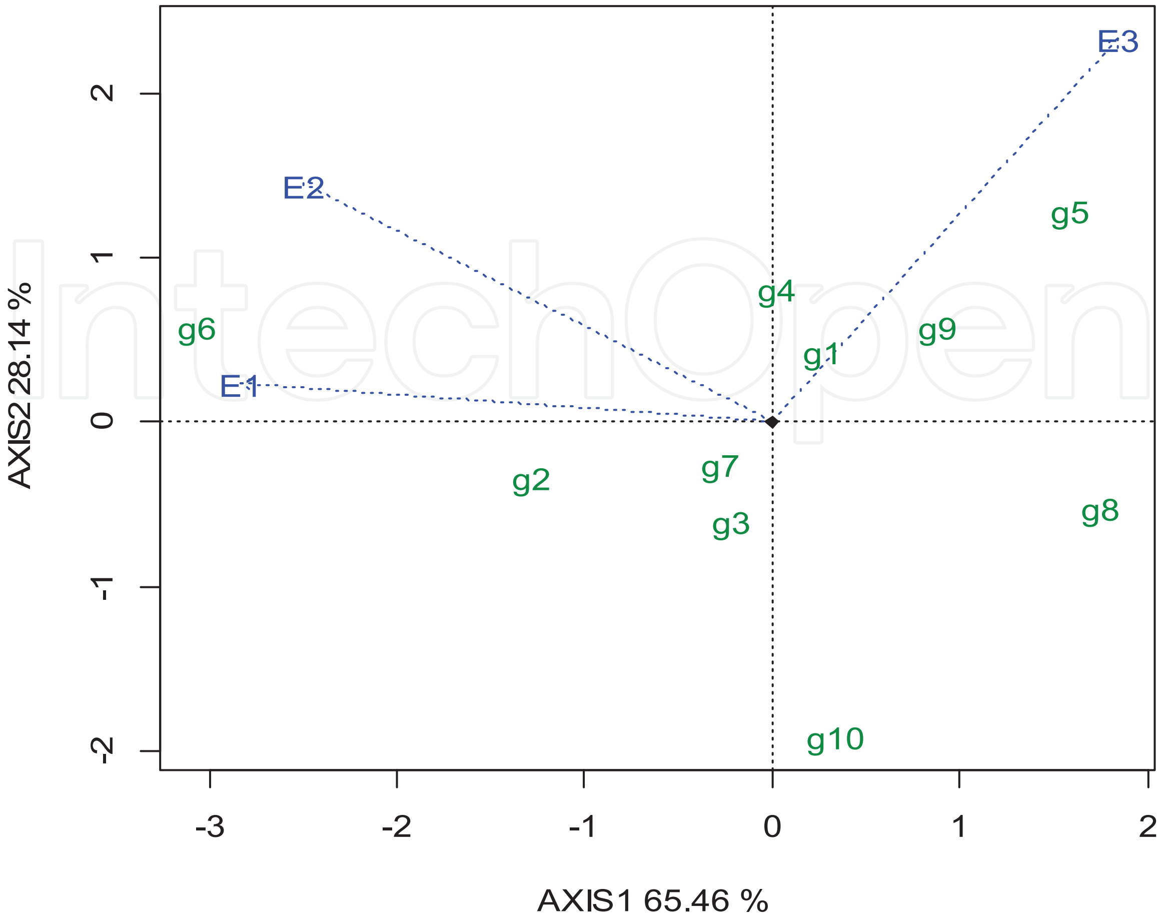

Figure 2. Graph produced in GGEbiplot showing the perspective of different hybrids in three distinct seeding periods, E1 (18/11/2011), E2 (31/01/2012) and E3 (20/02/2012). Codes: g1 = Truck, g2 = Formula, g3 = P30F53, g4 = P3646H, g5 = P30F35H, g6 = AGN 30A77H, g7 = AGN 30A37H, g8 = AG 8088 PRO, g9 = DKB 390 and g10 = DKB Bi9440. Source: Buso and Arnhold [8].

in row spacing, adjustments of plant density and the use of direct seeding. The adjustment of the spatial arrangement of the plants (in particular the density of the plantation) and the reduction of row spacing had positive effects on productivity, through the increase in the incidence of sunlight and the better exploitation of the environment by the genotype [11]. The increase in population density results in gains in productivity up to an optimum number of plants per unit area, which varies according to the hybrid and the environmental conditions, with productivity decreasing at densities above this optimum level [12]. Increasing the density of plants leads to an increase in the competition among plants for water, nutrients, sunlight and CO_2 [13], and may also induce sterility and reduce the amount of grain per cob, resulting in a loss of productivity.

In their analysis of different row spacing parameters and population densities (**Table 1**), Farinelli et al. [14] observed that productivity was influenced by the reduction in spacing and the increase in the density of seeding, with the highest productivity (7842 kg ha^{-1}) being obtained with the most reduced spacing, of 40 cm (**Table 1**). This result may be related to the increased efficiency of the plants in the interception of sunlight, and a decrease in the competition for sunlight, water and nutrients among the plants in the same row. These authors also recorded an increase in productivity with increasing population density, up to 80,000 plants ha^{-1} (**Table 1**). These gains in productivity accruing to increasing population density are related to the use of hybrids better adapted to high population densities. These hybrids are smaller, have more erect leaf architecture, rapid emission of the style-stigma, coordination of the anthesis with the emission of the stigmas, rapid development of the first cob, reduced size of the tassel and an even greater efficiency in the production of grain per unit area.

Silva et al. [15] found that a row spacing of 0.45 m resulted in a 17% gain in productivity in comparison with a 0.90 m spacing (**Table 2**), and found many other studies with similar results, showing that considerable gains can be obtained by reducing the 0.90 m row spacing that had been used for many years. These authors also found that densities of 60,000 and 80,000 plants ha^{-1} resulted in gains in productivity of 12.5 and 13.6%, respectively, in comparison with the more traditional density of 40,000 plants ha^{-1} (**Table 2**). These results indicate that the hybrids tested tolerate an increase in planting density without affecting productivity. However, the density of 60,000 plants ha^{-1} appears to be the most viable option, considering that the gain in productivity is only negligibly lower from that at 80,000 plants ha^{-1}, while the adoption of a greater plant density implies higher costs for the purchase of seed.

In an analysis of the harvests of 2 years, Buso et al. [16] recorded different patterns of productivity between years for different parameters of row spacing and planting density (**Table 3**). In the first year, productivity was greater at the higher densities (70,000 and 80,0000 plants ha^{-1}), with 10,922–11,796 kg ha^{-1}, while the lower density (60,000 plants ha^{-1}) produced only 9118 kg ha^{-1}. In the second year, the middle density (70,000 plants ha^{-1}) was significantly more

Spacing (m)	Productivity (kg ha^{-1})	Density (plants ha^{-1})	Productivity (kg ha^{-1})
0.4	7842 a	40,000	6320 b
0.6	7372 ab	60,000	7777 a
0.8	6974 b	80,000	8091 a

The mean values in the same column followed by different letters are significantly different (p ≤ 5%) from each other, based on Tukey's test. Adapted from Farinelli et al. [14].

Table 1. Productivity of corn according to different row spacing and plant densities.

Spacing (m)	Productivity (kg ha^{-1})	Density (plants ha^{-1})	Productivity (kg ha^{-1})
0.45	8514 a	40,000	7256 b
0.90	7263 b	60,000	8163 a
–	–	80,000	8246 a

The mean values in the same column followed by different letters are significantly different (p ≤ 5%) from each other, based on Tukey's test. Adapted from Silva et al. [15].

Table 2. Productivity of corn under different standards of row spacing and plant density.

productive (6253 kg ha^{-1}) than either of the other densities, with 60,000 plants ha^{-1} producing only 5045 kg ha^{-1} of corn and 80,000 plants ha^{-1} producing 5606 kg ha^{-1} (**Table 3**).

The reduction in row spacing contributes to gains in productivity through the optimal distribution of the plants per unit area and provides the best management strategy for the control of weeds, due to the rapid growth of the plants, which closes over the gaps and increases the interception of sunlight, impeding the growth of weeds. It also increases the exploitation of the soil by the root system of the plants, and reduces planting costs, given that the same machinery used to seed other crops, such as soybean, bean and sorghum, can be used to plant the corn, due to the fact that these crops use the same row spacing.

The majority of the 16 million hectares used to produce corn in Brazil are cultivated by direct planting [2]. However, the adequate management of the soil is essential to guarantee the efficiency of this system [17]. This requires mechanical-, edaphic- and vegetation-based conservation practices, in particular, the use of cover crops to form a layer of stover, increase the organic material and contribute to the greater retention of nutrients during the organic phase.

The maintenance of the surface stover is determined by the Carbon:Nitrogen (C:N) ratio and the lignin concentrations found in the different plant species used as cover and for the formation of the stover. Climatic conditions influence the velocity of the decomposition of the stover by microbial organisms, by determining the micro-environmental conditions for their development.

Carvalho et al. [17] studied the effects of cover crops and the successive cultivation of corn, and found that productivity was influenced by the type of stover, varying from 11,666 kg ha^{-1} (following wheat) to 12,780 kg ha^{-1} (following ruzi grass) during the 2010/2011 harvest (**Table 4**). Productivity was significantly higher for ruzi grass, brown hemp, Brazilian jackbean and pearl millet, in comparison with velvet bean and wheat. Productivity was highest in the context of the more accelerated decomposition of the residues of some of these species, which is associated with the quantity of dry matter produced. The chemical composition of the cover crops with the lowest concentrations of lignin, such as ruzi grass and Brazilian jackbean, and the production of greater volumes of dry matter may have favoured not only the quantity of nutrients, but also the synchrony of the liberation of the plantation for the seeding of the corn.

In general, the ruzi grass contributes to nutrient cycling and the excellent quality of the stover produced, which results in an increase in the levels of organic matter, protecting the soil from the direct impacts of erosive agents, as well as facilitating the management of weed growth. This grass also has a very aggressive root system, capable of recuperating nutrients that the planted crops are unable to access due to their depth in the soil profile.

The use of cover crops is essential to guarantee the sustainability of many different types of crops in all regions of Brazil, in particular those of the Cerrado domain, where the soils tend to be intensely weathered. In this case, the mineralization of the organic matter formed by the cover crops provides nutrients for the corn plantations. The most important nutrient for this crop (corn) is nitrogen, and the need for supplementation with this nutrient will depend on a series of factors, such as the history of the area and the crop planted before the corn, the definition of which will help define the optimum dosage, sources and the forms of nitrogen to be applied.

Harvest	Plant population (thousands ha^{-1})			Row spacing (m)	
	60	70	80	0.50	0.80
2010/2011	9118 aB	10,922 aA	11,796 aA	10,923 aA	10,301 aA
2011/2012	5045 bB	6253 bA	5606 bB	6437 bA	4831 bB

The mean values in the same row followed by different letters are significantly different (p ≤ 5%) from each other, based on the Scott-Knott test. Adapted from Buso et al. [16].

Table 3. Productivity of corn (kg ha^{-1}) in the 2010/2011 and 2011/2012 harvests for different plant densities and row spacing.

Cover crop	Level of N in the leaf (g kg^{-1})	Productivity (kg ha^{-1})
Ruzi grass (*Urochloa ruziziensis*)	26.0	12,780 a
Brown hemp (*Crotalaria juncea*)	27.1	12,710 a
Brazilian jackbean (*Canavalia brasiliensis*)	25.9	12,580 ab
Pigeon pea BRS mandarin (*Cajanus cajan*)	24.1	12,500 ab
Pearl millet 'BR05' (*Pennisetum glaucum*)	25.2	12,130 abc
Velvet bean (*Mucuna aterrima*)	26.4	11,750 c
Forage radish (*Raphanus sativus*)	28.8	12,280 abc
Sorghum 'BR 304' (*Sorghum bicolor*)	26.2	11,960 bc
Wheat (*Triticum aestivum*)	25.0	11,670 c
Native vegetation	24.4	11,940 c

The mean values in the same column followed by different letters are significantly different (p ≤ 5%) from each other, based on the Tukey-Kramer test. Adapted from Carvalho et al. [17].

Table 4. Level of N in the leaves of different cover crops and the productivity of the corn planted after these species.

Cover crop	Inoculated	Not inoculated
Crotalaria juncea	7795 b A	9124 a AB
Cajanus cajan	8299 b A	9338 a A
Pennisetum americanum	8487 a A	8159 a B
Pennisetum americanum + *Crotalaria juncea*	8632 a A	8569 a AB
Pennisetum americanum + *Cajanus cajan*	8164 a A	8796 a AB
Fallow	8288 a A	8153 a B

The mean values in the same row followed by different lower case letters, and in the same column by different upper case letters, are significantly different (p ≤ 5%) from each other, based on the Tukey-Kramer test. Adapted from Portugal et al. [18].

Table 5. Productivity (kg ha^{-1}) of corn from seed inoculated with the bacterium *Azospirillum brasilense* and seed not inoculated, raised following the planting of different cover crops.

One other management option, recommended by some authors, is the application of bacteria that contribute to the growth of the plants through a number of different mechanisms for the nitrogenous nutrition of the corn plantations. The most-studied crop-associated diazotophic bacteria are those of the genus *Azospirillum*. Portugal et al. [18] observed that inoculation of the corn seed with *Azospirillum* had different results, depending on the associated cover crop (**Table 5**). In this study, inoculation associated with *Crotalaria juncea* and *Cajanus cajan* did not result in any gains in productivity (**Table 5**), given that these two plants also fix nitrogen in the soil, benefiting the subsequent corn crop. In areas planted with grasses or left fallow, however, inoculation with *Azospirillum brasilense* tends to have an effect on productivity.

Author details

Wilian Henrique Diniz Buso* and Luciana Borges e Silva

*Address all correspondence to: wilian.buso@ifgoiano.edu.br

Instituto Federal de Ciência e Tecnologia Goiano Campus Ceres, Goiás, Brasil

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