Drought and Low N Status Limiting Maize Production in Brazil

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Abstract

The Brazilian territory has an area of approximately 8.5 million km^2, which is divided into five main regions with particular characteristics related to average climatic conditions and natural soil fertility. Climatic variations may be very accentuated within each particular region, but a common feature is the irregular distribution of rains, which causes droughts of variable intensities. Maize is an important crop in most Brazilian regions, occupying approximately 13 million ha and producing annually 28-30 million tons of grain. It has been estimated that drought problems, depending on year and intensity, reduce maize production by 14% to 28%. Another limiting factor for maize production in Brazil is the low natural fertility of the soils, especially in nutrients like phosphorus and nitrogen (N). It has been estimated that 80% of the soils in Brazil are deficient in N. Although fertilization is a common solution to this problem, its high costs make this option inaccessible to many farmers. The amount of supplemental N applied to maize in Brazil is low (36 kg N/ha), and of this only 50% to 60% is utilized by the crop. Considering that low N availability and drought are severe constraints to maize crops in Brazil, the National Maize and Sorghum Research Center (CNPMS/EMBRAPA) has initiated breeding programs aimed at the development of germplasm that performs more efficienctly under these two limiting conditions. Several genotypes have been developed on the basis of anthesis-silking interval selection for drought tolerance, and a variety is being developed for soils with low fertility where N is the most limiting nutrient.

Tropical regions are usually affected by marked climatic variations, with frequent periods of no or irregularly distributed rainfall, causing serious crop losses. Drought effects are exacerbated by several effects, including low natural soil fertility, inefficient crop management practices, biotic stresses and lack of government programs to financially support farmers.

Brazil has an area of 8,547,407 km^2, which is divided into five distinct regions. Maize is cultivated and considered a socially and economically important crop in all of them. Table 1 shows the size of each region and portion of total maize production. The characteristics of each region are briefly summarized below.

Northern Region

The northern region covers seven states in the Amazon basin and is dominated by lowlands (0-200 masl), with abundant and well distributed rains (1300 to 3000 mm). Temperatures and relative humidity are commonly high throughout the year. Natural soil fertility is usually low and farmers use low levels of fertilizer and other inputs on their

Table 1. Brazil's geographical regions, their areas, and their respective contributions to national maize production.

Regions	Area (km^2)	% of total area	% national maize production[†]
Northern	3,869,638	45.27	2.35
Northeastern	1,561,178	18.26	5.32
Southeastern	927,286	10.86	28.43
Southern	577,224	6.76	46.86
Central Western	1,612,077	18.85	17.04
Total	8,547,403	—	—

[†] Estimate from 6 years (1987-1992).

crops. Maize is planted between October and December and drought is not a common problem for this crop.

Northeastern Region

The northeastern region covers the nine states which have the highest occurrence of drought in Brazil. Altitudes in the region vary between 0 and 1200 masl and the climate in general is hot and dry, including high temperatures at night. The only area within the region where rains are frequent and well distributed is along the coast, where a string of forests exists. In the interior, precipitation varies between 300 and 500 mm and its irregular spatial distribution greatly affects agricultural production. Rains are concentrated in a short 1-3 month period, and usually occur as heavy precipitation, with up to 50 to 80 mm per shower. Soils have low fertility and not much fertilizer is used. The start of the growing period for annual crops is highly variable (from November to May), depending on the beginning of the rainy season.

Southeastern Region

The southeastern region comprises four states that vary from 0 to 300 masl in altitude. Rain distribution is more uniform than in other regions, varying from 800 to 1500 mm annually. Nevertheless, short periods of dry weather (10-20 days) occur during flowering time. Normally the temperature is very high for nine months and then cold for the other three. Natural soil fertility is generally low or medium, but some areas have relatively high fertility. Soil fertilizer use is common and the sowing season is from October to November.

Southern Region

The southern region covers three states. Altitude varies from 0 to 1110 masl. Rain distribution is very uniform and intense throughout the year (800 to 1500 mm). During the summer, temperatures are very high during the day and very mild at night. During three to four months of the year, the weather is very cold and thermal inversions can occur at any time, resulting in rain storms. Natural soil fertility is from medium to high and most farmers use fertilizer. The level of technology used by farmers is usually high.

Central Western Region

The central western region includes three states and the Federal District, Brasilia. Rain distribution is very irregular, with annual variation from 800 to 1300 mm. Dry periods, commonly known as "veranico", last from 10 to 20 days, and often coincide with flowering. The weather is predominantly hot, although temperatures are very mild during three months of the year. This region encompasses the majority of the Brazilian Cerrado. Natural fertility is from very low to medium, and the level of technology used by farmers has improved during the last few years. Crops are sown in October and November.

It is evident from these descriptions that rain distribution varies widely both between and within the regions. Furthermore, there are other factors constraining production, and they vary widely in importance across the regions. Specific data regarding drought-occasioned maize yield losses do not exist for Brazil. During the last two years, EMBRAPA has tried to organize a national database and develop simulation studies to assess the factors responsible for maize yield reductions. For the time being, reductions in maize area between planting and harvest and the fluctuations of maize yields between years may indicate the importance of drought, although other climatic factors and socioeconomic effects cannot be excluded (Table 2). For dryland conditions, cultivars that are drought tolerant or can escape drought during the more critical periods of plant development are much needed alternatives. Several public and private companies are trying to reduce the risk resulting from unstable rain distribution by developing very early-maturing cultivars that make the most efficient use of short rainy periods. Development of drought tolerant cultivars is one of the main goals of CNPMS. This effort was started in 1987 through the creation of a specific breeding program for tolerance to drought conditions. As a result, CNPMS has a population and several hybrids that they have begun to evaluate under water stress conditions. The population traces to nine S_4 lines, derived from synthetic elite NT. The methodology used to develop the lines was based on the selection of plants with short anthesis silking interval (ASI). The lines were crossed in a diallel and then recombined twice to form the population.

Three-way hybrids from parental lines selected for drought tolerance were evaluated in four locations in the year 1994/95, but drought stress only occurred in one location. Preliminary results shown in Table 3 include the 20 best hybrids for ASI and are from this drought stressed location. It is important to say that all the parental lines have zero or negative ASI values. Some hybrids had negative or very low ASI values; i.e., the stigmas were exposed before pollen release. In contrast, the controls had ASI values of 5 or 6 days. Although preliminary, these results clearly indicate that the short ASI observed in the parental lines was expressed in the F_1 generation. This was the case even when only 50% of the germplasm used to form a hybrid came from a short ASI parent. Plant and ear height of the high ASI hybrids was about average; these values were a little higher than for the controls. This may be explained by differences in the origin of the germplasm. High ASI hybrids tended to be more prolific than the controls.

Table 2. Maize production data, including planted and harvested area, reduction in area after planting, total production, and average grain yield for the five regions of Brazil, 1987-1992.

Regions	Area planted (ha)	Area harvested (ha)	Area reduction (ha)	Area reduction (%)	Production (t)	Yield (t/ha)
1987						
Northern	327,911	324,344	3,567	1.1	434,263	1.34
Northeastern	3,090,375	2,497,100	593,275	19.2	622,362	0.25
Southeastern	3,150,108	3,143,825	6,283	0.2	7,374,378	2.35
Southern	5,840,029	5,816,762	23,267	0.4	13,955,765	2.40
Central Western	1,730,381	1,721,397	8,984	0.5	4,415,641	2.57
Total	14,138,804	13,503,428	635,376	4.5	26,802,409	1.98
1988						
Northern	438,148	431,730	6,418	1.5	602,498	1.40
Northeastern	3,356,523	3,186,296	170,227	5.1	2,053,452	0.64
Southeastern	2,986,823	2,973,222	13,601	0.5	7,233,258	2.43
Southern	4,957,058	4,878,540	78,518	1.6	10,469,372	2.15
Central Western	1,713,011	1,695,215	17,796	1.0	4,389,456	2.59
Total	13,451,563	13,165,003	286,560	2.1	24,748,036	1.88
1989						
Northern	515,633	513,449	2,184	0.4	756,919	1.47
Northeastern	3,223,324	3,081,230	142,094	4.4	1,742,996	0.57
Southeastern	3,003,175	2,984,483	18,692	0.6	7,399,293	2.48
Southern	4,725,086	4,704,189	20,897	0.4	11,542,828	2.45
Central Western	1,661,274	1,648,433	12,841	0.8	5,130,556	3.11
Total	13,128,492	12,931,784	196,708	1.5	26,572,592	2.05
1990						
Northern	405,305	397,392	7,913	2.0	539,637	1.36
Northeastern	2,662,580	2,139,037	523,543	19.7	648,582	0.30
Southeastern	2,743,160	2,704,098	39,062	1.4	5,258,540	1.94
Southern	4,751,136	4,737,300	13,836	0.3	11,792,614	2.49
Central Western	1,461,590	1,416,480	45,110	3.1	3,108,401	2.19
Total	12,023,771	11,394,307	629,464	5.2	21,347,774	1.87
1991						
Northern	449,199	425,070	24,129	5.4	610,000	1.44
Northeastern	3,088,884	2,865,033	223,851	7.2	1,844,914	0.64
Southeastern	3,157,396	3,152,181	5,215	0.2	8,154,077	2.59
Southern	5,357,540	5,116,891	240,649	4.5	8,397,305	1.64
Central Western	1,527,628	1,504,526	23,102	1.5	4,578,044	3.04
Total	13,580,647	13,063,701	516,946	3.8	23,584,340	1.81
1992						
Northern	456,546	448,656	7,890	1.7	645,444	1.44
Northeastern	3,001,298	2,569,283	432,015	14.4	1,140,425	0.44
Southeastern	3,267,412	3,243,697	23,715	0.7	8,162,727	2.52
Southern	5,657,386	5,646,282	11,104	0.2	16,074,118	2.85
Central Western	1,505,442	1,455,691	49,751	3.3	4,483,413	3.08
Total	13,888,084	13,363,609	524,475	3.8	30,506,127	2.28
6 year average	13,368,560	12,903,639	464,922	3.5	25,593,546	1.98

Source: Brazilian Statistics Yearbook, years 1994, 1993, 1992, 1991, 1990, 1989.

Some interesting comparisons can be made between the hybrids and controls. The three-way hybrids used as controls are excellent when planted in environments with no water stress (data not shown), but under stress they show very low yield and a low shelling percentage (Table 3). By comparison, the 20 best hybrids for ASI showed higher productivity (7.0 to 8.9 t/ha) and a higher shelling percentage. If we take 8 tons of grain/ha as a reference for the five best ASI hybrids and compare it with the average of the controls, 5.5 t/ha, a yield difference of 30% is observed.

These preliminary results clearly indicate that the selection for short ASI can be an efficient method for developing drought tolerant cultivars and that water stress during flowering is a constraint on maize production. The use of drought tolerant cultivars, however, is not a guarantee that yield potential is fully expressed by a variety or hybrid. Other factors — low soil fertility, for example — can greatly influence yield as well.

Nitrogen is deficient in about 80% of the Brazilian soils. These tropical soils typically have enough N to produce a 2 to 3 t/ha grain yield, given that all the other factors are ideal. According to the National Association for Fertilizer Diffusion (ANDA) and the Brazilian Association of Potassium Research (POTAFOS), use of fertilizers for maize increased 23.9% from 1990 to 1993 (Table 4), and market analysis research suggests that increased fertilizer use will continue in the years ahead. In 1993, 145 kg of fertilizer was applied to maize on average. Assuming that this fertilizer was mainly applied using the formulation 10-15-15 (NPK, POTAFOS), applied N was around 14.5 kg/ha. If only 50% of this ultimately found its way into the plant (50% fertilizer efficiency), then only 7.25 kg/ha of N were available for the maize crop. This amount represents 50% of the requirement for a 5 to 6 t/ha yield for farmers using a low or medium level of technology. Clearly, the low N level of the Brazilian soils combined with the small amount that is applied every year is limiting maize production in Brazil. On the other hand, it is known that maize is highly responsive to N and that the largest responses are obtained from application rates between 30 and 50 kg/ha. Experimental data from 459 trials indicates that rates varying from 45 to 160 kg/ha generated yield increases from 6 to 197%. However, farmers are hesitant to use N fertilizer due to the high price of fertilizers and the risk of drought. One alternative to diminish risks in vulnerable rainfed agricultural systems is to develop cultivars with a high capacity for nutrient utilization and an almost linear response to nutrient levels. CNPMS is working to develop maize varieties for low fertility soil conditions. Preliminary results indicate that progenies can be developed which lose little yield when moved from an N+ to an N- environment (Santos et al., 1997).

We believe that exploring genetic variability will be the best strategy to minimize factors limiting maize production in tropical environments. While doing this it will be important to maintain close interactions with scientists from other research areas and with other research institutions, and to develop methodologies that result in consistent progress from efficient selection for desired traits.

Table 3. Mean values in maize under drought during flowering for male flowering (MF), female flowering (FF), anthesis-silking interval (ASI), plant height (PH), ear height (EH), ear index (EI), ear weight (EW), grain weight (GW), and shelling percentage (S). Sete Lagoas - MG, Brazil.

Treatments	MF (days)	FF (days)	ASI (days)	PH (m)	EH (m)	EI	EW (t/ha)	GW (t/ha)	S (%)
HT 17	58.0	58.5	+0.5	2.17	1.25	1.04	11.33	8.99	79.4
38	56.0	55.5	-0.5	2.12	1.37	1.02	11.12	8.49	76.4
HT 15	57.0	57.5	+0.5	2.10	1.32	1.04	11.03	8.36	75.8
HT 29	57.0	58.5	+1.5	2.22	1.40	1.02	10.71	8.36	78.1
HT 10	57.0	56.0	-1.0	2.15	1.35	1.02	10.28	7.52	73.2
HT 25	56.0	55.5	-0.5	2.20	1.27	1.00	10.24	8.11	79.2
HT 19	58.5	58.5	0.0	2.32	1.37	1.00	9.59	7.38	77.0
HT 26	58.0	59.5	+1.5	2.37	1.65	1.08	9.30	6.88	74.0
HT 37	56.5	57.0	-0.5	2.07	1.32	0.99	9.24	7.60	82.3
HT 24	57.0	57.5	+0.5	2.25	1.35	0.99	9.16	6.61	72.2
HT 13	57.5	58.0	+0.5	2.17	1.37	1.02	9.14	7.02	77.0
HT 11	58.5	58.5	0.0	2.05	1.27	1.02	9.11	7.14	78.4
HT 27	58.5	58.5	0.0	2.07	1.40	0.91	8.90	6.99	78.7
HT 06	59.5	61.0	+1.5	1.95	1.27	0.87	8.66	6.56	76.8
HT 40	57.5	58.0	+0.5	2.00	1.37	1.02	8.25	5.88	72.3
HT 22	59.5	60.0	+0.5	2.00	1.27	0.86	8.24	6.23	75.6
HT 32	57.5	58.5	+1.0	2.12	1.22	0.86	8.22	6.37	77.5
HT 45	57.0	57.0	0.0	2.15	1.35	1.00	8.02	6.19	77.2
HT 42	57.0	56.5	-0.5	2.10	1.27	0.98	7.99	6.02	75.4
HT 28	56.0	57.0	+1.0	2.05	1.25	0.85	7.78	5.64	73.0
P 3041 (check)	61.5	66.5	+5.0	1.95	1.22	0.98	7.88	5.52	70.1
ICI 3501 (check)	62.0	68.0	+6.0	2.00	1.22	0.64	6.32	4.74	75.0
XL 370 (check)	63.0	69.0	+6.0	1.95	1.22	0.91	4.85	3.43	70.8
CV%							13.2	15.1	

Table 4. Grain yield, fertilizer applied (kg/ha), and total fertilizer utilized on maize in Brazil during 1987, 1990 and 1993.

Years	Yield (t/ha)	Fertilizer (kg/ha)	Total fertilizer ('000 t)
1987	1.99	99	1,340
1990	1.87	117	1,350
1993	2.44	145	1,910