Drought Quantification and Preparedness in Brazil - The Example of São Paulo State

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Abstract

Drought in Brazil is a very important phenomenon that affects not only agricultural production but also society. The magnitude and large-scale variation of drought are analyzed specifically for São Paulo State. The quantification and monitoring of drought, rainfall distribution, and agricultural management are discussed. Daily climatological data from 114 localities are used to determine drought indices. These indices take into account soil type and crop characteristics; they are derived from the relationship between ETR/ETP and soil water availability obtained by the water balance. Crop response to drought, soil management, and agricultural practices are also analyzed. Meteorological variability and weather forecast parameters are used to give support to the warning system.

The indices used to quantify and monitor drought are the ratio ETR/ETP, soil water surplus, soil water deficiency, rainfall frequency and distribution, crop water requirement, dry spell frequency, probability of stored water in the soil, rainfall anomaly, and agricultural dryness.

Agrometeorological bulletins are issued twice a week and distributed to farmers, extension service, and media. All information related to crop planting and harvesting, drought intensity, rainfall anomaly, agricultural practices, and crop weather requirements are considered in the preparation of the agrometeorological bulletins. Aspects of climatic risks zoning are used to determine the best planting time to avoid or reduce drought risks during crop development.

Recently the Standardized Precipitation Index (SPI) concept has been incorporated into the bulletins. A specific analysis was made for the 1999–2000 drought period in São Paulo State. The results demonstrated that the SPI was useful for monitoring and quantifying drought regimes and their effects on crops.

Introduction

Drought concepts vary widely in Brazil, depending on soil characteristics and crops. For instance, 6-7 days without rainfall may characterize a severe drought period for shallow-rooted crops, whereas for crops with deep rooting systems this may not be considered drought. Another important aspect is the water storage capacity of the soil. Soils with a deep profile and good water retention capability provide a good water reservoir and also facilitate root expansion. Shallow soils enhance drought because of the smaller volume of stored water in the soil layer, but on the other hand, precipitation values may not have to be very high to return the soil moisture to field capacity.

The large variability in climatic conditions and topography have led to great differences in agro-ecological zones and agricultural production in Brazil. Although the northeastern region is more prone to drought, other regions of the country also may be affected by drought, particularly during the main crop growing season.

According to Repelli and Alves (1996), northeast Brazil is located between 1° S and 18° S latitude and from 35° W to 47° W longitude. The semiarid region is a subregion of this whole area; it is defined mostly by a rainfall regime with a great interannual variability. If drought is a normal climatological feature of northeastern Brazil, it is important to determine the probability of above- and below-normal rainy seasons.

Several studies of rainfall regime or dry spell frequency have been carried out for the region (Silva and Rao 1994; Andrade and Bastos 1997). Liu and Liu (1983) determined the probability of drought during the growing season for maize using the frequency distribution over 15 levels of soil water deficit obtained through the soil water balance (Thornthwaite and Mather 1955).

Silva et al. (1985) determined with 80% probability the occurrence of rainfall after March 19 for Paraiba State. In this case, the crop growing season lasted from September 22 to September 21 (next year), and the probabilities of rainfall for the first (Q1) and fourth (Q4) periods were very different. The last period (Q4) had a higher probability of rainfall deficits.

Nitzche et al. (1985) developed criteria to define the tendency of the rainy season. They defined the years as rainy (wet), dry, or normal. This study was based on the mean (X) and standard deviation (S) of the total rainfall observed for each year, and the limits are:

Dry Year $X_i < (\bar{X} - S)$

Normal $\bar{X} - S \leq X_i \leq \bar{X} + S$

Wet (rainy) $X_i > X + S$

($X \equiv$ expected rainfall)

Winter in southern Brazil is relatively humid, with a good rainfall distribution. Summer months receive a good amount of rainfall, except for some areas in Rio Grande do Sul, where the normal climatic values indicate water deficits, particularly for December and January. Although precipitation is not the limiting factor, there are often periods with severe dry spells or even drought periods which may reduce agricultural production substantially.

Mota (1979; 1987) presents a methodology to quantify drought effects on crops. His methodology is based on the ratio ETR/ETP, determined by the daily soil water balance. He proposed the use of the dry index as indicated by Shaw (cited in Mota 1979), which is given by:

$$DI = 1 - ETR/ETP$$

He used this index to estimate crop yield reductions in functions of drought for specific years, and the results he obtained were very reliable.

Rainfall characteristics are very well defined in the central and southeastern (S/C) regions. Summer months are humid and hot, and winter months are very dry, but not so cold, with occasional frost. Nevertheless, for some specific years, dry spells may seriously affect crop yield, and drought may last for up to 6-8 months, substantially decreasing the water stored in the reservoirs and causing problems for agriculture, human needs, and irrigation scheduling.

Crops cultivated in the S/C regions have their growing period during the summer (rainy) season, which lasts from October until April, but some crops can be grown during the dry or winter months, and the major crops cultivated during this period are maize, wheat, sorghum, sunflower, oat, and rye. These crops can be cultivated only by integrating suitable agronomic technologies and irrigation techniques and by choosing the best or correct planting date. Although irrigation practices are very important for dry-season agriculture, during the humid season (summer), dry spells occur often and crop water requirements can only be achieved by supplementary irrigation. For this reason, many studies have dealt with the probability of drought or dry spell periods during critical phenological stages (flowering, pod formation, fruitification) of crops. Those studies are intended to reinforce the importance of crop calendar aspects and crop zoning (Arruda et al. 1979).

Large-scale phenomena, like El Niño (ENSO) or La Niña, affect rainfall distribution markedly (Bergamaschi 1999), but their effects are more pronounced on the southern and northeastern regions of the country (Brunini and Pinto 1997).

Fontana and Berlato (1996) have observed that the El Niño phenomenon affects rainfall distribution in Rio Grande do Sul State, increasing the amount of rain particularly in October and November. On the other hand, Mota et al. (1996) have pointed out that drought and dry spells are very well correlated to La Niña in such regions.

Drought Monitoring in São Paulo State

Agrometeorological parameters and agricultural production are closely related in São Paulo State, and the most important climatic factors that may substantially reduce crop development or yield are frost, drought, and dry spells. For this reason, an agrometeorological monitoring system is being carried out to give support to drought forecasting, preparedness, and mitigation. This agrometeorological system is supported by previous work and studies that attempted to correlate crop development and weather parameters. These studies and their results are incorporated into agrometeorological bulletins that are prepared twice a week, enhancing the agrometeorological conditions (actual and future) that affect crop development. Irrigation demands and the climatic risks (drought, for instance) during the crop growing period are also analyzed and evaluated.

The studies try to incorporate the variability of climatic elements and more specific rainfall data, crop weather requirements, and soil type. The results are transferred to farmers and governmental agencies as technical or scientific papers; in some cases, they are summarized in state policy to support agricultural production and farmers' decisions. The studies and research are based on soil, plant, and climate interactions as described below.

Stored Soil Water

Most of the agricultural processes in São Paulo State are carried on under a rainfed regime. For this reason, knowledge of the stored water in the soil and its variation during the year or from year to year helps farmers choose the best planting date to avoid drought risks during critical crop stages.

Stored soil water has been determined in two ways: (1) continuous measurements over a reasonable number of years and (2) an estimate through the soil water balance on a 5-, 10-, 15-, or 30-day basis, using long-term weather parameters for at least 20 to 30 years of recorded data. Based on this, the probability of the stored water in the soil or the water deficiency for each type of soil can be predicted (Figure 1).

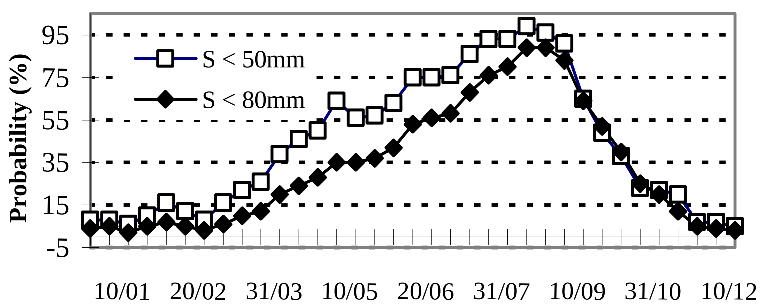


Figure 1. Probability of soil water deficiency in a 10-day analysis, considering critical levels of 50 mm and 80 mm of soil holding capacity.

Dry Spell Probability

In this case, all the studies try to determine the risks of severe drought or dry spell periods during critical phenological stages of crops. Arruda et al. (1979) and Alfonsi et al. (1979) used the moving average method (step 1) and calculated the total rainfall for every 10 days, then compared this to the crop water requirements. Crop water demand was estimated as a function of potential evapotranspiration and crop stage. An example is presented for the first 20 days of

January (Table 1) for rice cultivars, considering that this crop has a minimum water requirement of 40 mm in a 10-day period.

Table 1. Relative frequency of total rainfall less than 40 mm in a 10-day period for several localities in São Paulo State.

Period	Mococa	Campinas	Pindorama	Ribeirão Preto	Jaú	Ataliba Leonel	Presidente Prudente	Pindamo-Nhangaba
01-10	0.10	0.37	0.43	0.20	0.26	0.47	0.36	0.32
02-11	0.10	0.28	0.38	0.10	0.17	0.35	0.36	0.32
03-12	0.10	0.28	0.33	0.15	0.26	0.29	0.40	0.28
04-13	0.20	0.28	0.38	0.20	0.22	0.35	0.30	0.32
05-14	0.20	0.25	0.38	0.20	0.22	0.35	0.30	0.36
06-15	0.20	0.25	0.29	0.20	0.22	0.35	0.33	0.40
07-16	0.25	0.23	0.24	0.20	0.26	0.35	0.24	0.24
08-17	0.30	0.18	0.24	0.20	0.35	0.35	0.27	0.28
09-18	0.30	0.23	0.19	0.25	0.39	0.41	0.27	0.36
10-19	0.25	0.25	0.24	0.25	0.35	0.47	0.36	0.32
11-20	0.30	0.28	0.24	0.15	0.35	0.41	0.36	0.32

Crop Water Requirements

Camargo et al. (1985) and Alfonsi et al. (1989) defined the best sowing date for different crops based on crop water requirements and rainfall distribution for each critical phenological stage. First of all, the water requirement was determined for each crop for the planting dates. Potential evapotranspiration (ETP) was estimated according to Thornthwaite (1948) using the simplified "T index” as proposed by Camargo (1962). Instead of using the total rainfall for every ten days, the authors determined the probability of attaining the crop water requirement using the Gamma distribution concept:

$$f(x) = \frac{x^{\gamma-1} e^{-x/B}}{B^{\gamma} \gamma(F)}$$

γ was determined previously by Arruda and Pinto (1980).

$$f(x) = \exp(-\bar{X} / \bar{X}) / \bar{X}$$

The distribution function (F(x)) is:

$$F(X) = \int_{o}^{x} f(x)dx \qquad F(X) = 1 - \exp(-\bar{x} / \bar{X})$$

and the probability of (p(x)) of the crop water requirement for each period is:

$$p(x) = 1 - F(x)$$

These results are transferred to farmers and extension services to enable them to choose the best planting dates for crop sowing and emergence (Figures 2, 3, 4, 5).

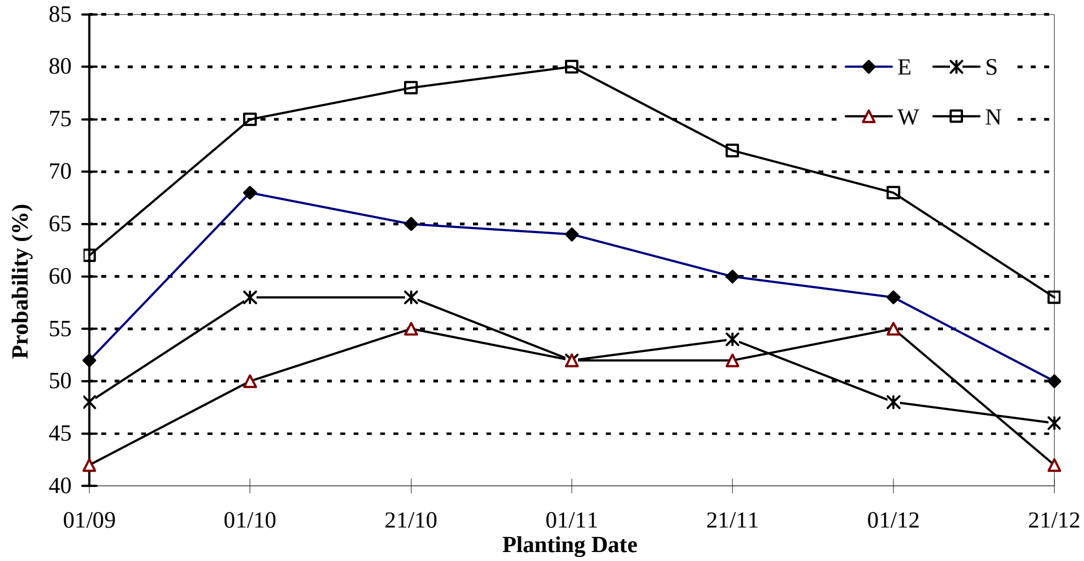


Figure 2. Probability of attaining soybean water requirements at flowering stage and pod formation as function of the planting date, for different regions in São Paulo State (N-North; S-South; E-East; W-West).

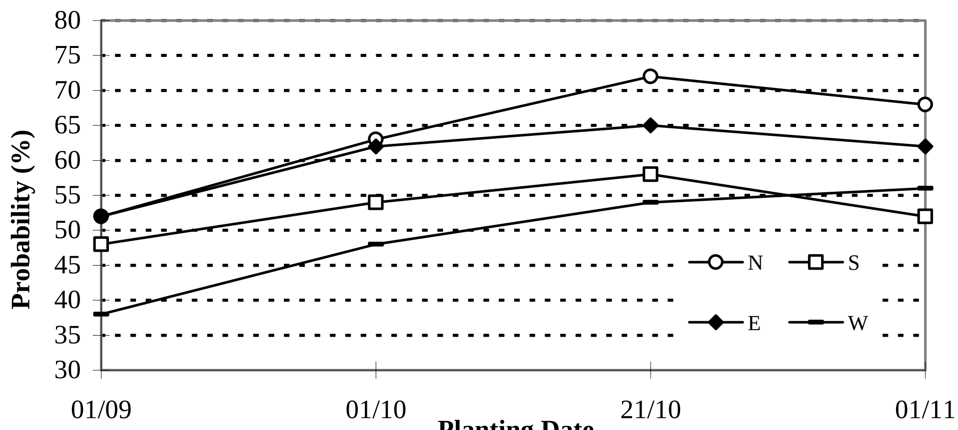


Figure 3. Probability of attaining upland rice water requirements at flowering stage as function of the planting date for different regions in São Paulo State (N-North; S-South; E-East; W-West).

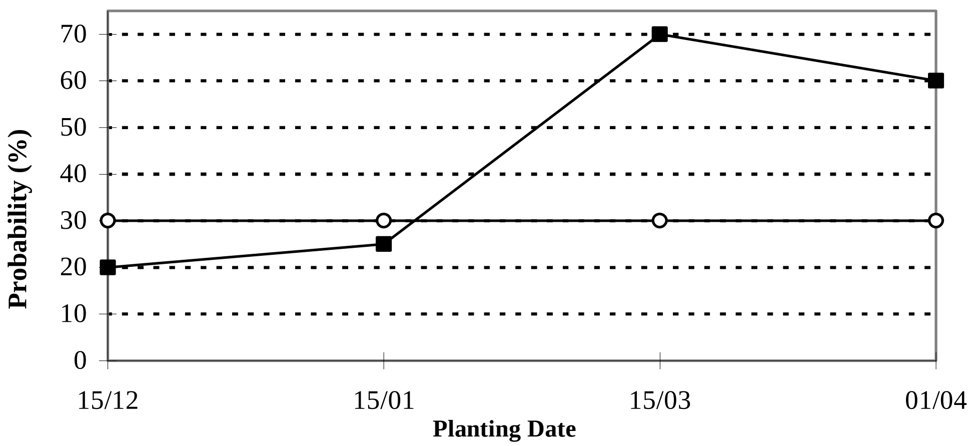


Figure 4. Probability of soil water deficits during the maize growing period as a function of the planting date for northern (N) and southeastern regions (S) of São Paulo State.

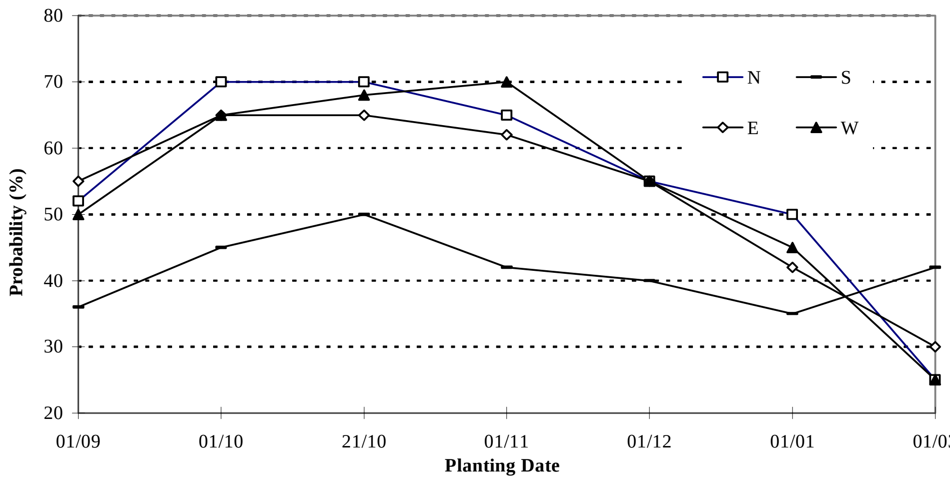


Figure 5. Probability of attaining the maize crop water requirement during flowering and silk stage as a function of the planting date for northern (N) and southern (S) regions of São Paulo State.

Climatic Risks Zoning

Because climatic risks are a normal feature of any region in the world, and because agricultural production in São Paulo State is affected every year by drought, several studies are being carried out to determine the probability of climatic hazards during the crop growing period.

The actual crop zoning studies determine the potential suitability of a specific crop for a given region and the probability of climatic risks, particularly drought and frost, during the crop growing period.

The agroclimatic indices used in climatic risks zoning are:

1. main factors affecting crop development (frost, drought);
2. phenological stage most susceptible to drought/frost;

3. cropping aspects (rainfed, lowland, irrigation); and
4. available meteorological data.

First of all, the ISNA (Water Requirement Index—Zullo and Pinto 1997) is determined for each crop at each phenological stage:

$$ISNA = (ETR)/(ETM)$$

ETR , ETM = actual and maximum crop evapotranspiration

The study was carried out considering long-term values of daily precipitation data for 390 localities (Figure 6). Crop development stages were determined using a heat unit concept or growing degree days. Base temperature (tb) and the total number of degree days required to reach a specific phase were previously determined (Brunini et al. 1995). It should be noted that water balances and the ISNA were performed in a 10-day analysis considering 3 types of soil (clay, sand, silt-loam).

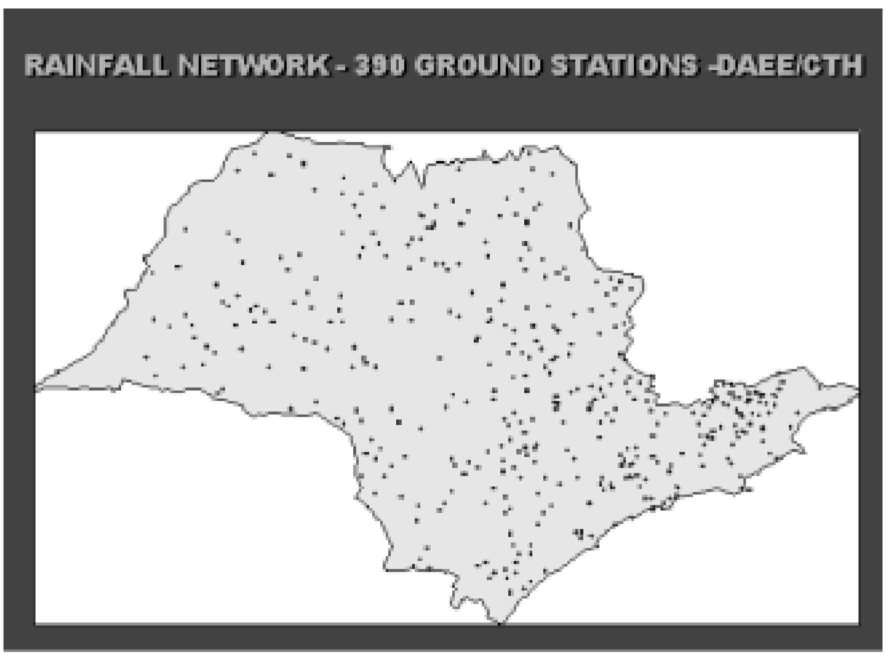


Figure 6. Map of São Paulo State with the 390 rainfall ground stations used in this work.

The steps used to determine ISNA and the climatic risks are indicated in Figure 7. A suitable planting date is adopted when the corresponding ISNA value is greater than or equal to 0.55 during critical crop phenological phases. Maps 1 and 2 present the climatic risks to maize and wheat cultivar development for specific planting dates. It should be noted that risks of high temperature and frost were also evaluated in this analysis.

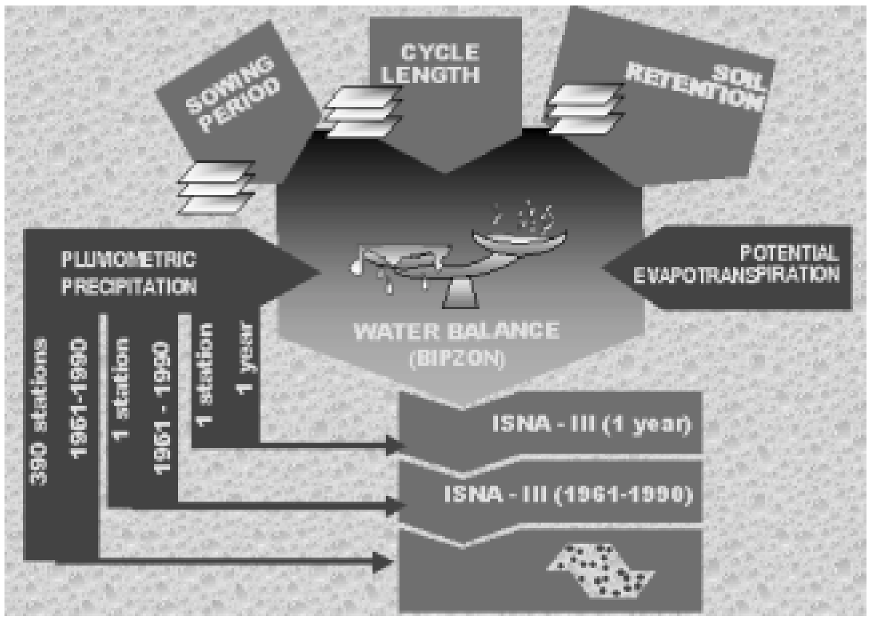
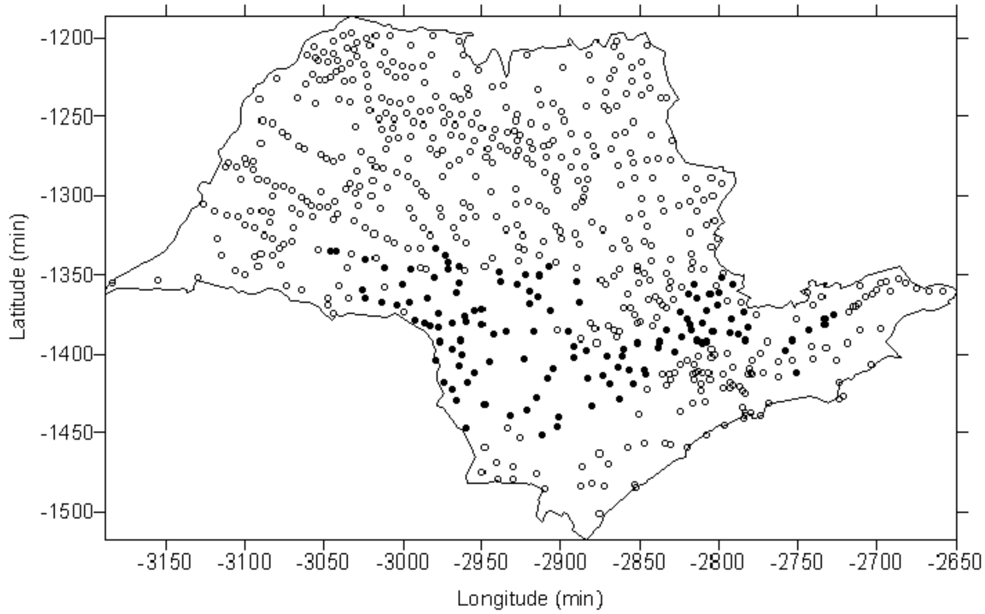
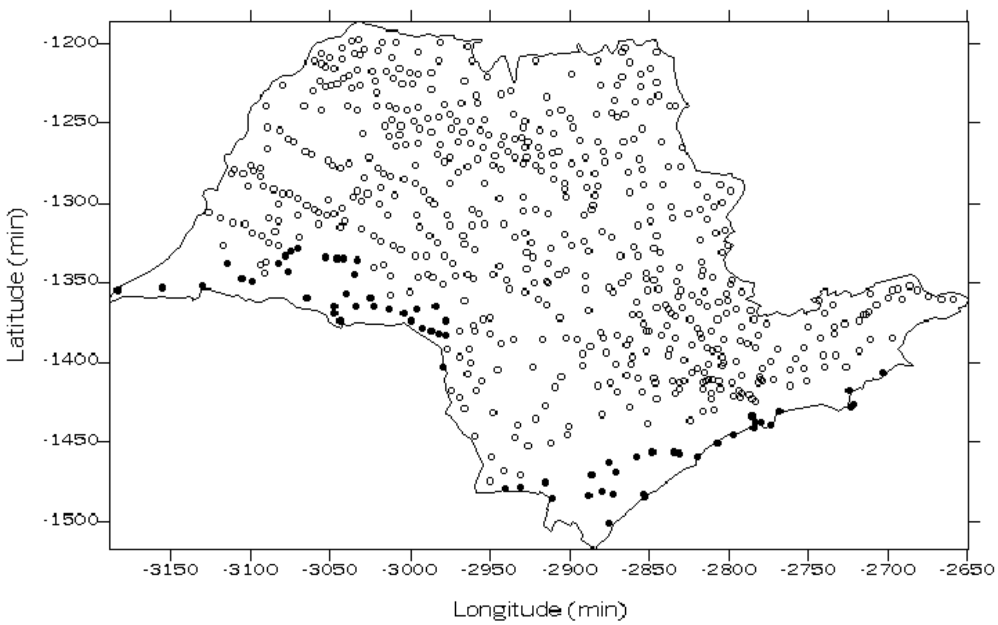


Figure 7. Definition of planting periods according to water supply restrictions.



Map 1. Climatic risks zoning for dryland wheat. Planting date: April 10-20. Full dots indicate probability of 80% of attaining crop water requirements.



Map 2. Climatic risks zoning for maize. Planting date: February 10-20. Full dots indicate probability of 80% of attaining crop water requirements.

Agrometeorology Warning System (AgWS)

In 1988, the Agrometeorology Information Center (CIIAGRO) started an agrometeorology warning system (AgWS), which gives support to agricultural production and crop development in São Paulo State (Brunini et al. 1996; 1998; 1999). It is an operational framework that provides agrometeorological information to farmers and extension services regarding the type of soil, crop development, agricultural practices, pest management, irrigation requirements, climatic risks (frost, drought, dry spell), stored water in the soil, water balance, crop yield, and weather forecast.

The AgWS is based on a network of 114 weather stations. Among these, 30 are automatic weather stations (AWS) and the others are First or Second Class Weather Stations. There is now a proposal to have an operational system based on at least 120 AWS. The basic concept of the AgWS is that all information related to weather, climatic variability, crop climate requirements, and pest management is integrated in a routine analysis to give support to farmers and governmental policies. Figure 8 describes the processes involved in the AgWS network.

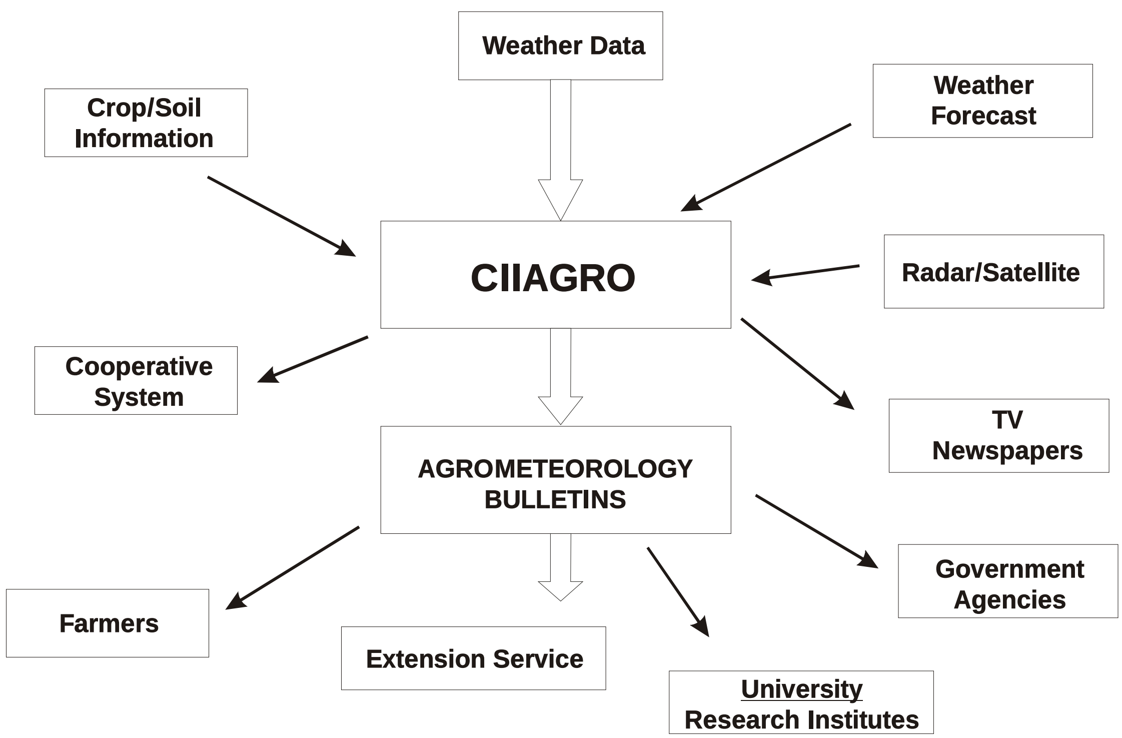


Figure 8. Processes involved in the AgWS procedure.

Most of the drought indexes are derived from an estimate of the actual water stored in the soil. For this it is assumed that the critical level of water in the soil is 60% of the maximum holding (field capacity) capacity of the soil.

Potential evapotranspiration is estimated according to Camargo's formula (Camargo and Camargo 1983). Comments are made regarding crop growing season, crop calendar, pest and disease management, soil management, planting and harvesting, and irrigation requirement.

Drought frequency and assessment are regularly analyzed. The indices used to monitor drought are ratio ETR/ETP, available soil water, dry spell duration, and rainfall anomaly. All information is included in agrometeorological bulletins that are prepared and issued twice a week. The major users are governmental agencies, newspapers, farmers, and extension services. The information is also transformed into agroclimatic maps to better explain the spatial variability of the climatic elements in the State (Maps 3, 4).

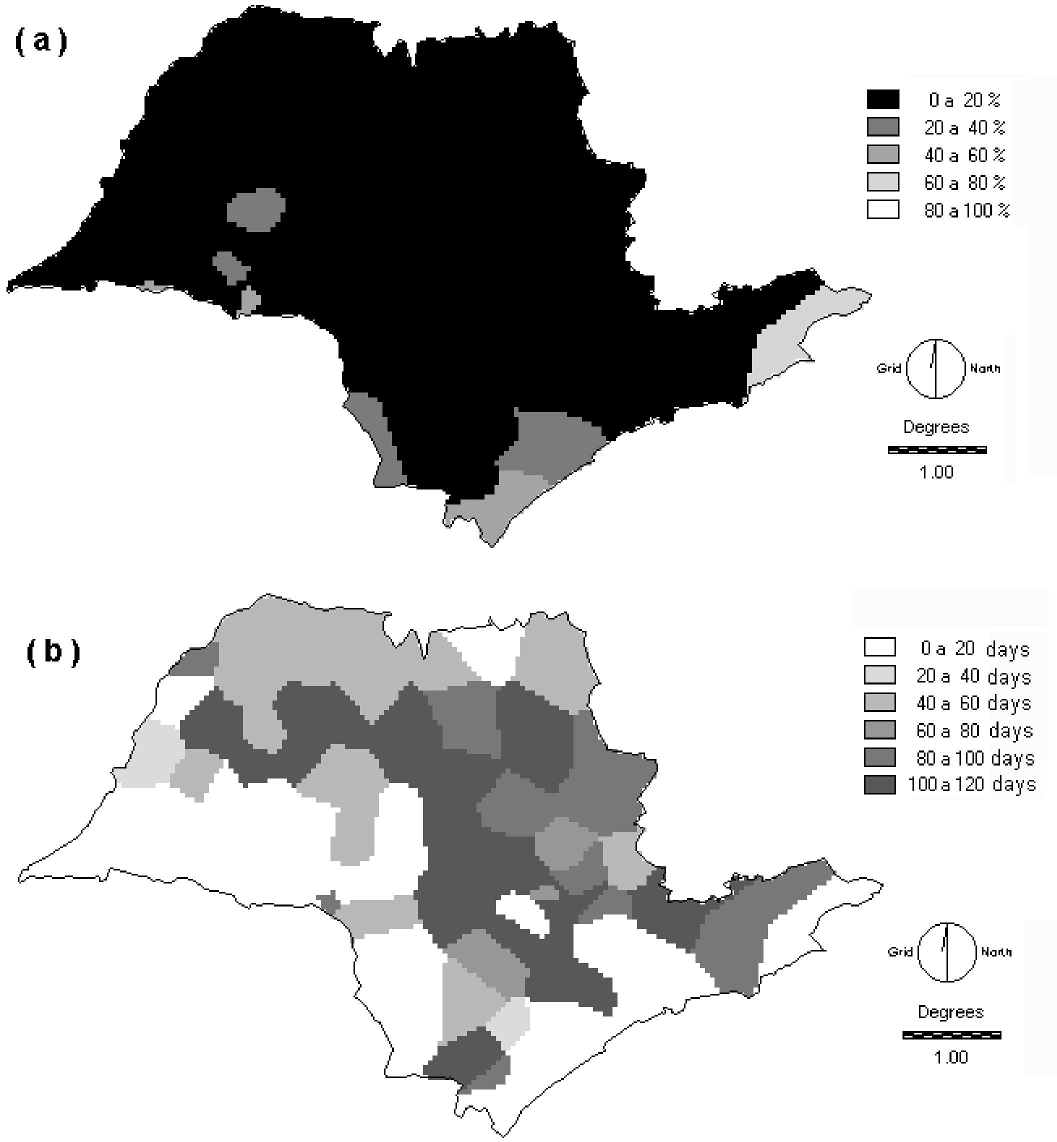
Drought Monitoring and Standardized Precipitation Index

The SPI was recently introduced to quantify and monitor drought in São Paulo State. Discussion related to the methodology and background of the SPI can be found elsewhere (Hayes et al. 1999). The SPI has never been used in a routine procedure in Brazil. For this reason, analyses were made to compare water balance parameters and the SPI.

The water balance was performed on a monthly basis, considering soil water holding capacity of 125 mm, and the parameters used in the analysis were soil water surplus and soil water deficiency. No specific parameters related to crop effects were evaluated at this time.

The drought years analyzed and compared to the SPI were 1963, 1969, 1979, and 1994, but only 2 are discussed in this chapter. There is a tendency for the SPI to follow the soil water regime (Figures 9, 10). All drought periods are clearly indicated by the SPI and water balance parameters. On the other hand, very humid periods, like 1982-83, are very well indicated by the SPI and water balance parameters.

Based on this, a prediction was made for the 1999-2000 drought. The results are very good (Figure 11a and 11b). Such an analysis was very important in quantifying the drought for specific crops (coffee, sugar cane, maize) and for supporting government policies to help farmers and to avoid price speculation. It is important to point out that the SPI indicates that from August to December 2000, São Paulo State will have a relatively humid period. This finding is corroborated by a climatic analysis projection made by INPE (Dr. Sattyamurthi, personal communication). Specific information related to soils and crop water demand will improve drought prediction.



Maps 3 and 4. Estimated available water in the soil (a), up to a depth of 40 cm, and days with rainfall below 10 mm (b).

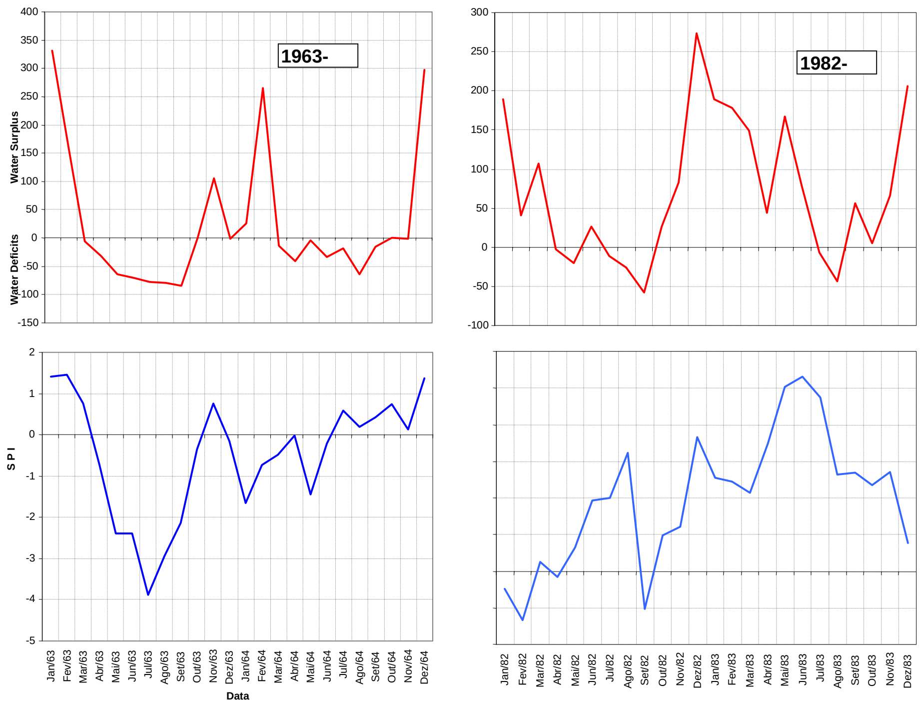


Figure 9. Variation of the SPI and soil water balance parameters for Campinas-SP-Brazil, during two constrasting rainfall regimes.

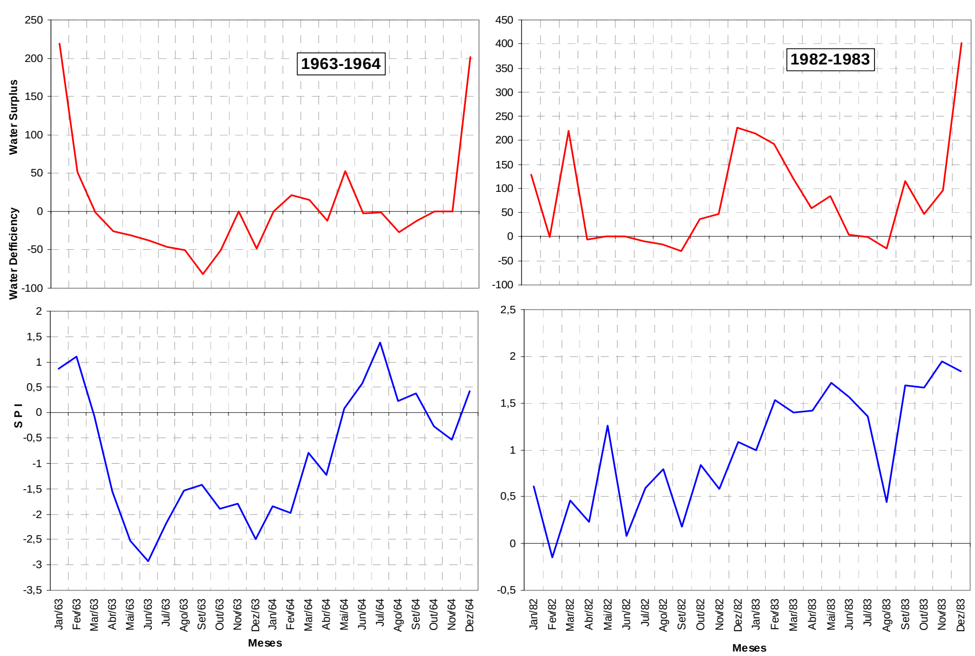


Figure 10. Variation of the SPI and soil water balance parameters for Mococa-SP-Brazil for two contrasting rainfall regimes.

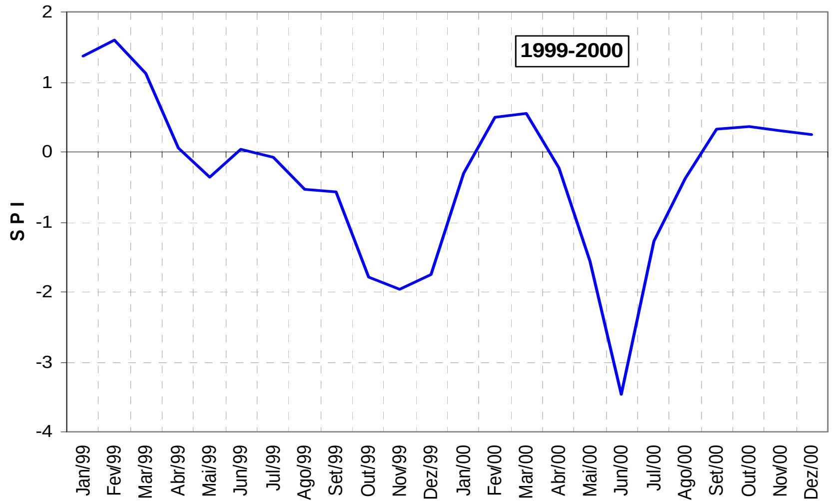


Figure 11a. Observed and estimated SPI values for Campinas-SP-Brazil during the 1999–2000 drought period.

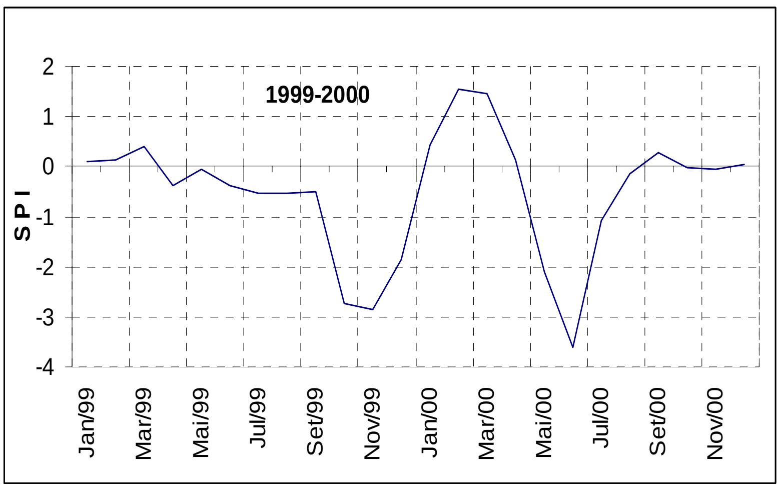


Figure 11b. Observed and estimated SPI values for Mococa-SP-Brazil for the 1999–2000 drought period.

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