Hydrologic scenarios applied to the agricultural management of the northwest of the Buenos Aires Province, Argentina

Juan Alberto Forte Lay · Eduardo Kruse · José Luis Aiello

Abstract The study area is located in the Pampean region of Argentina, in the northwest of Buenos Aires Province, covering about 50,000 km^2, within an area of great plain with particular hydrologic characteristics, where vertical water movements predominate over horizontal. The objective of this work is the analysis of the relations between different hydrologic scenarios (characterized by the soil water balance and the water table levels) and the yields of soybeans that have been increasing in recent years. It is concluded that water table fluctuations are strongly related to the elements of the local hydrologic balance. On the other hand, the geographic distribution of soybean yields corresponds directly with the values of the soil water reserve during the critical stages of the growth. After dry periods, the lowering of the water table makes access to water from the root zone difficult, and the crop is susceptible to the effects of drought. However, after wetter periods the extra contribution from the water table situated near the surface is favorable for growth, often preventing its deterioration in conditions of drought. Nevertheless, an excessive rise of the water table can produce disadvantages at seedtime and during harvest. The importance of an evaluation of the different scenarios that may have significant implications for agricultural activity is discussed.

Keywords Soil water balance · Water table · Soybean yields · Hydrologic scenarios

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Introduction

Social and economic activities in the Northwest of Buenos Aires Province, Argentina, are strongly influenced by the availability of water resources. This region represents a productive agricultural system. Significant crops include wheat, corn, sunflower and soybean.

The study of the variability of the hydrological processes is an important issue for the analysis and prediction of the behavior of this productive system. For agriculture, there are two factors to consider regarding the influence of hydrological processes. One of them is linked to the operational problems and the other is related to the water requirements of the crops. Analysis of the sowing and harvesting times in relation to water demand allowed us to establish critical dates when the hydrology becomes significant for agricultural activities.

The objective of this paper is to analyze the relations between different hydrologic scenarios (soil water balance and water table levels) and the crop yields. This case study focuses on the cultivation of soybeans, which has undergone the most significant expansion in recent years, not only in this region but also in other agricultural regions of Argentina and South America in general.

Hydrological characteristics

The main features of the Northwest region of Buenos Aires Province (Fig. 1) are its very low topographic slope, the lack of a drainage network and the presence of permeable sediments near the surface. As a consequence of these factors, there is no fluvial network and the ponds located in the depressions are important sources of water.

Fig. 1 Location of the study area, NW of the Buenos Aires Province, Argentina

The area is a great plain with a topographic slope of only about 0.1 m/km. Minor topographic forms that are important hydrologically can be differentiated within the general morphology. These are slight elevations alternating with depressions that give a relief of soft, somewhat aligned crinkles. They represent the typical forms of paleodune environments. A characteristic of this flatland is the low morphological energy of its terrain. As a consequence, the natural storage (depression and groundwater storage) and vertical movement of water (evapotranspiration and infiltration) dominate over horizontal movement (surface and subsurface runoff).

The mean annual rainfall in the region is about 850 mm/year, being less abundant towards the southwest and increasing towards the northeast. The seasonal regime indicates that 68–74% of the precipitation falls in the warm season (October–March), with increasing seasonality towards the northwest. The mean annual temperature is of 16°C (60°F):9°C (48°F) in winter and 23°C (73°F) in summer.

The annual rainfall pattern in the region shows an alternation between dry and humid periods. In the humid period, the input of water to the hydrological system exceeds the output. It generates a rise of the water table and an increase in the pond areas. The water table is nearer the surface, usually producing outflows onto the surface and negatively affecting agricultural production. The extent of the outflow areas associated with the shallow depth of the water table directly affects sowing and harvesting operations. It determines the area available for cultivation. In a dry period, as a consequence of low rainfall, and/or negative soil water balance, the water table falls and some existing depressions become dry. The reduction in the area of the ponds is directly related to the fall in the water table. The falling water table makes it difficult to meet the required agricultural production. The depressions are empty, as the water table increases its depth. Under these conditions the soil water content is low and may reach drought levels.

The water table is often very close to the surface, which indicates that surface waters (ponds) and groundwater are strongly related, so they should be treated as part of a single system. The water table fluctuations are important indicators of hydrologic behavior. On the other hand, knowledge of the current water table state and the historical data of the

other indicators allow us to predict future hydrologic scenarios in the medium term, with the aid of meteorological and oceanic parameters, like the Equatorial Pacific phenomena: "El Niño" and "La Niña". Kruse et al. (2001) have already shown how these scenarios can be significant for agricultural activities.

Materials and methods

The region under study is located in the province of Buenos Aires, Argentina, covering an area of approximately 50,000 km². It is delimited by the parallels 34° 30′ and 37° 00′ S and the meridians 61° 00′ and 63° 30′ W (Fig. 1).

Since 1997, a monitoring network has existed that includes monthly recording of the water table in 21 wells. In addition, this network includes daily precipitation data. Daily precipitation data corresponding to the period 1997–2004 were used in this study. These comprised data recorded by the National Meteorological Service—SMN (13 stations), the National Institute of Agronomic Technology—INTA (4 stations), FECEACOP (28) and 2 more stations from other sources. Figure 2a and b shows the location of these measurement stations.

For each location, the potential evapotranspiration, calculated according to the Penman method (FAO, 1972), was obtained from Damario and Cattáneo (1982). The actual daily evapotranspiration was estimated using a field capacity specific for each locality, considering the effective capacity of each zonal soil (Forte Lay and Spescha 2001). From a daily soil water balance according to Forte Lay and Aiello (1996), the soil water storages for 1997 to 2004 were obtained. The average values of available soil moisture, as a percentage of available soil moisture at field capacity for a permanent reference prairie, were obtained for all the years from February 1 to March 15. This period is considered to be when the soybean crop in the region is most sensitive to the lack of soil moisture. It coincides with the periods of bloom and seed development in the different crops, which have a very diverse phenology derived from the different dates of sowing and the different varieties used. The soil moisture is the most important variable and a good climatic indicator that summarizes the balance between precipitation and the evapotranspiration, which depends on the air temperature, the radiation, the wind and the atmospheric humidity. The values of average available soil moisture were obtained from the daily hydrologic balance without considering the crop and/or management coefficients (K_c). Available soil water storages obtained
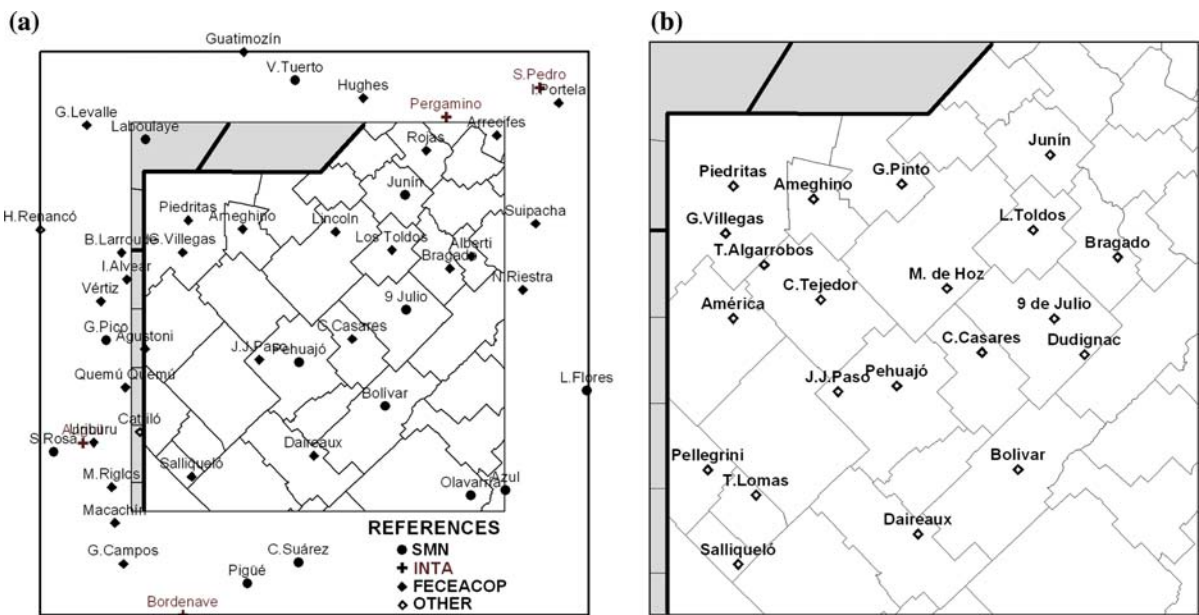
Fig. 2 (**a**) Pluviometric network; (**b**) Water table network

correspond to a permanent, grass-covered prairie reference with water consumption throughout all the year.

The values of available water on the actual estates growing soybeans may be higher than those calculated. This is because the crop may only consume more water than the reference prairie during the critical period from February 1 to March 15. In preceding periods and during the preparation of the ground, water consumption is far below to that of the prairie. Therefore, the cultivated ground approaches the critical period with a higher water reserve.

The values of average available soil water storage were plotted in maps, showing areas with different average edaphic humidity levels in the periods considered for every year from 1997 to 2004. The annual yields of soybean, obtained from production data and seeded area per plot, were provided by the Secretariat of Agriculture, Fisheries and Food (SAG-PyA). The data were registered to the central point of each plot in order to produce annual maps with yield isolines that could be comparable with the corresponding soil water maps.

Where there were gaps in the water table data observations, these were filled by linear interpolation. The formula developed by Cisneros et al. (1997) was used:

$$VFL = a + b * WB$$

where VFL = change in water table level in a determined period of days. WB = water balance, represented by the value of (P − PEt) where P = precipitation of the period, Pet = potential evapotranspiration of the period.

In deep soils, where the water balance of the surface layers of the ground acts as an attenuator for the water table, we change to the calculation of the term of the water balance to:

$$WB = W_s - W_d$$

where W_s = surplus precipitation after reaching the field capacity. W_d = water deficit for the period, the difference between the potential evapotranspiration and the real evapotranspiration, which is the actual water yielded by the ground.

This way some additional relations between the soil water balance and the variations of the water table levels can be established.

Results

Figure 3 shows the relation between the soil water balance and variations in the depth of the water table at Junín. According to the linear regression, the coefficient of correlation (R) is 0.84. Values between
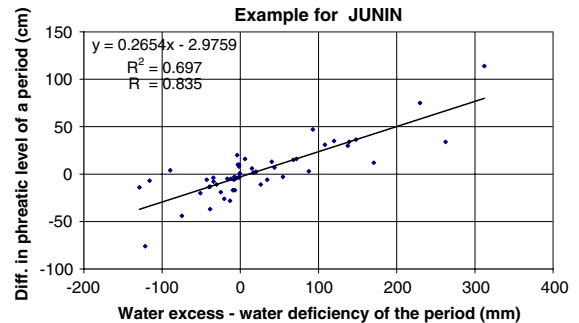
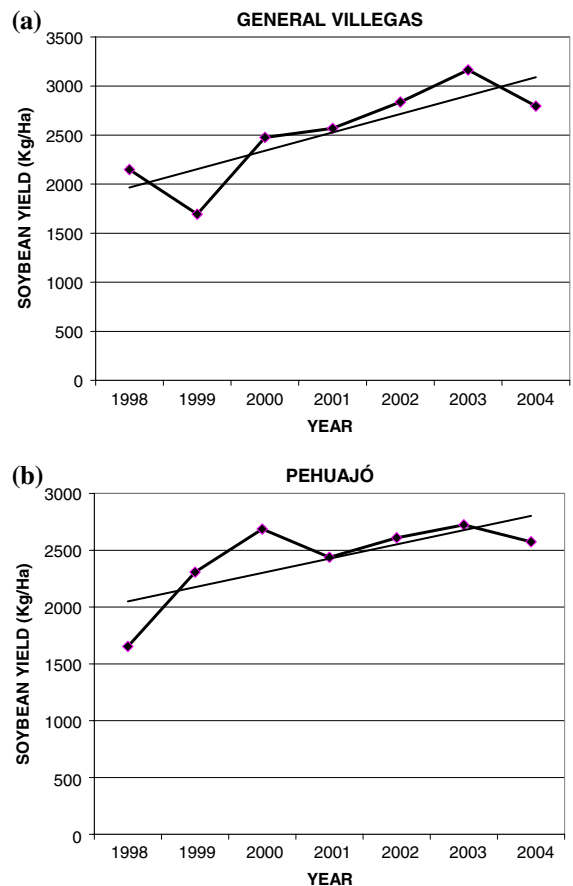**Fig. 3** Relation between water balance and water table level

Fig. 4 (**a**) Soybean yields and trend in General Villegas; (**b**) Soybean yields and trend in Pehuajó

0.60 and 0.84 were obtained at the remaining localities. It is deduced that the periods with predominance of water surplus are matched by a higher elevation of the water table level, and the opposite in periods with a water deficit.

The soybean yields, showed an increasing tendency during the period of analysis in all the localities (Fig. 4a and b). This increase is basically due to technological reasons (new varieties, new methods of culture management, etc.), stimulated by economic advantages. Therefore it would be necessary to filter out this trend in order to carry out a statistical analysis to quantify the relation between the soybean yields and the environmental variables. This has not been done in this study because the short period of records only allows a qualitative analysis, but this factor does need to be considered.

Figure 5a, b, c and d shows the maps that represent the geographic distribution of the average available soil water for the period February 1 to March 15 in 1999, 2000, 2001 and 2002, respectively. Figure 6a, b, c and d shows the corresponding maps that represent the geographic distribution of the yields of soybean at the same years. In general, it is recognized that the higher yields are located towards the north and the northeast of the area, not only because these regions have the best environment for growing the crop and are the areas where soyabean cultivation is more traditional, but also because cultivation in the south and southwest is new and expanding very slowly with little technological development. Nevertheless, it is clear that there is a strong relation between higher yields and the greater available soil water reserves during the period of study.

Fig. 5 (a) Percent of average available soil moisture from February 1 to March 15 1999; (b) Percent of average available soil moisture from February 1 to March 15 2000; (c) Percent of average available soil moisture from February 1 to March 15 2001; (d) Percent of average available soil moisture from February 1 to March 15 2002
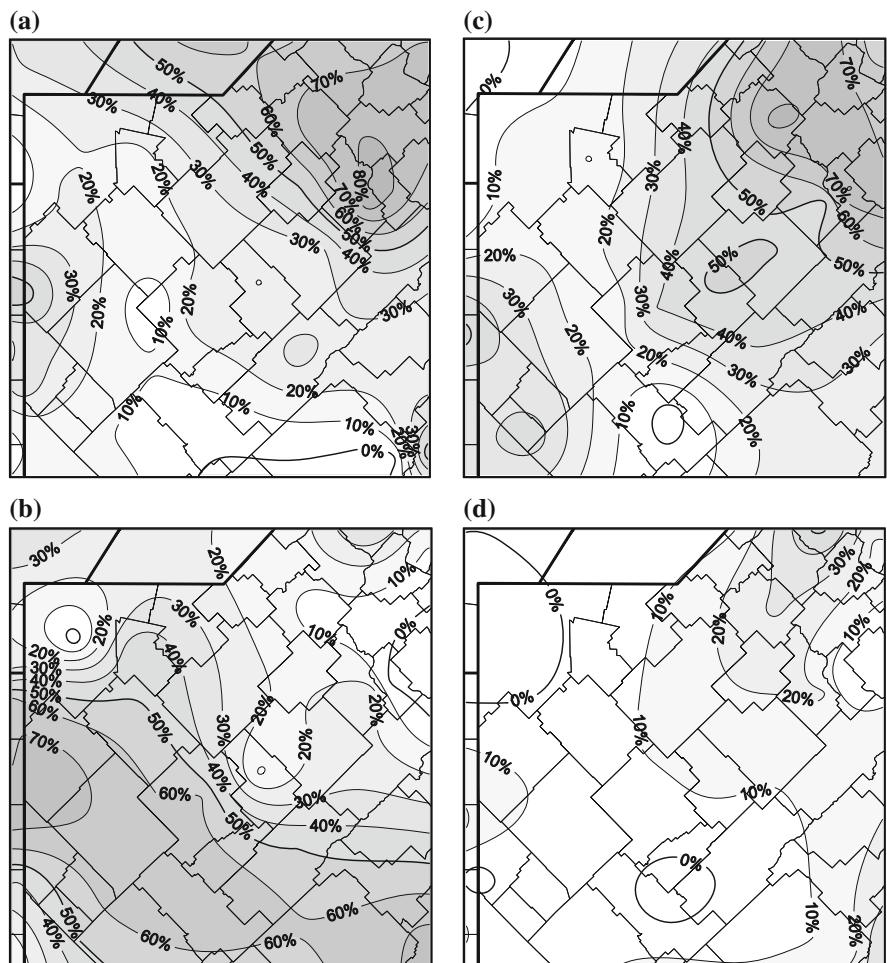
Fig. 6 (**a**) Soybean yields (Kg/ha) in 1999; (**b**) Soybean yields (Kg/ha) in 2000; (**c**) Soybean yields (Kg/ha) in 2001; (**d**) Soybean yields (Kg/ha) in 2002
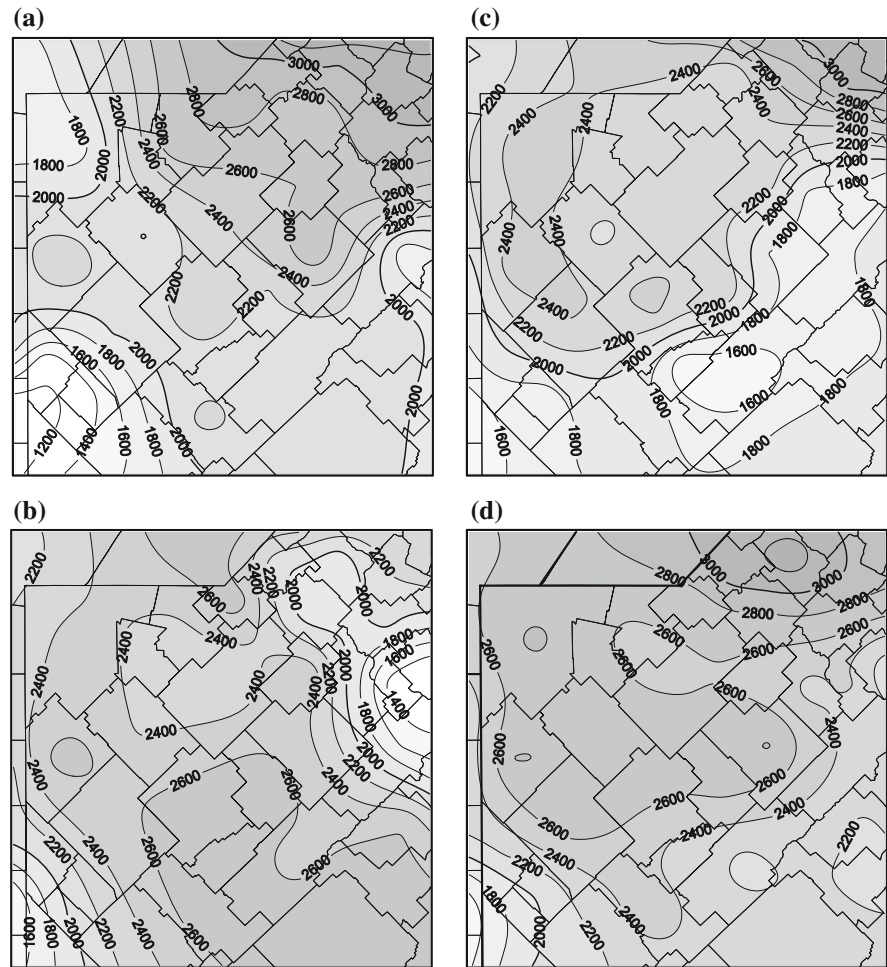
There is a significant correspondence between the soil water storages of 1999 (Fig. 5a) and 2000 (Fig. 5b) and the soybean yields in Fig. 6a and b, respectively). In spite of this, there are areas where this relationship does not hold and variations in the yield cannot be explained solely by the estimation of the soil water reserve. For example, in 2000 it appears a small area of drought (with very little or no available soil water reserves) in the northwest of the region in the area of General Villegas that did not display a noticeable diminution in yields. Observing the graph of depth of the water table in that locality (Fig. 7a), we can notice that in February 2000 it showed the water table near the surface (depth less than 2 m). It is possible to deduce that in this situation a water contribution takes place by capillarity from the water table towards the root zone and this factor is not considered in the soil water balance

calculation. However, in the eastern-northeastern of the region, the sector with the greater surface area suffering drought conditions, there is a marked diminution of soybean yields. In the graph of water table depths at Bragado (Fig. 7b), the representative locality for that sector, is observed that in February 2000 the water table was at its lower position during the period under study (almost 4 m down). Therefore an extra water contribution from the water table would be difficult. A similar situation as that described is observed in the vicinity of Junín (Fig. 7c). In 2001 and especially in 2002 (Fig. 5c and d), an intense drought in the northwest of the region can be observed, not corresponding with minima in the yields, but with certain relative maxima (Fig. 6c and d). This situation can be explained by reference to the graph of water table variations for General Villegas in Fig. 7a), which in

Fig. 7 (**a**) Depth of the water table in General Villegas; (**b**) Depth of the water table in Bragado; (**c**) Depth of the water table in Junín; (**d**) Depth of the water table in Nueve de Julio
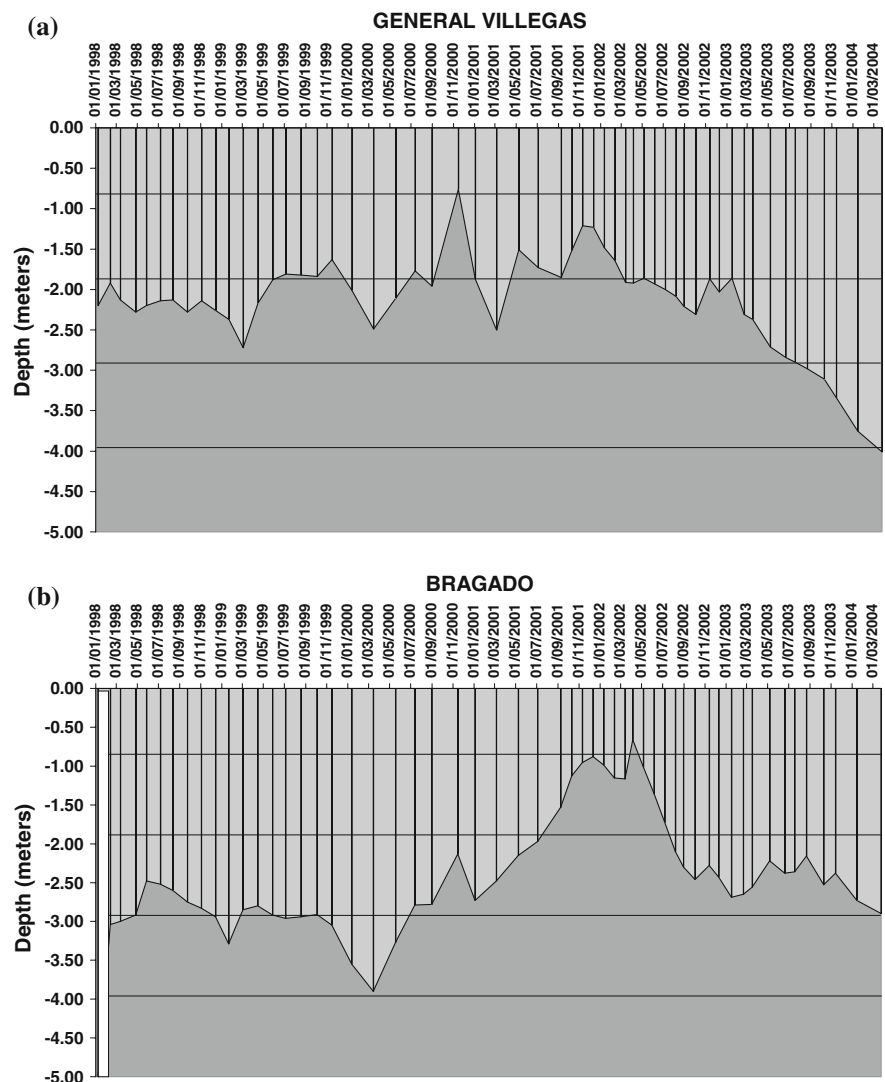
February–March shows that the water table depth is located close to the ground surface (less than 2 m). Something similar happens in the vicinity of Nueve de Julio (Fig. 7d), where the water table is near the surface for the February–March period supporting a secondary maximum in the soybean yields in 2002, which is not reflected in a greater soil moisture content as estimated by the water balance calculation.

When studying the graphs of water table variations, it is important to note that the depths of the water table that we can visualize are only representative of the locality where the well is installed. Therefore, it is not advisable to extrapolate the values to surrounding sectors due to the presence of the minor topographic forms described above. The water table level can be at a greater depth where the land surface is slightly higher, and nearer the surface in depressions or lower areas. It can even rise to the surface in overflowing areas and ponds. Nevertheless, at the regional scale, the relative water table levels shown in the graphs are valid.

Conclusions

Soybean yield is increasing rapidly due to technological and economic factors. But there is also a strong climatic signal. We can conclude that in each year the geographic configuration of the soybean yields is generally related to the average available

Fig. 7 continued
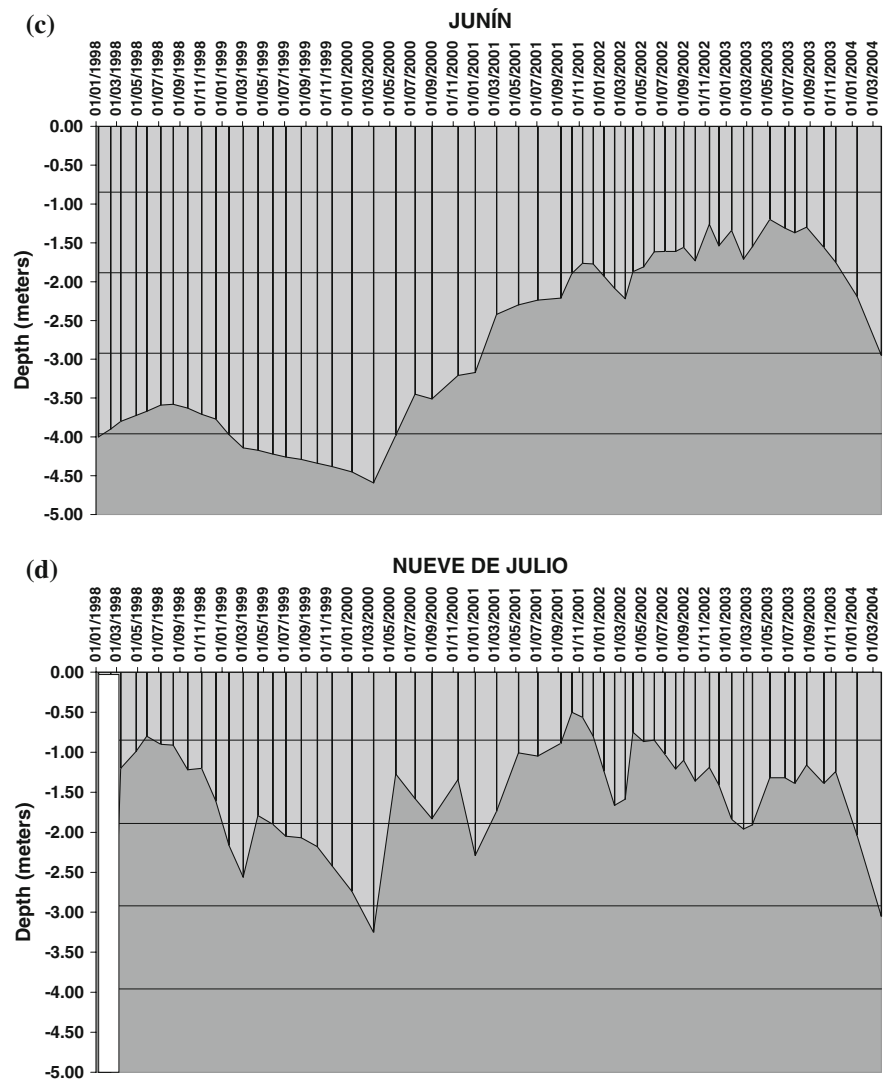
soil water reserve. Water table fluctuations and soil water balance (water surplus and water deficit) are strongly correlated. During a dry period, deepening water table (>3 m) makes attainment of soybean targets difficult and diminishes the yields. During excessively wet periods, the water table is shallow (<1 m), usually producing overflows and negatively affecting soybean yields.

Knowledge of the current soil water reserves, soil water excesses (water surplus), surface water level, water table level, and the historical scenarios data of these indicators allow us to predict future hydrologic scenarios in the medium term. Analysis of sowing, growth and harvesting times in relation to water demand, allowed us to evaluate critical dates for the crop and the hydrologic scenarios which are most significant for agricultural activities.

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