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Drought Risk in Argentine Pampean Region

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ABSTRACT

This paper analyses the drought risk in argentine Pampean region using statistical results of soil water storage. These are calculated by daily soil water balance whose methodology has been tested using values obtained in situ.

The goal of the paper is define a level of drought or minimum level of soil water storage, for the entire region which is, at the same time, the minimum optimum soil water content for crops. Over this moisture level, crops can yield with all their potential. The occurrence probability of values, for a determined time period, under that minimum is proposed.

The established level of drought is considered as the half of the available soil water capacity, which coincides with the minimum limit of optimum soil moisture (so called conditional drought level).

The possibility of the use of crop and/or soil management coefficients, allowing a more particular evaluation for different agricultural exploitation, is also analyzed. The less risk is founded at the corn area par excellence.

Key Words: Drought, risk, soil water balance, soil water deficit, Pampean Region, Argentina

Mathematics Subject Classification: 33B20, 03C40

Computing Classification System: Q25

1. INTRODUCTION AND OBJECTIVE

Drought is a normal, recurring feature of the climate in most parts of the world. It occurs almost everywhere, although its features vary from region to region. Modern peoples can effectively mitigate much of the impact of drought through irrigation and crop rotation. Failure to develop adequate drought mitigation strategies carries a grave human cost in the modern era, exacerbated by ever-increasing population densities. Periods of drought can have significant environmental, agricultural, health, economic and social consequences. The effect varies according to vulnerability.

As a drought persists, the conditions surrounding it gradually worsen and its impact on the local population gradually increases.

Defining drought is therefore difficult; it depends on differences in regions, needs, and disciplinary perspectives. In the most general sense, drought originates from a deficiency of precipitation over an extended period of time, resulting in a water shortage for some activity, group, or environmental sector. Whatever the definition, it is clear that drought cannot be viewed solely as a physical phenomenon. People tend to define droughts in three main ways:

Meteorological drought is brought about when there is a prolonged period with less than average precipitation. Meteorological drought usually precedes the other kinds of drought.

Agricultural droughts are droughts that affect crop production or the ecology of the range. This condition can also arise independently from any change in precipitation levels when soil conditions and erosion triggered by poorly planned agricultural endeavors cause a shortfall in water available to the crops. However, in a traditional drought, it is caused by an extended period of below average precipitation.

Hydrological drought is brought about when the water reserves available in sources such as aquifers, lakes and reservoirs fall below the statistical average. Hydrological drought tends to show up more slowly because it involves stored water that is used but not replenished. Like an agricultural drought, this can be triggered by more than a lost of rainfall.

Because there is no single definition for drought, its onset and termination are difficult to determine. We can, however, identify various indicators of drought, and tracking these indicators provides us with a crucial means of monitoring drought. Determining which indicators to use poses more difficulties for planners: should they rely on data collected for specific parameters (such as streamflow and snowpack), or should they select one or more indices, which incorporate and weigh various types of data in various combinations? Equally important in choosing these indicators is a consideration of the type or types of water shortage facing the planner an index or parameters well suited to agricultural concerns are of limited use to urban planners.

Understanding the historical frequency, duration, and spatial extent of drought also assists planners in determining the likelihood and potential severity of future droughts. The characteristics of past droughts provide benchmarks for projecting similar conditions into the future.

Hayes (2006) describes the main indexes used in USA and Australia - Percent of Normal Precipitation, Standardized Precipitation Index (SPI), Palmer Drought Severity Index (The Palmer; PDSI), Crop Moisture Index (CMI), Surface Water Supply Index (SWSI), Reclamation Drought Index and Deciles of precipitation amount – and their vantages and disadvantages.

NIDIS (2009) publishes monthly maps showing the spatial patterns of SPI for seven different periods ranging from one month (short-term conditions) to 24 months (long-term conditions). When taken together, they give a combined geographical and temporal picture of the severity of precipitation anomalies. On these maps, the red shading denotes dry conditions while the green shading indicates wet conditions.

Ravelo *et al*, (1999) applied Palmer index to all Pampean flatlands for two different periods (1931/60 and 1961/90) obtaining a more important drought risk for the first one.

Scian and Donnari (1997) analyzed the Palmer drought severity index in the semi-arid Pampas region.

The argentine National Institute of Agricultural Technology (2003), which acronym is INTA, classified the severity of drought duration as incipient, weak, moderate, severe and extreme. For example, the 1988 drought passed for all the steps reaching extreme drought, the worse stage.

This paper analyses the drought risk in argentine Pampean region using statistical results of daily soil water balance and monitoring the soil moisture and its anomalies. It is defined a level of drought or minimum level of soil water storage. Over it, crops can yield with all their potential without being affected by soil water deficit. Hence, the occurrence probability of values under that minimum is proposed for a determined period of time (a month, a ten days period, a week, etc.).

The main crop region of Argentina, the pampean region, has possibilities of drought risk, mainly during summer season. However, it generally shows areas with different drought ranks and in different times of the year, according to their seasonal precipitation and soil water regimes.

The yield loses not only occurred in exceptional years; almost every year water deficits affect different areas of the pampean region.

Other objective of this research is to obtain isolines maps with the probability of drought risk's, which could be interpreted quickly by the use of a fitted colours´ scale. These maps can show the other possibility: a good soil moisture content probability. All maps can be seen for every moment of the year and for the whole region.

2. MATERIALS AND METHOD

Figure 1 shows the location of the studied area.

The daily precipitation data, for the period 1968-2007, were provided by the National Meteorological Service (SMN), the National Institute of Agronomic Technology (INTA), and by other sources (agricultural cooperatives).

The normal daily mean reference evapotranspiration was estimated by the Penman-Monteith method (Allen *et al.,* 2004), for most of the meteorological stations and estimated by means of geographical interpolation for a few stations without data.

At Figure 2 can be seen the location and names of the meteorological stations, which have daily mean reference evapotranspiration (Etp) calculated with measured data and which have Etp obtained by geographical interpolation.

Former similar papers like Forte Lay *et al*. (2007), Kruse *et al.* (2001) and Scarpati *et al*. (2007) used potential evapotranspiration according Penman - Frère (FAO, 2004) with data obtained by Damario and Cattáneo (1982).

The soil hydrologic constants: field capacity (FC) and permanent wilting point (PWP) were those used by Forte Lay and Spescha, (2001), Forte Lay *et al.* (2007) and Scarpati *et al*., (2007).

The Model of soil water balance used is:

$PP - EP + \Delta St + Su + Def = O$

Where:

PP: daily precipitation

EP: mean reference evapotranspiration

Δ *St*: Soil water storage variation

Su: Soil water surplus

Def: Soil water deficit

The spatial and temporal variability of the soil water storage was examined using the Forte Lay - Aiello method (1996) which permits the estimation of the soil water content and its anomalies. It is based on Thornthwaite and Mather daily soil water balance method, using measured precipitation from the meteorological stations and daily mean reference evapotranspiration.

For the statistical study, the series of soil water content data obtained were adjusted, following Forte Lay and Troha, (1992), by means of the theoretical normal cubic-root probability distribution.

Three meteorological stations: Río Cuarto (33° '07 S 64° 14' W, 421 m), Junín (34° 33' S 60° 55' W, 81 m) and Dolores (36° 21' S 57° 44' W, 9 m) were used to illustrate the variations of soil water moisture for the period 1968-2007. These stations are located transversely in the study area.

2. 1. Considered concepts referred to soil water balance

The total soil moisture can be divided in two equal parts: the available soil water content and the non useful water. The permanent wilting point (PWP) is the limit between them.

The available soil moisture, as well, can be divided in two parts: the optimum soil water content (OC) and the conditional drought content (CD) which limit is the conditional drought level (CDL). The last one has been chosen as the upper limit of drought according to Forte Lay *et al*. (2007). The total soil moisture content varies from field capacity (FC) until the natural limit of desiccation (LD). LD is variable according to soil texture, being more closed to the PWP in loamy and clay soils than in sandy ones. All the mentioned parameters varies according the soil texture and the effective depth (root zone), which depends of a restrictive horizon existence. Some soils with high effective depth reach one meter or more and have high FC. Other soils, with low effective depth root zone, only reach lower depths and then the FC diminishes. All these variables were considered in the realization of this paper.

An established level of drought, the half of the available soil water capacity, is considered in this paper, it coincides with the minimum limit of optimum soil moisture (so called conditional drought level (CD)) and over this moisture level, crops can yield with all their potential.

The probability of occurrence of threepossible soil water content situations: absolute drought, conditional drought, and optimum humidity and water surplus, are calculated. The sum of the 3 ones has to be 100%.

2. 2. Maps construction

The calculus of the occurrence probability of values below the established drought level (CD) was realized, and the maps showing the results were performed using the software SURFER 8.0 which allows the construction of the isolines maps of soil water content.
The maps can be interpreted as maps of risk of regional drought, understanding in this case for drought a very wide concept, since it includes all kind of deficits implying, at least, a decrease in the vegetable cover potential yields.

2. 3. Considered concepts referred to soil coverage

The water consumption varies notably if the studied region is covered with a reference permanent prairie or with a summer crop, by using different coefficients Kc (FAO, 2004).

The reference permanent prairie means a prairie of active and permanent low grasses during the whole year.

The crop Kc multiplied by the evapotranspiration allows simulating the necessity of water with regard to that of a prairie. It is assumed for the reference prairie a Kc equal to 1. When a crop is considered, there are several steps to fulfil. Leaving winter and early spring the consumption of fallow or a prepared soil to sowing is approximately 40% of that of the prairie, so the value is 0.4 for the Kc. Starting with the emergence, this value increases by crop development and returns a little superior -to that of the reference prairie- in a certain moment of the year, coinciding with the flowering and grain formation and it descends again during maturation returning to the initial values.

3. RESULTS

3. 1. Soil water storage climatology

The soil moisture climatology for 10 days periods throughout the year for three stations, Río Cuarto, Junín and Dolores can be seen at Figures 3, 4 and 5. Dolores represents a more uniform climate while Río Cuarto has a clear trend of summer seasonal rains.

At Dolores the effect of potential evapotranspiration annual ´s distribution is evident, showing the biggest drought probabilities (absolute and conditional) in summer and smallest probabilities in winter. The probabilities of good soil water content and water surplus are inversed: maximum in winter and minimum in summer.

Junín has little precipitation seasonality, however, the effect of the potential evapotranspiración regime prevails over the rains distribution and so, the maximum probability of drought is in summer. It can be seen a little development of a secondary maximum of the conditional drought probability at the end of winter and early spring (September), coinciding with periods when heavy rains probability is even low and the evapotranspiración grows.

Río Cuarto shows evident summer precipitation seasonality. However, the period of high soil drought probability is not in winter but at early spring (September - October), when dry station has finished but the rains do not reach to the growing evapotranspiración. The maximum of summer drought is of minor importance and is evident only at the end of February. On the other hand, the biggest probabilities of good soil moisture content and with water surplus are at the beginning of autumn (March - April), when the evapotranspiration descends and the precipitation is still important, with a secondary maximum in early summer (December - January).

3. 2. Drought risk: permanent prairie

The drought risk in pampean region, as occurrence probability (%) of soil water storage equal or smaller than the conditional drought level, in a reference permanent prairie was obtained for all seasons.

In winter (Figure 6) the maximum probabilities of soil drought are observed in the west and mainly to northwest, being increased as season advances, and reaching a probability of 80-90%. At the eastern sector, they are very small, deducing that water surpluses are more probable in this region.

In the end of winter and early spring (Figure 7), the differences between the west-northwest and the eastern sector become big, because at the first sector, the water deficit probabilities grow up to 95% while they continue small in the oriental area.

In December, is observed an increase in soil moisture content which diminishes the drought probability. A relative low drought probability remains at the north center and southeast of Buenos Aires, Santa Fe and Entre Ríos provinces (Figure 8).

In January (Figure 9) low probabilities of drought are maintained in the surroundings of Córdoba and San Luis and quite high in the rest of the region, especially in the southwest where they are high: upper 95%. It can be observed a “bridge” of relatively smaller drought probabilities than the surroundings, which connects Córdoba with the centre-north of the region, wrapping the called “nucleus area of corn and soybean”. It is the main summer crops region and where these crops have their biggest yields. This area extends too, towards the southeast of the Buenos Aires province.

At the ends of summer and early autumn (Figure 10), being re-established a positive water balance in almost the whole region diminishes the probabilities of soil conditional drought, and increase, in consequence, those of good soil water content and water surplus. In April, the water deficit probabilities are smaller than 50% in the whole region, with the exception of the southwest boundary and in the center of Córdoba province, where they are more or less 50% (Figure 11). At the north and southeast of Buenos Aires, at the northern Córdoba, and at the most part of Santa Fe and Entre Ríos provinces they are lower than 30%.

At end of autumn and early winter (Figure 12) the region returns slowly to the pattern shown in the first map (Figure 6). In June, small drought probabilities, lower than 20%, are already observed at the east, while the areas with high probabilities of this condition in the west and northwest, especially in the center of Córdoba, are going wider, reaching 80%, so, the differences between both areas are increased.

3. 3. Drought risk: summer crops

The results vary notably if we suppose the studied region covered with a summer crop like corn or soybean and using coefficients Kc.

To visualize the effect of soybean crop, it is shown the drought risk maps for February, month of maximum water requirements for this crop (Figure 13 and 14). At Figure 13 there is the drought risk for the reference prairie, while at Figure 14 it can be seen the great difference when are applied the soybean coefficient Kc and the soil management.

Important differences are observed between the two figures, being evidenced a very low drought probability under soybean crop. This is only 30% at the area with high crop density for the drought conditional level selected and lower in Córdoba and southeast of Buenos Aires. This is due to that the consumption is very small in the rest of the year, so, the soil arrives to the critical period (February) with good water content.

Another example is observed using the coefficient Kc for corn crop. Values of Kc = 0.4 (40%) are found during autumn and winter, corresponding to the period when crop has been harvested and the soil is in fallow. With crop development the Kc values grow quickly to culminate in flowering with values higher than 1 (bigger to those of the reference prairie). After the grain formation the values decrease quickly during maturation returning to 0.4 during the harvest and in later periods.

The Figures 15 and 16 show the drought risk maps for the reference permanent prairie (Figures 15) and the corresponding to corn crop for the period December 15 to January 15 (Figures 16). Again it can be seen the great difference in risk values applying specific coefficients for a crop. Once, it is demonstrates that the entire region has high risks of conditional drought, being the most favoured (less risk) that one situated among the north of Buenos Aires, south of Santa Fe and southeast of Córdoba, exactly the corn area par excellence.

However, Figure 16, - with corn Kc – shows low risks of drought in a belt that unites west of Cordoba province with north of La Pampa and northwest of Buenos Aires and from there, to Buenos Aires southeast, while regions presumably more humid have high risks of soil drought.

The reason is the different sowing dates. At the west, center and southeast, in the chosen period (December 15 to January 15), the high water consumption appears because the latest sowing dates, due to the soil water content in some areas and the spring frost risk, especially toward the south. To northeast the sowing dates are early and, in the period of this figure, the moment of high water consumption has already passed. Hence, the small values of water content and therefore the high risks of conditional drought

4. CONCLUSIONS

There is provides a criterion for estimate the climatic drought risk, which will be useful for the agriculture of any region.

The main crop region of Argentina, the pampean region, has possibilities of drought risk, mainly during the summer season. It presents different drought levels, according to seasonal precipitation and soil water content and different severity according the season and the soil coverage. The consequences of a particular level of drought are different between a prairie and a crop.

The use of crop and/or soil management coefficients, allow a more particular evaluation for different agricultural exploitation. The selection of the Kc coefficients is very important because they influenced the obtained results, so they have to be chosen very carefully.

To estimate the drought risk with others periods of time are possible. It can be proposed, the statistical analysis of shorter periods than a month, like 15-days or 10-days. And so, it would be necessary a probability study of the complete crop’s period, to evaluate each region risk.

The need of soil water economy can be deduced by means of an appropriate soil management and /or the implementation of complementary irrigation, when it is possible.

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Figure 1: Studied area.

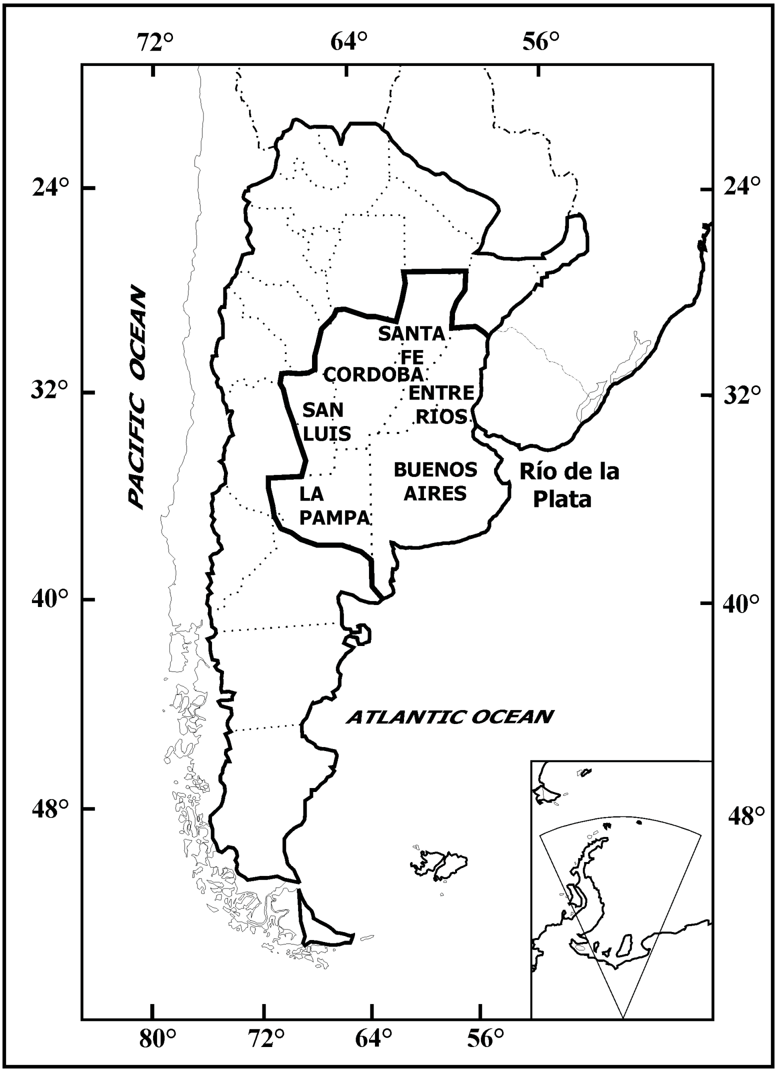
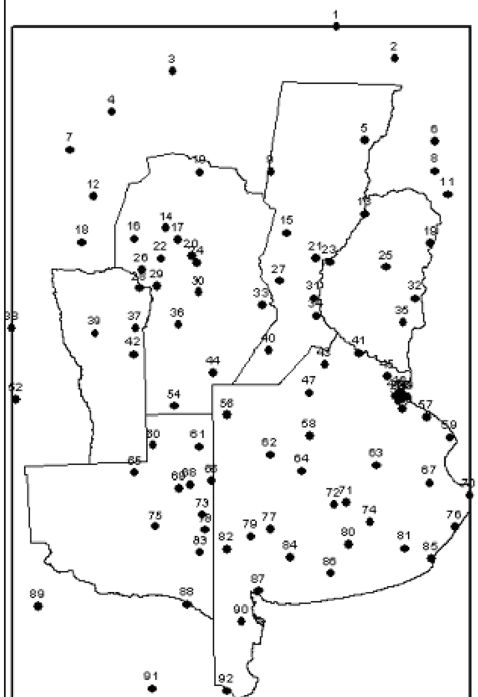


Figure 2: Geographic location of the used stations. D: Etp calculated by measured data. I: Etp obtained by geographical interpolation.

GEOGRAPHIC LOCATION OF THE USED STATIONS

D: calculated by measured data

I : calculated by geographical interpolation



Nᵉʳ	STATION NAME	Source of Pp. data	Source of Etp. data	Nᵉʳ	STATION NAME	Source of Pp. data	Source of Etp.data
1	Pres. Roque Sáenz Peña	S.M.N.	D	47	Junín	S.M.N.	D
2	Resistencia	S.M.N.	D	48	San Miguel	S.M.N.	D
3	Santiago del Estero	S.M.N.	D	49	Aeroparque	S.M.N.	I
4	Catamarca	S.M.N.	D	50	Buenos Aires	S.M.N.	D
5	Reconquista	S.M.N.	D	51	El Palomar	S.M.N.	I
6	Mercedes (Corrientes)	I.N.T.A.	D	52	San Rafael	S.M.N.	D
7	La Rioja	S.M.N.	D	53	Castelar	I.N.T.A.	D
8	Curuzú Cuatiá	S.M.N.	I	54	Huinca Renancó	Other	D
9	Ceres	S.M.N.	D	55	Ezeiza	S.M.N.	I
10	V. María del Río Seco	S.M.N.	D	56	General Villegas	Other	D
11	Monte Caseros	S.M.N.	D	57	La Plata	S.M.N.	D
12	Chamical	S.M.N.	D	58	Nueve de Julio	S.M.N.	D
13	La Paz	S.M.N.	D	59	Punta Indio	S.M.N.	D
14	Estación Thea	Other	D	60	La Maruja	Other	I
15	Rafaela	I.N.T.A.	D	61	General Pico	S.M.N.	D
16	Control 1	S.M.N.	D	62	Pehuajó	S.M.N.	D
17	Córdoba	S.M.N.	D	63	Las Flores	S.M.N.	I
18	Chepes	S.M.N.	D	64	Bolívar	S.M.N.	I
19	Concordia	S.M.N.	D	65	Victorica	Other	D
20	Pilar (Córdoba)	S.M.N.	D	66	Catriló	Other	I
21	Sauce Viejo	S.M.N.	D	67	Dolores	S.M.N.	D
22	Control 2	Other	D	68	Anguil	I.N.T.A.	I
23	Paraná	S.M.N.	D	69	Santa Rosa	S.M.N.	D
24	Manfredi	I.N.T.A.	I	70	Santa Teresita	S.M.N.	I
25	Villaguay	S.M.N.	D	71	Azul	S.M.N.	D
26	Villa Dolores	S.M.N.	D	72	Olavarría	S.M.N.	I
27	El Trébol	S.M.N.	I	73	Macachín	Other	D
28	Control 3	S.M.N.	I	74	Tandil	S.M.N.	D
29	Control 4	Other	D	75	General Acha	Other	D
30	Hernando	Other	I	76	Villa Gesell	S.M.N.	I
31	Oliveros	I.N.T.A.	I	77	Coronel Suárez	S.M.N.	D
32	Concepción del Uruguay	I.N.T.A.	D	78	General Campos	Other	I
33	Marcos Juárez	S.M.N.	D	79	Pigüé	S.M.N.	D
34	Rosario	S.M.N.	D	80	Benito Juárez	S.M.N.	I
35	Gualeguaychú	S.M.N.	D	81	Balcarce	I.N.T.A.	D
36	Río Cuarto	S.M.N.	D	82	Bordenave	I.N.T.A.	I
37	Control 5	Other	D	83	Bernasconi	Other	I
38	San Martín (Mendoza)	S.M.N.	I	84	Coronel Pringles	S.M.N.	I
39	San Luis	S.M.N.	D	85	Mar del Plata	S.M.N.	D
40	Venado Tuerto	S.M.N.	I	86	Tres Arroyos	S.M.N.	D
41	San Pedro	I.N.T.A	I	87	Bahía Blanca	S.M.N.	D
42	Villa Reynolds	S.M.N.	D	88	Río Colorado	S.M.N.	D
43	Pergamino	I.N.T.A.	D	89	Neuquén	S.M.N.	I
44	Laboulaye	S.M.N.	D	90	Hilario Ascasubi	I.N.T.A	D
45	Delta del Paraná	I.N.T.A.	I	91	San Antonio Oeste	S.M.N.	D
46	Don Torcuato	S.M.N.	I	92	Viedma	S.M.N.	I

Figure 3: Soil moisture climatology for 10 days periods in Río Cuarto.

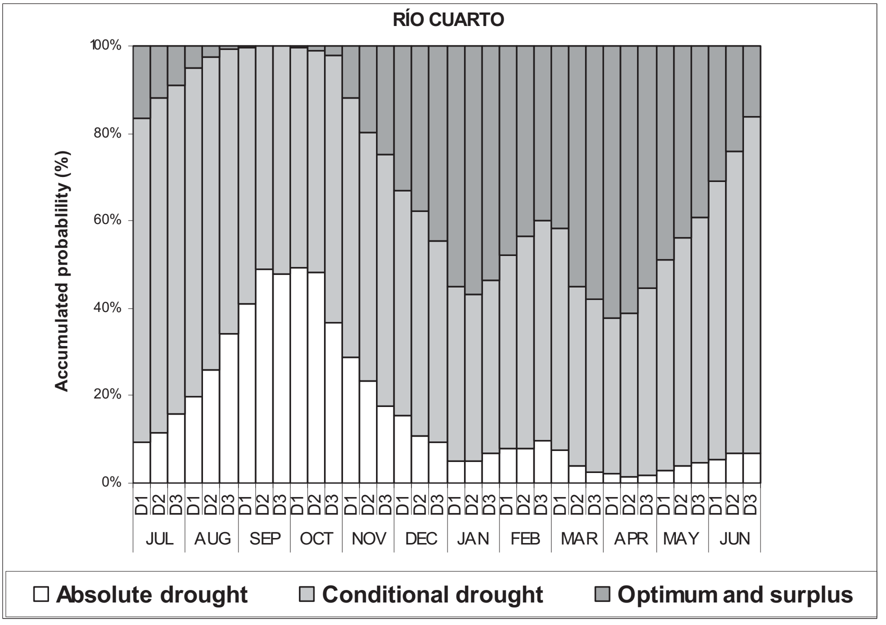


Figure 4: Soil moisture climatology for 10 days periods in Junín.

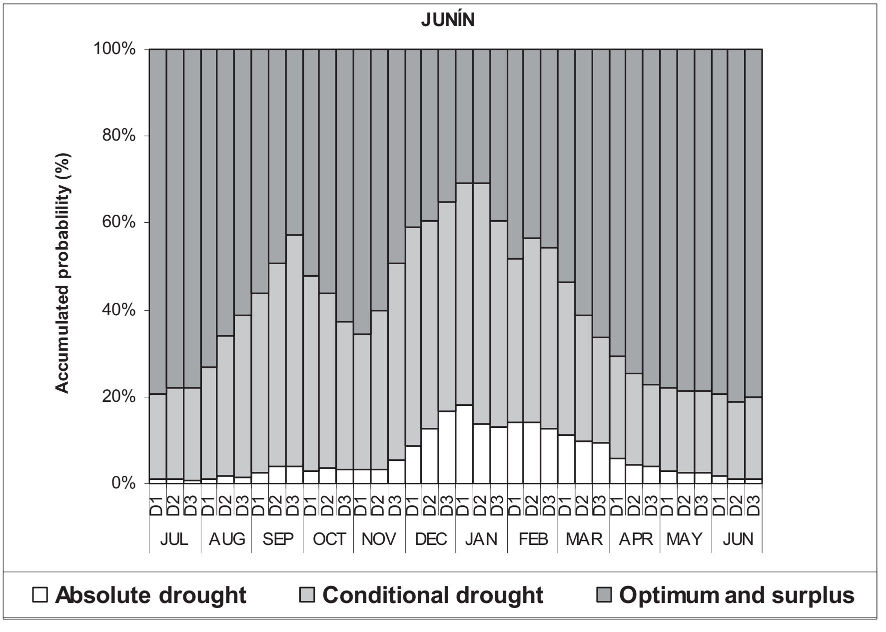


Figure 5: Soil moisture climatology for 10 days periods in Dolores.

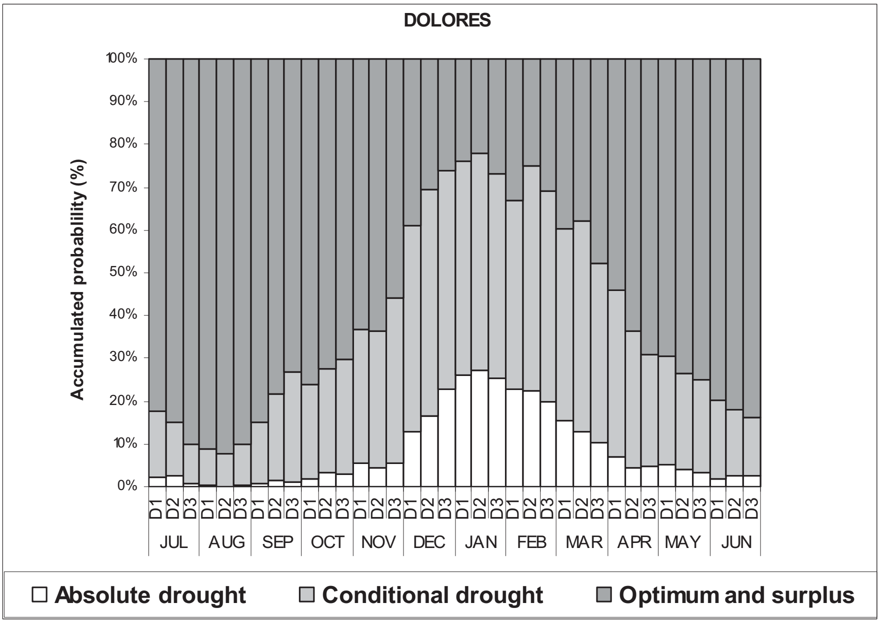


Figure 6: Probability of drought risk. Soil water storage occurrence probability (%) equal or smaller than the conditional drought level in a permanent prairie during July.

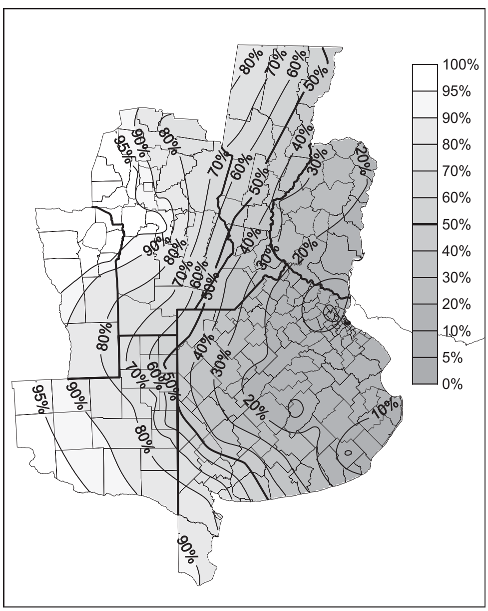


Figure 7: Probability of drought risk. Soil water storage occurrence probability (%) equal or smaller than the conditional drought level in a permanent prairie during September.

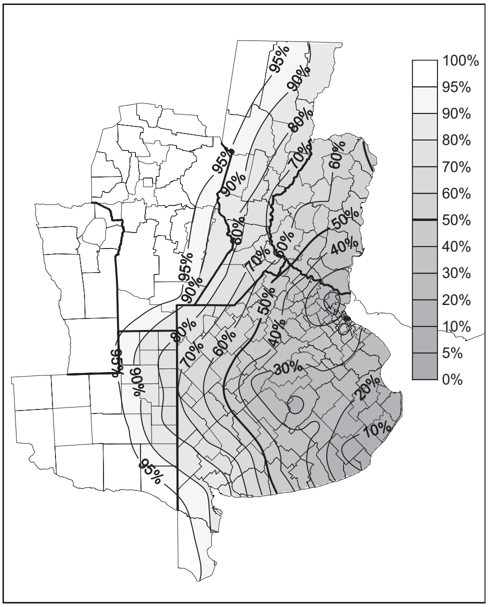


Figure 8: Probability of drought risk. Soil water storage occurrence probability (%) equal or smaller than the conditional drought level in a permanent prairie during December.

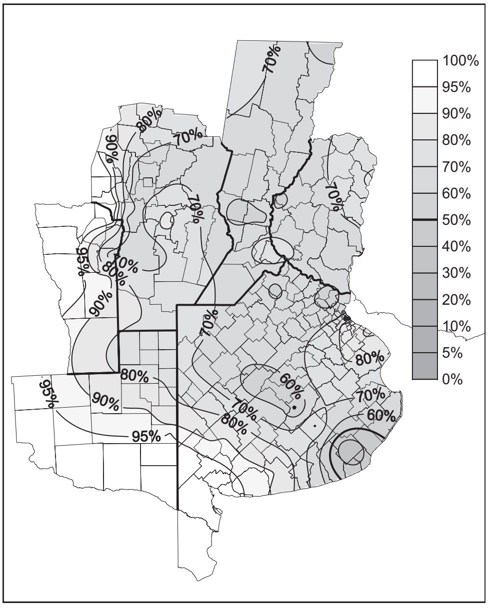


Figure 9: Probability of drought risk. Soil water storage occurrence probability (%) equal or smaller than the conditional drought level in a permanent prairie during January.

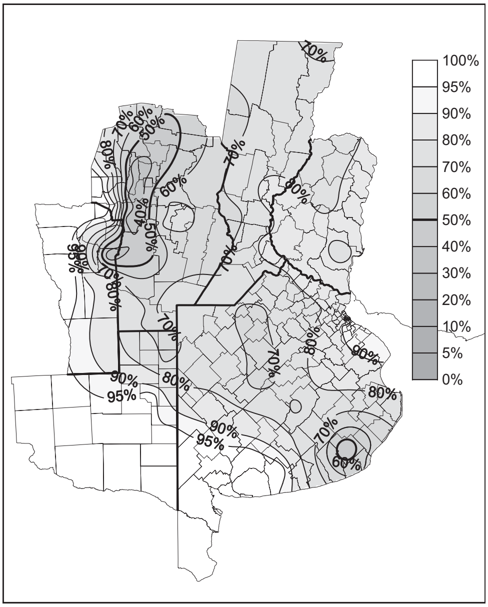


Figure 10: Probability of drought risk. Soil water storage occurrence probability (%) equal or smaller than the conditional drought level in a permanent prairie during March.

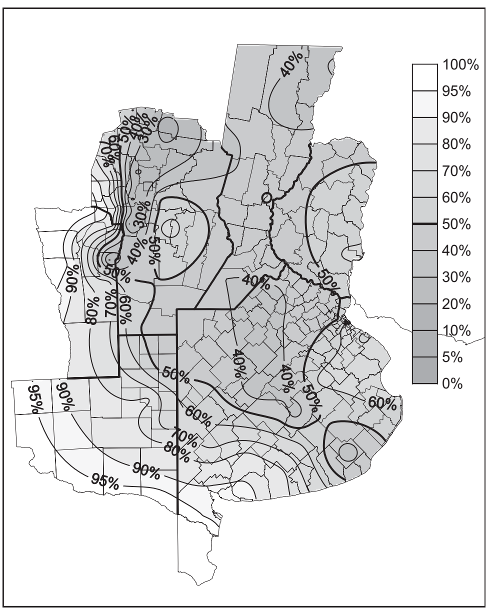


Figure 11: Probability of drought risk. Soil water storage occurrence probability (%) equal or smaller than the conditional drought level in a permanent prairie during April.

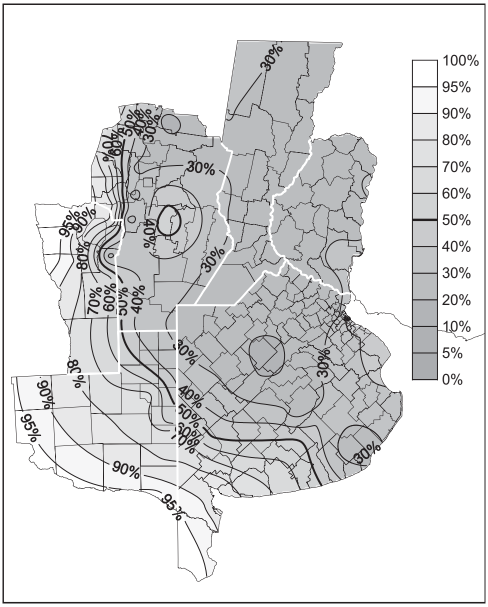


Figure 12: Probability of drought risk. Soil water storage occurrence probability (%) equal or smaller than the conditional drought level in a permanent prairie during June.

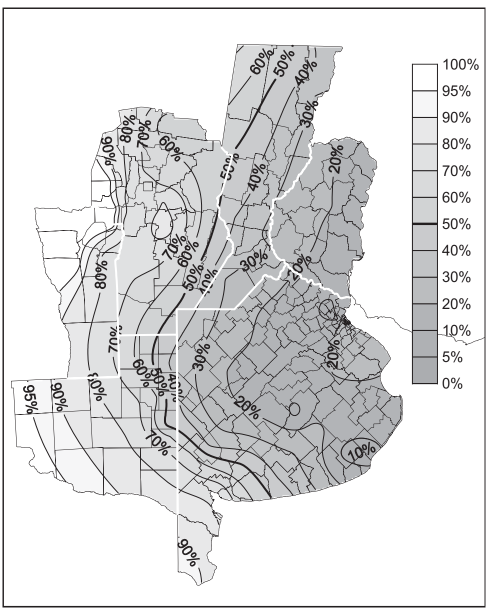


Figure 13: Probability of drought risk. Soil water storage occurrence probability (%) equal or smaller than the conditional drought level in a permanent prairie during February.

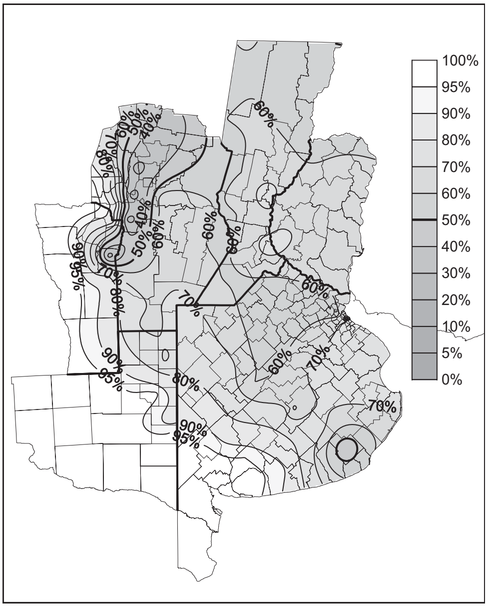


Figure 14: Probability of drought risk. Soil water storage occurrence probability (%) equal or smaller than the conditional drought level for a soybean culture during February.

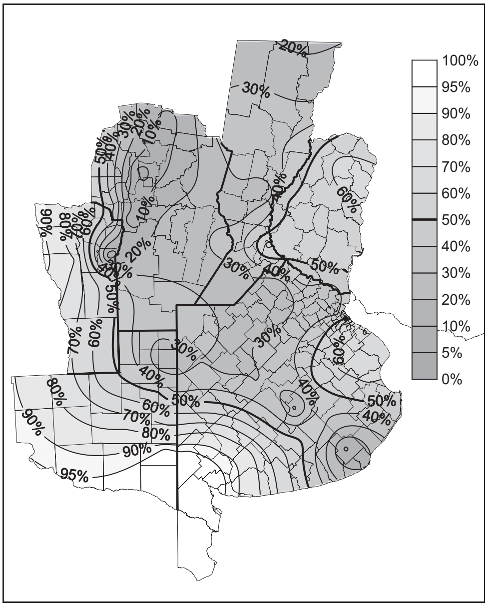


Figure 15: Probability of drought risk. Soil water storage occurrence probability (%) equal or smaller than the conditional drought level in a permanent prairie during December 15 to January 15.

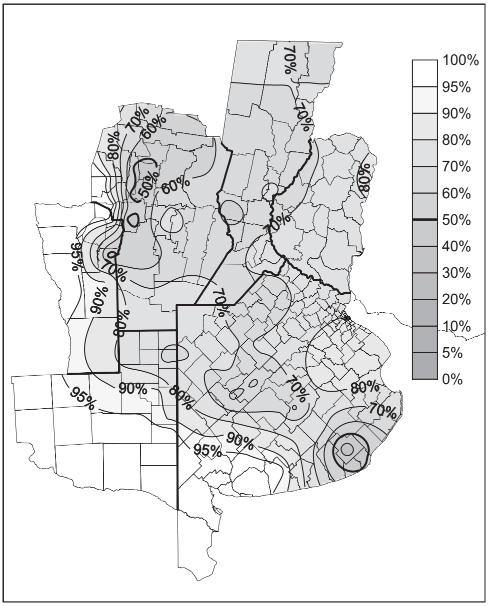


Figure 16: Probability of drought risk. Soil water storage occurrence probability (%) equal or smaller than the conditional drought level for a corn culture during December 15 to January 15.