

The probability of potentially useful work days during the year in Londrina

Probabilidade de dias potencialmente úteis de trabalho durante o ano em Londrina

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Abstract

The probabilities associated with the number of days suitable for working outdoors and for working with machinery in the field were estimated for the municipality of Londrina, state of Parana, Brazil. Days with less than 10 mm of precipitation were considered suitable for outdoor operations. The number of days per month and the number of ten-day periods satisfying this condition were modeled with a negative binomial distribution, and the probabilities were estimated at different levels. The days suitable for working with machinery in the field were specified as those days for which the values of water storage in the soil were at or below 90% of the available water capacity in the upper 30 cm of the soil and for which the precipitation was less than 5 mm. A first-order Markov chain was used to estimate the conditional probabilities of favorable days for working with machinery in the field. The results indicated that the best time to work outdoors in Londrina extends from April through September, with the most favorable period occurring between late July and early September. The highest probabilities of favorable days for working in the field occur during April and from June through August. The probabilities of two consecutive days favorable for working with machinery in the field are highest between June and August. These probabilities allow the determination of the needs for the performance of tasks involving mechanized equipment.

Key words: Negative binomial distribution, Markov Chain, conditional probability, outside works, agriculture trafficability

Resumo

Foram estimadas as probabilidades de dias úteis de trabalho em locais descobertos e a trafegabilidade de maquinários no campo, para o município de Londrina-PR. Dias com precipitação igual ou superior a 10 mm foram considerados inadequados para operações a céu descoberto. O número de dias mensais e decendiais que satisfazem essa condição foram ajustados à distribuição binomial negativa e foram estimadas as probabilidades em diferentes níveis. Os dias favoráveis ao trabalho com máquinas no campo foram estabelecidos como aqueles em que os valores de armazenamento de água no solo eram iguais ou inferiores a 90% da capacidade de água disponível na camada superficial de 30 cm do solo e a menor que 5 mm. O método da cadeia de Markov de primeira ordem foi utilizado para estimar as

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probabilidades condicionais de dias favoráveis ao trabalho com máquinas. Os resultados indicam que o melhor período para realização de obras em ambiente externo em Londrina se estende de abril a setembro, com ótimo entre final de julho e início de setembro. As maiores probabilidades de um dia ser favorável à execução de práticas mecanizadas no campo compreendem o mês de abril e os meses de junho a agosto, e as probabilidades de dois dias seguidos favoráveis ao tráfego de maquinários no campo apresentam ótimo entre os meses de junho e agosto. Essas probabilidades possibilitam determinar as necessidades de máquinas para execução das práticas mecanizadas.

Palavras-chave: Distribuição binomial negativa, cadeia de Markov, probabilidade condicional, obras em ambiente externo, trafegabilidade agrícola

Introduction

The climatic conditions of a place or region will determine the number of days available during the year to perform outdoor work, such as the construction and repair of houses, buildings, roads and dams and the operation of machinery on agricultural soils. Prolonged and intense rainfall events cause the greatest difficulties for outdoor operations, contributing to cost increases associated with manual labor and delays in schedules (SILVA et al., 2007). The actual number of days of work in the State of São Paulo during the summer is approximately 50% lower than in winter, with an average interruption of activities of 15% due to weather conditions (RICARDO, CATALANI, 1990).

The displacement of work crews and the exposure of materials in open places are factors that raise costs and delay projects in general. In these cases, two situations must be addressed by decision makers. These situations are based on the weather (forecasts at short intervals, from few hours to one week) and on the climate, indicated by the mean rainfall for at least 30 years, as recommended by the World Meteorological Organization. The weather forecast can direct the initiation of tasks such as road rehabilitation, the renovation and installation of roofs, external finishing and the transport of workers. However, project planning activities must be based on the climate of the region, with priority allocated to outdoor activities when rainfall is less probable (BAZZANO; ELTZ; CASSOL, 2007).

In agriculture, the feasibility of operation of the machinery, from soil preparation to harvest, depends

on the dynamics of water in the surface layers of soil as an indicator that can assist in decision making (FERNANDES; SOUZA; VITORIA, 2000). The moisture in the surface layers of the soil affects the properties of bearing capacity, shear force, friction and adhesion, determining its ability to bear traffic (CASTRO NETO, 2001). Because soil moisture influences the conditions under which motorized machinery (e.g., tractors) can be operated, planning based on the distribution and amount of rainfall can produce a count of the number of days favorable for field work and can therefore reduce the manpower and time expenses required to conduct such activities (ASSIS et al., 1989). Achieving greater use of the days on which agricultural machines can be used is of utmost importance because tractors can travel only with difficulty if the soil moisture is excessive. The excess moisture causes soil compaction, and the soil collects on the working surfaces of the machinery. This situation results in unsatisfactory yields (ASSIS et al., 1989).

According to Assis et al. (1989), the statistical dependence of a given day's weather on the previous day's weather justifies the use of Markov chain methods to obtain forecasts of the number of days suitable for working in the field. Assis et al. (1989) and Fernandes, Souza and Vitoria (2000) considered that the conditions for field work would be favorable on a given day if the available soil water on that day was less than or equal to 90% in the first 15 cm of the profile. A day with 5 mm or more rainfall (equivalent to the average daily potential evapotranspiration) was considered an unfavorable day for field work regardless of the

amount of available soil water. Any day that showed precipitation of 10 mm or more on the previous day was also classified as an unfavorable day for field operations. Selirio and Brown (1972) concluded that cultivation is possible if the soil water content is equal to or less than 90% of the capacity of the field depth of 12 cm, irrespective of the water content in the deeper layers.

According to Pelloia and Milan (2010) and Salvador et al. (2010), it is of fundamental importance under the conditions of intensive cultural practices and of farms occupying large areas to program operations with machines in the field in a rational manner for the efficient use of agricultural machinery and hand labor. Castro Neto (2001) observed that if a long series of meteorological data is available, it is important to conduct climatological studies by calculating the water balance in the soil and classifying the days as fit or unfit for various mechanized activities, types of soil and agricultural activities of interest.

The objectives of this study were to estimate the probabilities of potentially useful days for work in open places and for the trafficability of the soil for machinery in the field in the municipality of Londrina, northern Parana State, Brazil.

Materials and Methods

We used daily rainfall data for 1961-2010 from the meteorological stations of the Agronomic Institute of Paraná (IAPAR) and the National Institute of Meteorology (INMET) for the city of Londrina (23° 22'S latitude, 51° 10'W longitude, 585 m altitude). The local soil in the region where IAPAR is located is classified as Oxisol clayey (EMBRAPA, 2006). Note, however, that the local soils in the city of Londrina include other types of soils in addition to those cited in this study.

Days suitable for working outdoors

Initially, we recorded the days in the data series on which the rainfall was less than 10 mm. Days with greater amounts of rainfall were considered to be days on which tasks requiring clear skies could not be performed.

As the variance (s^2) of the data was higher than the average (\bar{X}), we used the negative binomial distribution model (ASSIS; ARRUDA; PEREIRA, 1996) to analyze monthly and ten-day periods by determining the theoretical frequency distribution of the number of days during the year on which the rainfall was greater than or equal to 10 mm. This analysis was based on the 50-year data series.

According to Assis, Arruda and Pereira (1996), the probability function for the negative binomial distribution takes the following form:

$$p(X) = \frac{\Gamma(X+K)}{\Gamma(X+1)\Gamma(K)} \frac{P^K}{(1+P)^{K+X}}$$

The parameters P and K are estimated as follows:

$$P = \frac{1}{\bar{X}} (s^2 - \bar{X}), \quad K = \frac{\bar{X}^2}{s^2 - \bar{X}}$$

where

s^2 = variance of sample data

\bar{X} = sample mean.

A nonparametric Kolmogorov-Smirnov (KS) test was used to evaluate the fit of the negative binomial distribution to the observations. This test can be used to evaluate the null hypothesis (H_0) that the values of a time series originate from a population with a pre-established theoretical distribution (ASSIS; ARRUDA; PEREIRA, 1996; BLAIN; BRUNINI, 2007). The test was defined as follows:

$$D_{\max} = \text{Max } |F'(x) - F(x)|$$

$$F(x) = Fa/(N + 1),$$

where

Max = largest absolute value among the frequency classes defined for the test;

Dmax = difference value calculated for the Kolmogorov-Smirnov test;

F*(x) = theoretical distribution function;

F(x) = empirical distribution function (derived from the sample data);

Fa = cumulative frequency of each class;

N = number of classes of default values.

The null hypothesis (**H₀**) that the sample data represent a negative binomial distribution is rejected if the calculated value of Dmax is greater than or equal to the tabulated value (critical value) corresponding to the specified significance level (5% for this study). The KS test was applied to the monthly and decennial data for all months of the year. Adjusted polynomial functions were used to fit the cumulative probabilities, and values were obtained from these functions to describe the number of days on which the rainfall was greater than or equal to 10 mm at probability levels of 10, 25, 50, 75 and 90% (ASSIS; ARRUDA; PEREIRA, 1996).

Days allowing the operation of machinery in the field

To calculate the number of days of work in the field, we used the sequential water balance method of Thornthwaite and Mather (1955) with the daily potential evapotranspiration estimated by the Penman-Monteith method. We used a spreadsheet developed for this purpose and available at IAPAR. According to Faria and Caramori (1986), the available water in the soil is approximately 10% by volume. A depth of 30 cm corresponds to the soil layer used for cultivation. This layer includes approximately 80% of the root system of most annual species. Under these conditions, the value of the yield of available water (CAD) in the soil is 30 mm.

In the model of Thornthwaite and Mather (1955), the storage of water in the profile (ARM) is given by the following negative exponential function:

$$\text{ARM} = \text{CAD} e^{-[\text{NAc}/\text{CAD}]},$$

where

NAc = cumulative negative when $\Sigma = (\text{P-ETP}) < 0$

$$\text{NAc} = \text{CAD} \text{Ln ARM}/\text{CAD}.$$

The days on which the precipitation was less than 5 mm and / or the value of the ARM was less than 90% of the CAD in the 30-cm surface layer of the soil were considered favorable for work in the field (ASSIS et al., 1989). Otherwise, the days were considered unfit for traffic involving machinery because such traffic would increase the occurrence of soil compaction in the presence of excessive moisture. Under these conditions, the performance and wear of the tractor are also affected (NAGAOKA et al., 2003; ARAUJO-JUNIOR et al., 2011).

Because two consecutive days with rain reflect the persistence of the previous day's weather, the values of the meteorological parameters for the previous day were incorporated in the selection of favorable days to work. Therefore, a first-order Markov chain was used to estimate the conditional probabilities of occurrence of days suitable for work. These estimates were based on the methodology adopted by Assis et al. (1989):

P (F) = number of years in which favorable conditions occurred on the first day / total number of years;

$$\text{P (D)} = 1.0 - \text{P (F)};$$

P (F | F) = number of days with favorable conditions on both the first and second days / number of years in which favorable conditions occurred on the first day;

$$\text{P (D | F)} = 1.0 - \text{P (F | F)};$$

$$\text{P (F | D)} = [\text{P (F)} * \text{P (D | F)}] / \text{P (D)};$$

$$\text{P (D | D)} = 1.0 - \text{P (F | D)},$$

Where:

$P(F)$ = probability of a favorable day;

$P(D)$ = probability of one unfavorable day;

$P(D | F)$ = probability that a day is unfavorable if the previous day was favorable;

$P(F | D)$ = probability that a day is favorable if the previous day was unfavorable;

$P(D | D)$ = probability that a day is unfavorable if the previous day was unfavorable;

$P(F | F)$ = probability that a day is favorable if the previous day was favorable.

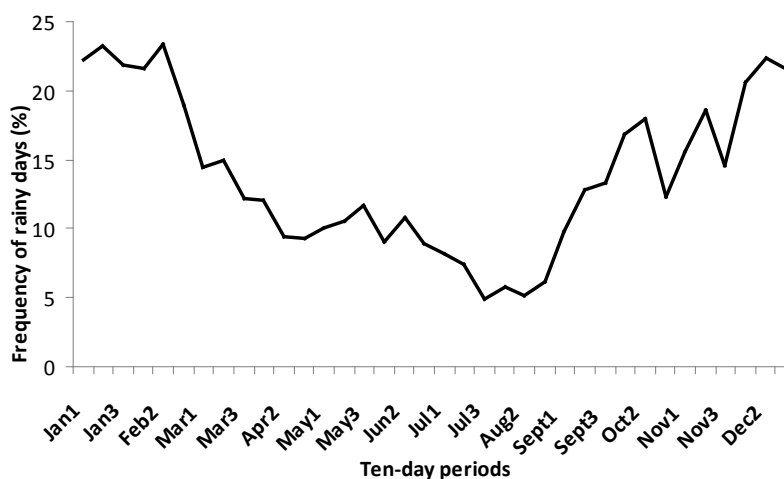
Results and Discussion

Figure 1 shows the frequency of occurrence (expressed as a percentage) of rainy days in Londrina, PR. The driest period of the year occurred from April to September, with an optimum between

the third ten days of July and the first ten days of September. This period is ideal for the harvesting and drying of grains and for activities involving the performance of services in the external environment.

All of the monthly and decennial frequency distributions of the days on which the rainfall was greater than or equal to 10 mm day^{-1} in Londrina were well described by negative binomial probability distributions. The critical value of the KS statistic was <0.1937 (Table 1). The theoretical distribution appears to fit the empirical distribution throughout the period of analysis. This result shows that the parameters of the negative binomial probability distribution can be used to represent the trend of the series of monthly and decennial rainfall equal to or greater than 10 mm day^{-1} in Londrina to model the sequences of dry days suitable for outdoor work (Table 1).

Figure 1. Frequency of ten-day periods with rainfall equal or higher than 10 mm day^{-1} in Londrina, PR.



Source: Elaboration of the authors.

Table 1. Adjustment of the series of rainfall values greater than or equal to 10 mm day⁻¹ in Londrina to the negative binomial distribution for the months of the year and periods of ten days by the Kolmogorov – Smirnov test (calculated value of the goodness-of-fit test). The critical value at the 5% significance level is 0.1937.

Month	Monthly	1 st 10 days	2 nd 10 days	3 rd 10 days
January	0.0654	0.0442	0.0577	0.0542
February	0.0526	0.0398	0.0364	0.0674
March	0.0549	0.0643	0.0263	0.0604
April	0.0239	0.0465	0.0518	0.0757
May	0.0721	0.0402	0.0544	0.0410
June	0.0587	0.0313	0.0436	0.0518
July	0.0330	0.1100	0.0348	0.0300
August	0.0422	0.0430	0.0354	0.0544
September	0.0751	0.1043	0.0600	0.0584
October	0.0723	0.0464	0.0636	0.0476
November	0.0298	0.0244	0.0508	0.0513
December	0.0519	0.0418	0.0549	0.0856

Source: Elaboration of the authors.

The negative binomial distribution has also been successfully used to estimate the number of days during the year when the rainfall exceeds 50 mm in Pelotas (ASSIS; ARRUDA; PEREIRA, 1996) and by Massignam and Dittrich (1998) to estimate the average number and monthly probability of occurrence of frost in the State of Santa Catarina.

Buriol et al. (1998) investigated the probability of occurrence of the minimum air temperature harmful to the pollination of rice flowers and found that the negative binomial distribution did not fit data series of air temperatures ≤ 13 ° C, 15 ° C and 17 ° C. According to the authors, a cold air mass located over the region will remain for a day or more, producing a group of days with low temperatures.

A set of fourth-degree polynomial functions was used to represent the cumulative distributions of the occurrence of precipitation greater than or equal to 10 mm per day for periods of ten days each month. The correlation coefficients calculated for this analysis were near 1.0. Table 2 shows the number of days in the month with precipitation greater than or equal to 10 mm for probability levels of 10, 25, 50, 75 and 90%. These values were extracted from the fitted curves specified by the polynomial functions for the city of Londrina. These levels refer to a specific

probability of occurrence of a minimum number of days on which the rainfall would be unlikely to prevent the performance of outdoor tasks.

For example, for the month of January, the probability of the occurrence of at least 5.85 days on which the precipitation is less than 10 mm was 50%. This probability indicates that the number of days of impairment is expected to exceed this value in two out of every four years. The 75% probability indicates that the number of days in January with rainfall less than 10 mm is not less than 3.85 days in one out of every four years. These data are useful if it is necessary to determine the month in which it is most probable that the work environment will be unsuitable based on a given rainfall value. The same reasoning is used to interpret Table 3.

In developing agricultural projects, the recommended level is a 75% probability of rainfall. A fixed probability value is used because the use of average values may cause the undersizing of projects (BERNARDO; MONTOVANI; SOARES, 2005; MURTA et al., 2005). This probability level can be used to calculate the duration of operations in environments in which the opportunities for performing necessary work depend on the weather conditions.

Table 3 shows the number of days with precipitation not less than 10 mm in a ten-day period at probability levels of 10, 25, 50, 75 and 90% for the city of Londrina.

Table 2. Days with rainfall greater than or equal to 10 mm estimated from the negative binomial distribution for monthly periods from January to December in Londrina, PR, with different probability levels.

Month	Probabilities (%)				
	10	25	50	75	90
January	10.35	8.15	5.85	3.85	2.40
February	8.57	6.80	4.83	3.00	1.65
March	6.70	5.05	2.99	1.40	0.40
April	5.00	3.45	1.85	0.72	0.15
May	5.80	3.70	1.78	0.41	0.00
June	5.40	3.40	1.50	0.15	0.00
July	3.90	2.30	0.80	0.00	0.00
August	3.20	1.75	0.40	0.00	0.00
September	5.81	4.25	2.45	1.02	0.29
October	6.80	5.45	3.78	2.20	1.00
November	7.40	5.80	3.85	2.10	0.80
December	10.05	7.76	5.42	3.40	1.90

Source: Elaboration of the authors.

Table 3. Days with rainfall greater than or equal to 10 mm estimated from the negative binomial distribution for 10-day periods from January to December in Londrina, PR, with different probability levels.

Periods	10-day periods	Probabilities (%)				
		10	25	50	75	90
01-10/01	Jan 1	4.30	3.19	2.00	1.00	0.40
11-20/01	Jan 2	4.70	3.35	2.00	0.95	0.32
21-31/01	Jan 3	4.70	3.41	2.11	1.05	0.40
01-10/02	Feb 1	3.80	3.01	2.10	1.25	0.65
11-20/02	Feb 2	4.60	3.35	2.09	1.01	0.40
21-28/02	Feb 3	3.40	2.30	1.21	0.49	0.10
01-10/03	Mar 1	2.95	2.12	1.25	0.62	0.31
11-20/03	Mar 2	3.40	2.25	1.18	0.43	0.08
21-31/03	Mar 3	3.35	2.01	0.90	0.20	0.00
01-10/04	Apr 1	2.80	1.81	0.95	0.35	0.05
11-20/04	Apr 2	2.25	1.45	0.72	0.22	0.00
21-30/04	Apr 3	2.50	1.60	0.75	0.20	0.00
01-10/05	May 1	2.50	1.55	0.70	0.12	0.00
11-20/05	May 2	2.81	1.61	0.60	0.00	0.00
21-31/05	May 3	2.98	1.95	1.00	0.35	0.50
01-10/06	Jun 1	2.30	1.41	0.60	0.08	0.00
11-20/06	Jun 2	2.60	1.68	0.80	0.22	0.00
21-30/06	Jun 3	2.70	1.50	0.51	0.00	0.00
01-10/07	Jul 1	2.18	1.30	0.53	0.02	0.00
11-20/07	Jul 2	2.10	1.18	0.35	0.00	0.00
21-31/07	Jul 3	1.65	0.90	0.18	0.00	0.00

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01-10/08	Aug 1	1.82	0.90	0.05	0.00	0.00
11-20/08	Aug 2	1.71	0.70	0.00	0.00	0.00
21-31/08	Aug 3	2.00	1.09	0.25	0.00	0.00
01-10/09	Sept 1	2.60	1.50	0.60	0.00	0.00
11-20/09	Sept 2	3.00	1.95	0.98	0.34	0.02
21-30/09	Sept 3	3.10	2.20	1.23	0.55	0.20
01-10/10	Oct 1	3.45	2.50	1.45	0.70	0.29
11-20/10	Oct 2	3.70	2.65	1.55	0.70	0.26
21-31/10	Oct 3	3.00	2.05	1.11	0.49	0.16
01-10/11	Nov 1	3.20	2.30	1.35	0.65	0.30
11-20/11	Nov 2	3.60	2.70	1.70	0.85	0.40
21-30/11	Nov 3	3.60	2.40	1.29	0.50	0.10
01-10/12	Dec 1	3.90	2.98	1.89	0.95	0.41
11-20/12	Dec 2	4.10	3.18	2.10	1.15	0.51
21-31/12	Dec 3	4.35	3.33	2.21	1.22	0.55

Source: Elaboration of the authors.

For the first ten days of January, the probability of at least two days with rainfall greater than 10 mm was 50%. This probability indicates that in two out of every four years, the number of days that will be unsuitable for outdoor work will exceed this value. The fewest days on which the rainfall level was greater than 10 mm were found during the second ten days of August. This period represents the ideal time to work under clear skies.

Table 4 presents the simple and conditional probabilities of favorable days (F) and unfavorable days (D) for work in the field in Londrina. The probabilities reflect a strong dependence on the condition of the previous day. Thus, a favorable day will be more probable if it is immediately preceded by a favorable day. In contrast, a favorable day will be less probable if it is immediately preceded by an unfavorable day. Analogous reasoning applies to the probability of an unfavorable day.

Table 4. Probabilities of favorable days for work in the field (P(F)), favorable days if the previous day was favorable (P(F|F)), favorable days if the previous day was unfavorable (P(F|D)), unfavorable days for work in the field (P(D)), unfavorable days if the previous day was favorable (P(D|F)) and unfavorable days if the previous day was unfavorable (P(D|D)). Londrina, PR.

10-day periods	P(F)	P(F F)	P(F D)	P(D)	P(D F)	P(D D)
Jan 1	0.68	0.79	0.48	0.32	0.21	0.52
Jan 2	0.65	0.78	0.37	0.35	0.22	0.63
Jan 3	0.66	0.81	0.43	0.34	0.19	0.57
Feb 1	0.68	0.75	0.51	0.32	0.25	0.49
Feb 2	0.64	0.76	0.40	0.36	0.24	0.60
Feb 3	0.72	0.80	0.45	0.28	0.20	0.55
Mar 1	0.77	0.85	0.48	0.23	0.15	0.52
Mar 2	0.70	0.82	0.43	0.30	0.18	0.57
Mar 3	0.77	0.86	0.47	0.23	0.14	0.53

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Apr 1	0.83	0.88	0.61	0.17	0.12	0.39
Apr 2	0.83	0.89	0.57	0.17	0.11	0.43
Apr 3	0.83	0.89	0.52	0.17	0.11	0.48
May 1	0.79	0.91	0.35	0.21	0.09	0.65
May 2	0.75	0.88	0.38	0.25	0.12	0.63
May 3	0.76	0.87	0.36	0.24	0.13	0.64
Jun 1	0.82	0.91	0.40	0.18	0.09	0.60
Jun 2	0.82	0.93	0.40	0.18	0.07	0.60
Jun 3	0.77	0.90	0.31	0.23	0.10	0.69
Jul 1	0.85	0.93	0.47	0.15	0.07	0.53
Jul 2	0.84	0.92	0.35	0.16	0.08	0.65
Jul 3	0.88	0.94	0.40	0.12	0.06	0.60
Aug 1	0.89	0.95	0.53	0.11	0.05	0.47
Aug 2	0.89	0.95	0.43	0.11	0.05	0.58
Aug 3	0.88	0.92	0.49	0.12	0.08	0.51
Sept 1	0.79	0.90	0.47	0.21	0.10	0.53
Sept 2	0.77	0.88	0.47	0.23	0.12	0.53
Sept 3	0.78	0.85	0.47	0.22	0.15	0.53
Oct 1	0.76	0.84	0.50	0.24	0.16	0.50
Oct 2	0.75	0.84	0.55	0.25	0.16	0.45
Oct 3	0.81	0.85	0.64	0.19	0.15	0.36
Nov 1	0.76	0.79	0.64	0.24	0.21	0.36
Nov 2	0.77	0.82	0.58	0.23	0.18	0.42
Nov 3	0.76	0.81	0.62	0.24	0.19	0.38
Dec 1	0.67	0.76	0.50	0.33	0.24	0.50
Dec 2	0.69	0.76	0.51	0.31	0.24	0.49
Dec 3	0.71	0.81	0.50	0.29	0.19	0.50

Source: Elaboration of the authors.

The value of $P(F)$ varied from 64% in the second ten days of February to 89% in the first and second ten-day periods in August. The average value of $P(F)$ was 77%, with a standard deviation of 7%. The periods of the year most favorable to trafficability in the field were the month of April and the period from the first ten days of June to the third ten days of August, all with $P(F)$ between 77-89%.

The conditional probabilities $P(F|F)$ ranged from 75% in the first ten days of February to 95% in the first and second ten-day periods in August, with an

average of 85% and a standard deviation of 6%. These figures show that a favorable day is relatively probable immediately after a favorable day, resulting in two consecutive days favorable to the use of motorized equipment in the field. These conditional probabilities demonstrate the phenomenon of the persistence of the previous day's weather conditions (ASSIS et al., 1989). Based on this information, the optimum period for agricultural operations extends from the first ten days of June to the third ten days of August. The values of $P(F|F)$ were greater than 90% for these time intervals (Table 4).

However, the conditional probabilities $P(F|D)$ varied between 31% in the third ten days of June to 64% in the third ten days of October and the first ten days of November. These values are relatively low because a favorable day is relatively less probable after an unfavorable day.

The most probable ten-day periods for the use of agricultural machinery in the field are determined by the local rainfall for the city. The knowledge of the most favorable periods is considered in conjunction with the moisture content of the soil to determine the times for sowing, harvesting and for the rational use of pesticides (ASSIS et al., 1989; PELOIA, MILAN, 2010).

The values shown in Table 4 can be used to identify the months associated with a higher probability of unfavorable days for the operation of machines in the field.

The $P(D)$ values were complementary to the $P(F)$ values, ranging from 11% in the first and second ten-day periods in August to 36% in the second ten days of February. The average value of $P(D)$ was 23%, with a standard deviation of 7%. The least favorable period for field work includes the months of December and January and continues until the second ten days of February, with probability values between 29% and 36%. This period coincides with the period during which the greatest precipitation occurred.

The occurrence of an unfavorable day immediately following an unfavorable day was relatively probable and demonstrated the dependence of adverse conditions for the use of machinery on the previous day's weather conditions, although the conditional probability was less than $P(D|F)$. The conditional probabilities $P(D|D)$ ranged between 36% in the third ten days of October and the first ten days of November to 69% in the third ten days of June. The second ten days of January, the month of May, the third ten days of June and the second ten days of July proved to be the most unfavorable as a result of the persistence of the previous day's

weather conditions.

The values of $P(D|F)$ were substantially less than the values of $P(F|D)$, ranging from 5% in the first and second ten-day periods in August to 25% in the first ten days of February. The highest values were concentrated in December, January and February (19-25%), with lower values during July and August (5-8%). The probability of an unfavorable day if the previous day is favorable is much smaller than the probability of a favorable day if the previous day is unfavorable.

The results of this study are consistent with the findings of Assis et al. (1989), who applied the same methodology to obtain the probabilities, on a weekly basis, for days on which tractors could be operated between August 31 and May 2 in Uberaba, MG. The authors concluded that the probable number of favorable days, at a probability level of 0.93, was 33 days throughout the observation period. At a probability level of 0.80, zero to four favorable days are expected to occur.

Similarly, Fernandes, Souza and Vitoria (2000) determined the number of potentially useful days for working with machines in Forest Ganhães, MG, Brazil. A total of 170 working days per year occurred between March and September, with the best period from June to August. The authors concluded that the months from October to February provided the smallest number of working days due to the distribution of rainfall during the year and the water-holding capacity of the soil in the region.

Conclusions

The negative binomial distribution function was adequate to adjust the monthly data and the ten-day periods of the year in which rainfall equals or exceeds 10 mm in Londrina, PR.

The most favorable period for outdoor work in Londrina is from April to September, with an optimum between the third ten days of July and the first ten days of September. The period that would

not be recommended is the period of concentrated rainfall, from October to February.

The probability of a favorable day for work with farm machinery is highest in April and from the first ten days of June to the third ten days of August. The odds of two consecutive favorable days for field work with machinery are best between June and August.

The probabilities presented enable the determination of the needs for machinery to be used for the implementation of mechanized agricultural practices.

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