INFLUENCE OF IRRIGATION ON WHEAT CROP

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ABSTRACT: The use of irrigation has been increased significantly in wheat crops in Brazil. This study aims to evaluate the effect of irrigation on the productivity, on flour technological quality and on the wheat root system. In a field experiment conducted at IAPAR, in Londrina - state of Paraná (PR), Brazil, the IPR 118 cultivar was grown under sprinkler irrigation (Irrigated Treatment) and without irrigation (Non-irrigated Treatment). The productivity was determined by harvesting three samples of 25 m^2 per treatment. The same samples were used to evaluate the flour technological quality, considering, among other parameters, gluten strength (W). The evaluation of the root system was performed after the harvest, considering a profile of 0 to 45 cm of soil depth, and sampling eight plants per treatment. The profile wall method was used to determine the roots number (RN) and the monolith method to determine the root dry mass (RDM). Irrigation increased wheat productivity in three times, while W was reduced in the flour. Nevertheless, the value of W found in the Irrigated Treatment (249 10^{-4} J) was sufficient to keep wheat classification as bread type, the same as IPR 118 cultivar is classified. The measured values of RN and RDM were similar or higher for the Non-irrigated Treatment.

KEYWORDS: *Triticum aestivum* L., spinkler, productivity, alveograph, root system.

INFLUÊNCIA DA IRRIGAÇÃO NA CULTURA DO TRIGO

RESUMO: O uso da irrigação na triticultura tem aumentado significativamente nos últimos anos no Brasil. Neste trabalho, objetivou-se avaliar a influência da irrigação na produtividade, na qualidade tecnológica da farinha e no sistema radicular do trigo. Em experimento de campo no IAPAR, em Londrina, Paraná, a cultivar IPR 118 foi cultivada sob irrigação por aspersão convencional (Tratamento Irrigado) e sem irrigação (Tratamento Sequeiro). A produtividade foi determinada, colhendo-se três amostras de 25 m^2 por tratamento. Nestas mesmas amostras, procedeu-se à análise da qualidade tecnológica da farinha, sendo avaliada, entre outros parâmetros, a força de glúten (W). A avaliação do sistema radicular foi realizada após a colheita, no perfil de 0 a 45 cm de profundidade do solo, amostrando-se oito plantas em cada tratamento. O método da parede do perfil foi utilizado para determinar o número de raízes (NR) e o método do monólito para determinar a massa seca de raízes (MSR). A irrigação aumentou em três vezes a produtividade do trigo, porém diminuiu o W na farinha. Ainda assim, o valor de W encontrado no Tratamento Irrigado (249 10^{-4} J) foi suficiente para manter a classificação do trigo como tipo-pão, a mesma para o qual a cultivar IPR 118 é classificada. Os valores medidos de NR e a MSR foram iguais ou maiores no Tratamento Sequeiro.

PALAVRAS-CHAVE: *Triticum aestivum* L., aspersão, produtividade, alveografia, sistema radicular.

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Recebido pelo Conselho Editorial em: 24-2-2011
Aprovado pelo Conselho Editorial em: 13-8-2012

INTRODUCTION

Wheat is one of the main agricultural crops in Brazil, and in 2007/2008 there were 1.852 million hectares of planted area, of which almost half (821.300 thousand hectares) was located in the state of Paraná, Brazil. At that harvest, the average productivity of the crop in Brazil was 2,212 kg ha^{-1} and in Paraná was equal to 2,340 kg ha^{-1} (CONAB, 2010).

Although wheat crop in not usually irrigated in Brazil, its adoption has increased significantly in the last years, especially in the central of Brazil, due to the fact that the use of irrigationminimizes the risk and increases the productivity potential of crops (SILVA et al., 2001). However, the studies about the influence that irrigation may have on productivity, flour technological quality and wheat root system are insufficient, especially when it comes to studies that assess these variables together, rather than analyze them in isolation.

Evaluating the productivity of different wheat cultivars in the state of São Paulo, FELÍCIO et al. (1992) concluded that the water regime was an important factor in production. According to the authors, irrigation provides good productions in the dry season and ensures production during the rainy season, when dry weather occur occasionally submitting the plants to water deficit and reducing the productivity of them. GAJRI et al. (1991), FRIZZONE et al. (1996) and SCALCO et al. (2002) studied and showed a positive relation between irrigation practice and wheat productivity.

The concept of technological quality of wheat is closely related to the industrial use of flour to be produced (FELÍCIO et al., 2006). According to GUTKOSKI & JACOBSEN NETO (2002) and COSTA et al. (2008), quality is determined by the interaction between the growing conditions (cultivar, soil, climate, pests and crop management), and the operations of harvest and postharvest (drying and storage). Thus, the quality of wheat as well as productivity is also influenced by the water regime. However, unlike productivity, SCALCO et al. (2002) found that the technological quality decreases with irrigation, demonstrating the need for the adoption of irrigation management practices that meet both the criteria of productivity, and the quality of the commercial product.

The analysis of crop root system generates important information related to productivity and also to quality of the commercial product, such as in wheat case (PASSIOURA, 1983; KLEPPER, 1991). The root system develops according to certain biological standards (KLEPPER, 1991), however, the amount of roots produced at a given point on the ground is the result of interactions between these patterns and other factors including soil conditions where the crop is grown. Thus, the analysis of the root system development can be divided between the growth in depth and spatial variation of the density of roots. Working in soil profile of 60cm depth, PIRES et al. (1991) found that in the 0 to 40cm layer was 83% of the total mass of roots of wheat grown under center pivot irrigation. According to these authors, this layer may be considered as the one corresponding to the effective depth of the root system used in irrigation practice.

Thus, the aim of this study was to evaluate the influence of irrigation on productivity, on flour technological quality and on root system of wheat crop.

MATERIAL AND METHODS

The study was conducted at the Agronomic Institute of Paraná (IAPAR) in Londrina - state of Paraná (PR), Brazil (latitude 23º18'S, longitude 51º09'W and altitude of 585 m). The soil is classified as Eutroferric Red Latosol (EMBRAPA, 1999), presenting in the 0 to 20 cm layer, 13.3% of sand, 13.3% of silt and 73.4% of clay. The climate is humid subtropical (Cfa), according to the Köeppen classification, with an average annual temperature of 21.5 ºC and precipitation between 1,400 and 1,600 mm per year (IAPAR, 1994). Table 1 presents the results of the chemical analysis of the soil of the experimental area, and the samples were collected before the experiment installation in the 0 - 20 cm layer.

TABLE 1. Results of the soil chemical analysis on the 0 - 20 cm layer prior to the experiment installation.

Variable*	Irrigated Area	Non-irrigated Area
P (mg dm^{-3})	10.90	12.90
C (g dm^{-3})	15.70	15.90
pH in $CaCl_2$	4.80	4.90
Al ($cmol_c$ dm^{-3})	0.11	0.07
H + Al ($cmol_c$ dm^{-3})	6.68	6.20
Ca ($cmol_c$ dm^{-3})	3.57	4.05
Mg ($cmol_c$ dm^{-3})	2.59	2.92
K ($cmol_c$ dm^{-3})	0.59	0.78
Sum of basis ($cmol_c$ dm^{-3})	6.75	7.75
CEC ($cmol_c$ dm^{-3})	13.43	13.95
Saturation by basis (%)	50.30	55.60
Saturation by aluminum (%)	1.60	0.90

* P is phosphorus; C is carbon; pH is potential of hydrogen; Al is aluminum; H is hydrogen; Ca is calcium; Mg is magnesium; K is potassium; CEC is cation-exchange capacity.

The experimental area was located next to the Meteorological Station of the Meteorological System of Paraná (SIMEPAR). Precipitation, temperature, global solar radiation, relative humidity and wind speed were collected during the experimental period and used to determine the daily reference evapotranspiration (ETo) by the Penman-Monteith method (ALLEN et al., 1998) using the REF-ET program (ALLEN, 2000).

Seeds of wheat (*Triticum aestivum L.*) of IPR 118 cultivar were sown in an area of 0.2 ha (Figure 1). The sowing was performed on May 10th, 2007, with spacing of 17cm and about 70 plants m^{-1}. It was performed fertilization at sowing of 250kg of 4-30-10 and another of 40kg of N 30 days after sowing. The control of pests, diseases and weeds were done whenever necessary. The total area was divided roughly in half, one part was conducted with conventional sprinkler irrigation (Irrigated Treatment) and the other without irrigation (Non-irrigated Treatment).

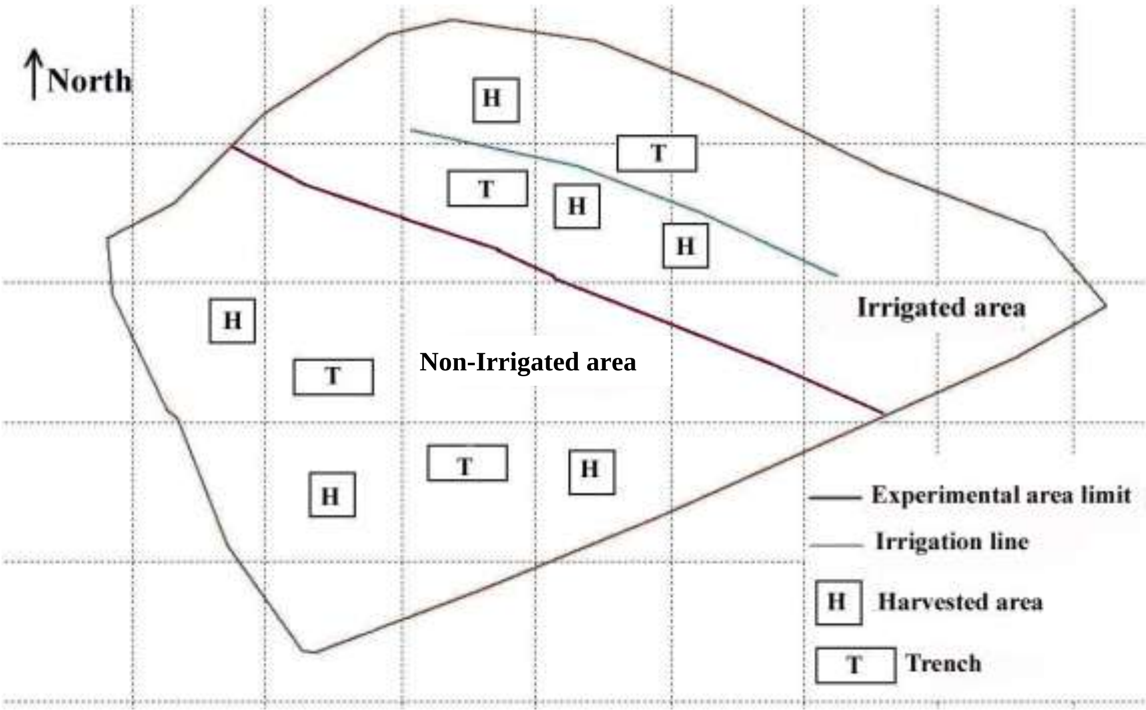


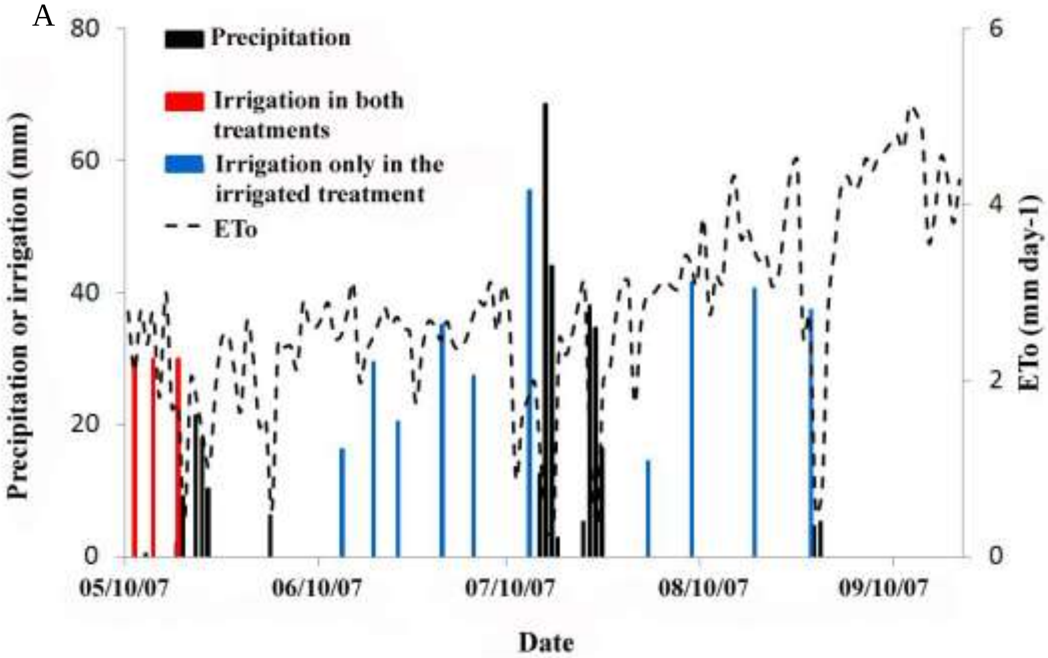
FIGURE 1. Layout of the experimental area.

To permit the establishment of the culture in both treatments, the Irrigated and the Non--irrigated Treatments were irrigated until the emergence of plants. For this, three irrigations were performed on the 11th, 14th and 18th of May 2007 totaling 90 mm (Figure 2A). After the emergence, eight days after sowing, the irrigation was suspended in the Non-irrigated Treatment, but was kept in the Irrigated Treatment (Figure 2A). Thus, ten irrigations were performed totalizing an application of 318.2 mm. The irrigations were performed on the 13th, 18th, 22nd and 29th of June, 4th and 13th of July and finally 1st, 8th, 18th and 27th of August 2007. At physiological maturity (about 20 days before harvest), the irrigation was suspended to ensure adequate grain maturity to allow good quality of flour (Figure 2A), as recommended by GUERRA & ANTONINI (1996).

The irrigation management was conducted by the Agroclimatic Monitoring System (AMS), which is operated by IAPAR (CARAMORI & FARIA, 2002). The AMS simulates the daily water balance for specific crops using metereological data of the SIMEPAR network and soil characteristics of the local stations, providing the results at: http://www.iapar.br/modules/conteudo/conteudo.php?content=900. The AMS incorporates the computational model described by FARIA & MADRAMOOTOO (1996), which estimates the water balance components of a cultivated area. In this model, the water infiltration in the soil and its redistribution are governed by the Darcy's Law and the evapotranspiration is partitioned into three components: soil evaporation, transpiration and evaporation of water retained in the leaf canopy after precipitation or irrigation events. These terms depend on atmospheric demand (ETo), the availability of water in the soil, water extraction by roots and characteristics of crop growth.

Thus, the AMS model developed by FARIA & MADRAMOOTOO (1996) was implemented with data from experiments that were conducted by FARIA et al. (1994) on the same place where this study was conducted. Thus, irrigation management was performed to maintain soil moisture near to the field capacity condition, so that irrigations were applied when the AMS indicated extraction of maximum of 60% of the available water in the soil profile up to 40 cm depth (Figure 2B).

A



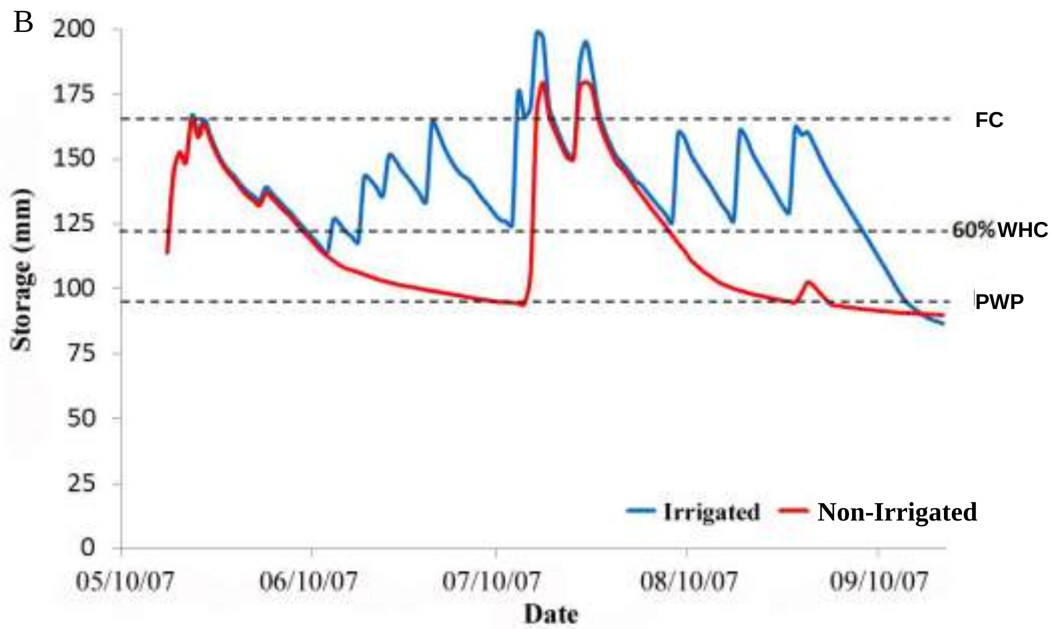


FIGURE 2. A) Distribution of precipitation, reference evapotranspiration (ETo), and irrigation during the wheat crop cycle on Irrigated and Non-irrigated Treatments in Londrina-PR; B) Variation of soil water storage on the 0 to 40 cm layer as simulated by the AMS.

The development stage of the plants in both treatments was monitored by taking as reference the Feekes and Large Phenological Scale (Table 2). In addition, on the 10th, 21st and 30th of July and on the 10th of August of 2007, we determined the Leaf Area Index (LAI) in each treatment. For this, all plants were collected from four replicates sampled in the experimental area of each treatment, each one consisting of a row of planting of 1m length. In each sample the number of tillers was determined, the number of leaves in ten tillers and the length and width of 20 leaves. LAI values were calculated using Equation 1, which was previously calibrated using a sample of 40 independent leaves of the IPR 118 cultivar (R^2 = 0,9212):

$$LAI = \frac{\left[0.6868\left(\overline{L \times W}\right) + 2.7034\right]\overline{NL} \times NT}{LA} \quad (1)$$

in which LAI is the leaf area index (dimensionless), $\overline{L \times W}$ is the average product between length and width of the 20 leaves (cm^2), $\overline{NL}$ is the average number of leaves per tiller, NT is the number of tillers of the sample and LA is the land area correspondent to the sample (cm^2).

TABLE 2. Date of occurrence of several wheat crop phases on Irrigated and Non-irrigated Treatments in Londrina - PR.

Crop phase	Irrigated	Non-irrigated
Seeding	05/10/2007	
Emergency	05/18/2007	
Tillering	06/12/2007	
Booting	07/01/2007	
Physiological maturation	09/01/2007	09/10/2007
Harvest	09/20/2007	

The harvest was performed on September 20th, 2007, picking up three replicates of 5 x 5 m (25 m^2) per treatment within the experimental area (Figure 1). After the harvest, the hectolitre weight (HW) and the seed moisture were determined, with the aim of correcting and equalizing all productivity data for the same level of 13% moisture.

The three replicates harvested from each treatment were analyzed for the technological quality of flour. For this purpose, the milling was performed in the Chopin ® mill, model CD1, after preparation of 500 g of wheat during 16 h to reach 15.5% of moisture, in accordance with the Method 26-10 as described in AACC (1995). The products obtained during the milling were: break flour (BFL), reduction flour (RFL) and extraction rate.

The viscoelastic properties of wheat flour were determined in the Chopin ® alveograph, model NG, using Method No. 54-30 of AACC (1995), by weighing 250g of flour and volume of 129.4 mL of water, corrected on the basis of 14% moisture. The parameters obtained in the alveograph are the tenacity (P), which measures the maximum pressure exerted on the mass expansion (mm); the extensibility (L), which measures the curve length (mm) and the strain energy of the weight or gluten force (W) which corresponds to the mechanical work necessary to expand the bubble to break (expressed in 10^{-4} J). The ratio of P and L (P / L) was determined.

The moisture of flour (%) was determined by loss of the original weight of the samples (2 g of ground grain, flour or grain finely ground) for 1 hour in a dryer at a constant temperature of 130 °C as described in Method 925.10 of AOAC (1990).

The protein in wheat grain was determined by the Kjeldahl method described in AACC (1995), Method 46-13 and using the factor 5.7 to convert the nitrogen value in total protein (%).

The falling number (FN), which assesses the degree of wheat germination was determined according to AACC Method 56-81B. The value of FN was obtained by measuring the ability of the alpha-amylase enzyme to liquefy a starch gel, performing how long (in seconds) is required to allow the mixture to fall from the stirrer until a fixed distance, in a aqueous gel of crushed grain or flour subjected to a constant temperature of 100 °C (AACC, 1995).

The evaluation of the root system was performed by the method of profile wall and monolith (BÖHM, 1979). For that, immediately after harvesting the crop four transversal trenches were opened to plant lines, two in the irrigated area and two others in the area without irrigation (Figure 1). Each trench showed approximately 1m depth, 1.5m length and 1m width. In each trench two plants were analyzed on each side of the profile, totalizing four plants per trench and eight per treatment (Figure 3A).

First it was determined the root number (RN) by the method of profile wall (Figure 3B). For this, the profile was leveled on both sides after its opening using a straight shavel and the roots were exposed using a manual scarifier roller. Then, the exposed roots were painted with white spray ink to facilitate the visualization against the soil profile of dark coloration. Subsequently, a frame of 40 x 45cm containing 5 x 5 cm squares was disposed on each analyzed plant. Finally, a count of exposed RN for each small square of rectangle of the profile was performed and the data were integrated for each 5 cm layer of the soil.

In the second analysis, the root dry mass (RDM) was determined by the monolith method (Figure 3C). For this, the roots that were exposed after the evaluation by the trench profile method were cut and the profile was leveled again. It was used metal rings of 10.5 cm inner diameter and 10 cm of depth (0.8659 dm^3). The rings had one of the edges beveled to facilitate the insertion of the rings in the soil and were lubricated with vegetal oil on its exterior part. Then, with the aid of a hydraulic tensioner supported on the opposite wall of the profile, the rings were inserted into the ground to full completion of its volume. After the insertion, the rings were removed by digging up the sides to the bottom of the ring and then were wrapped in PVC film, identified and stored in refrigerator.

After the collection, all samples were analyzed within 72 hours. In the analysis, the soil contained in the volume of each ring was washed with tap water on a sieve of 2 mm mesh. After the separation of the roots, they were taken out to dry in dryers of forced air circulation at 65 °C for 48 h, time identified as sufficient to stabilize the mass of samples. Finally, any impurities were removed from the samples and the roots were then weighed on scale of 220 g capacity, with divisions of 0.001 g.

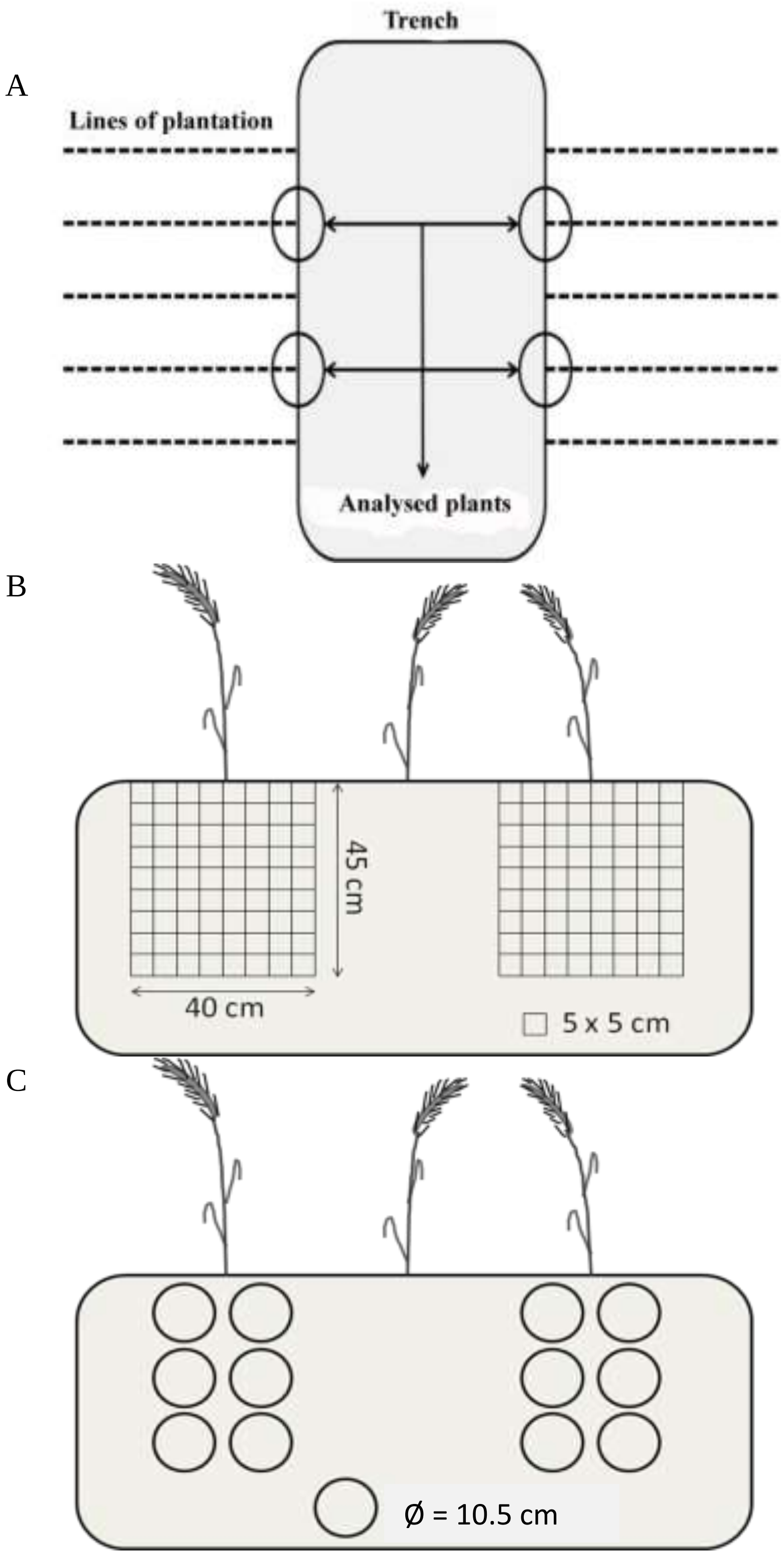


FIGURE 3. Root system analysis scheme: A) Plants analyzed in each trench; B) Frame disposition for the profile wall method; C) Rings disposition for the monolith method.

To evaluate the influence of irrigation on productivity and technological quality of wheat flour, the data were subjected to analysis of variance with the averages being compared by applying the Tukey test (p <0.05 or p <0.01). Regarding the evaluation of the root system, the data were subjected to analysis of variance with comparison of means by the Scheffé test (p <0.05). The Scheffé test was applied due to the fact that some samples were lost. However, even with the loss of some samples, it was always used in the analysis at least 75% of the total potentially analyzable samples.

RESULTS AND DISCUSSION

The average number of tillers and LAI, both determined in four samples of 17x100cm, were higher in the Irrigated Treatment compared to the Non-irrigated Treatment (Figure 4). On average the number of tillers formed in plants of the Irrigated Treatment was 1.7 times higher than that found in plants of the Non-irrigated Treatment. Furthermore, the LAI values of the Irrigated Treatment were 3 times higher than those observed in the Non-irrigated Treatment. This was due to good availability of water in the soil of the Irrigated Treatment (Figure 2B). In this treatment, in addition to the pluviometric precipitation (297 mm), 318.2 mm were irrigated throughout the crop cycle. The Non-irrigated Treatment, by having available only the pluviometric precipitation was sometimes subjected to hydric deficit that occurs in the winter and that limits the tillering of plants and leaf formation and expansion.

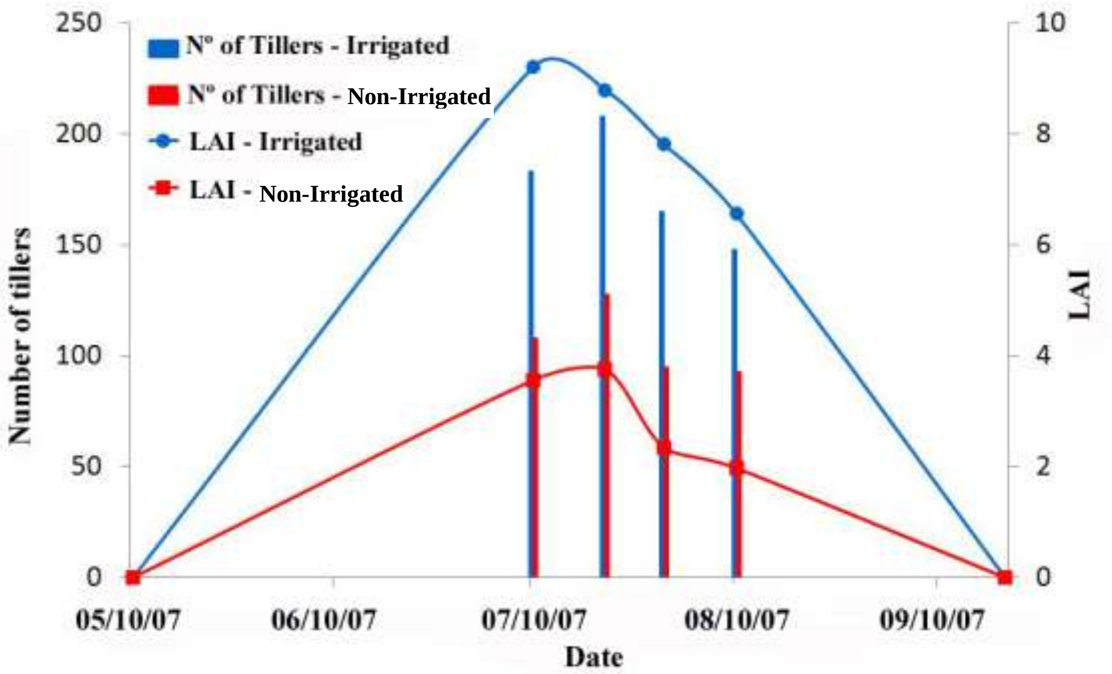


FIGURE 4. Evolution of the average number of tillers and Leaf Area Index (LAI) determined in four samples of 17 x 100 cm on Irrigated and Non-irrigated Treatments in Londrina-PR.

The maximum LAI value was reached around the initiation stage of booting and, finally, the leaf area was reduced as the cycle followed to the physiological maturation and harvest (Table 2, Figure 4). Thus, the maximum LAI value observed in the Irrigated Treatment was equal to 9.2 and 3.8 for the Non-irrigated Treatment, both occurring at booting stage.

The grain moisture collected in both treatments showed no significant difference (Table 3). According to ELIAS et al. (2009), the wheat moisture at harvest influences their subsequent conservation and quality of flour. In this study, both treatments were harvested with moisture around 14%. This value is considered the lower limit suitable for the wheat harvesting, being values of 16 to 18% more recommended because they provide better flour quality and longer storage time (ELIAS et al. 2009).

There were significant differences between the treatments for HW average (Table 3). The HW is associated with the grain filling velocity and factors such as water stress and temperature, in addition to nutrient deficiency, influences directly its value (WARDLAW, 2002).

The productivity of the Irrigated Treatment was statistically superior to the Non-irrigated Treatment (Table 3). The higher productivity observed in the Irrigated Treatment may be justified due to adequate water supply obtained by irrigation. Through the irrigation along the crop cycle, the water was always available to plants, so they could attend the demand of the atmosphere and increase the leaf area, supporting the observed healthy production (3,435.1 kg ha^{-1}). On the other hand, in the Non-irrigated Treatment the observed productivity was low (1,159.4 kg ha^{-1}), which may be justified due to the uneven supply of water which normally occurs in non irrigated cultures. As it can be seen in Figure 2A, the Non-irrigated Treatment plants were subjected to a period without precipitation from 06/03 to 07/14/2007 (42 days) and from 07/26 to 08/27/2007 (33 days). Furthermore, in the first period, of 42 days, the accumulated demand on the atmosphere was 104.6 mm, with a daily average of 2.5 mm. In the second period (33 days), these values were 106.6 and 3.2 mm, respectively. Therefore, the water deficit seen in Figure 2B was due to a combination of precipitation and ETo factors, resulting in little tillering and growth of the leaf area in plants of Non-irrigated Treatment in the first period (Table 2; Figure 4). In the second period, the grain filling was reduced, which can be evidenced by its lower HW (Table 3) when compared to the Irrigated Treatment, agreeing with WARDLAW (2002). Therefore, due to what happened in these two periods, the productivity observed in the Non-irrigated Treatment was statistically lower than the observed in the Irrigated Treatment (Table 3).

TABLE 3. Seed moisture at harvest, hectoliter weight (HW), and corrected productivity to 13% of wheat moisture on Irrigated and Non-irrigated Treatments in Londrina - PR.

		Irrigated	Non-irrigated
Moisture (%)*	Average ± SD***	14.37 ± 0.55 a	13.93 ± 0.07 a
	C.V. (%)****	6.7	0.8
HW (kg hL^{-1})*	Average ± SD	82.33 ± 0.33 a	78 ± 1 b
	C.V. (%)	0.7	2.2
Productivity (kg ha^{-1})**	Average ± SD	3435.1 ± 215.5 a	1159.4 ± 72.8 b
	C.V. (%)	10.9	10.9

* Averages followed by different letters in the line differs by the Tukey test ($p < 0.05$) ** Averages followed by different letters in the line differs by the Tukey test ($p < 0.01$) *** SD is the standard deviation **** CV is the coefficient of variation

RIEDE et al. (2007) conducted a study of adaptability and stability to launch the IPR 118 wheat cultivar. The authors determined the productivity obtained with the cultivar for four years, cultivated in different regions in the states of Paraná, Mato Grosso do Sul, São Paulo and Santa Catarina. In this study, the average productivity obtained was 3,753kg ha^{-1}, which is higher than the obtained in this study for both treatments.

It is also possible to observe that the productivity obtained by Irrigated Treatment (3,435.1 kg ha^{-1}) was higher, while that obtained by Non-irrigated Treatment (1,159.4 kg ha^{-1}) was lower than the national average (2,212 kg ha^{-1}) and the state of Paraná (2,340 kg ha^{-1}) in the 2007/2008 crop set up by CONAB (CONAB, 2010). The uneven distribution of precipitation during the crop cycle in Non-irrigated Treatment resulted in approximately 49% of reduction in production compared to that obtained in the state of Paraná. Moreover, the adoption of irrigation allowed an increase of approximately 52% compared to the state average. Thus, the productivity observed in the Irrigated Treatment was three times higher than the observed in the Non-irrigated Treatment.

The results obtained in this study agree with those obtained by FRIZZONE et al. (1996) on wheat irrigated by conventional sprinkler irrigation. The authors studied the application of increasing depths (0 to 274 mm) during the cycle of wheat and found that the lowest productivity (513.6 kg ha^{-1}) was obtained for non irrigated condition (0 mm). Moreover, the highest productivities (on an average equal to 4,357.9 kg ha^{-1} with no statistical difference) were found by applying depths of 240 and 274mm. The same was observed in the SCALCO et al. (2002) study. These authors evaluated the productivity of wheat irrigated by conventional sprinkler irrigation applying increasing depths (replacement of 0; 30; 60 and 90% of evaporation of class A tank) and found that the productivity increased as the water depth increased.

The practice of irrigation did not affect the presence of alpha-amylase in wheat grain, which was determined indirectly by FN (Table 4). The values found in both treatments were always higher than those recommended for the preparation of sandwich loaf and bread roll. This low alpha-amylase activity may be attributed to lesser presence of enzyme and/or to changes occurring in starch during periods of low precipitation during grain development (EVERY et al., 2002; JOHANSSON, 2002).

TABLE 4. Technological quality results (average and standard deviation) of wheat flour for Irrigated and Non-irrigated Treatments in Londrina - PR.

	Irrigated	Non-irrigated
Moisture (%)*	11.49 ± 0.48 a	11.62 ± 0.33 a
Falling Number (FN; s)*	534 ± 17 a	584 ± 95 a
Proteins (%)**	15.87 ± 0.74 b	18.38 ± 0.26 a
Gluten force (W; 10^{-4} J)**	249.33 ± 17.62 b	321 ± 19.31 a
Tenacity (P; mm)*	98.33 ± 1.15 a	83.67 ± 6.43 b
Extensibility (L; mm)*	73 ± 8.54 b	118 ± 19.98 a
P/L*	1.36 ± 0.17 a	0.73 ± 0.19 b

* Averages followed by different letters in the line differs by the Tukey test (p < 0,05) ** Averages followed by different letters in the line differs by the Tukey test (p < 0,01)

The protein concentration in wheat grain depends on genetic and environmental factors (JOHANSSON, 2002; GUTTIERI et al., 2005). In this study, the protein concentration was influenced by the availability of water during the cultivation cycle (Table 4). It was observed higher values of protein in the Non-irrigated Treatment (18.38%) compared to the Irrigated Treatment (15.87%). GUTTIERI et al. (2005) also observed a lower concentration of proteins in irrigated wheat compared with those grown in conditions of low water availability.

In the alveographic analysis it was observed that under irrigation conditions the values of W were lower as compared to non irrigated conditions (Table 4). The value of W was higher for wheat of Non-irrigated Treatment probably by the largest amount of protein, as it is known, both the quality and the amount of protein in the grain has effects on its technological quality (GUTTIERI et al., 2005; COSTA et al., 2008). Despite the reduction of proteins and consequently the W in the Irrigated Treatment, this decrease was not enough to change the classification of IPR 118 cultivar, which by the standards of classification in force (BRAZIL, 2010) is considered bread wheat, with values of W exceeding 220. Moreover, the values of W obtained in the Non-irrigated Treatment allowed to classify the wheat in this treatment as improver (W greater than 300). In the alveographic analysis was possible to note that the P/L relation was significantly higher in the Irrigated Treatment. The relation of 1.36 observed in this treatment gives it the characteristic of tenacious gluten. Moreover, the Non-irrigated Treatment showed P/L equal to 0.73, which characterizes the balanced gluten.

In general, the Non-irrigated Treatment produced more root system when compared to the Irrigated Treatment, as it can be seen from the data presented of RN (Figure 5A; Table 5) and RDM (Fig. 5B, Table 5).

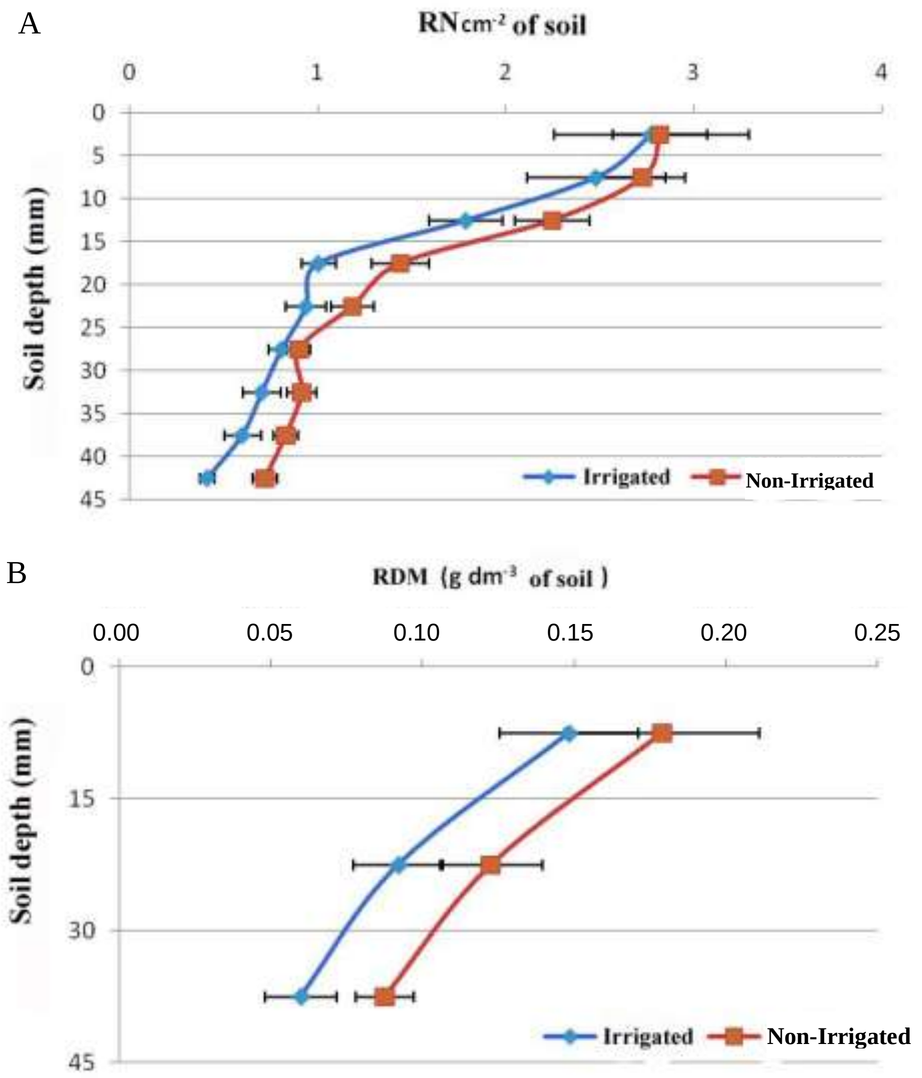


FIGURE 5. A) Roots number (RN) exposed in each cm^2 of soil surface; B) Root dry mass (RDM). Data for wheat Irrigated and Non-irrigated Treatments in Londrina - PR.

TABLE 5. Roots number (RN; roots cm^{-2}) and root dry mass (RDM; g dm^{-3} of soil) of wheat in Irrigated and Non-irrigated Treatments in Londrina - PR.

	Deep (cm)	Irrigated			Non-irrigated		
		Average	Standard deviation	C.V. (%)**	Average	Standard deviation	C.V. (%)
RN*	0 - 5	2.78 Aa	1.47	53.0	2.82 Aa	0.71	25.0
	5 - 10	2.48 Aa	1.04	41.9	2.73 Aab	0.65	23.8
	10 - 15	1.79 Bb	0.55	30.8	2.25 Ab	0.56	25.0
	15 - 20	1.01 Bc	0.25	25.3	1.44 Ac	0.43	29.7
	20 - 25	0.94 Acd	0.30	32.3	1.19 Acd	0.33	27.5
	25 - 30	0.81 Acd	0.20	25.3	0.90 Acd	0.18	19.7
	30 - 35	0.71 Acd	0.28	40.1	0.92 Acd	0.23	24.9
	35 - 40	0.60 Acd	0.27	45.6	0.83 Ad	0.19	23.3
	40 - 45	0.42 Ad	0.11	26.7	0.72 Ad	0.19	25.7
RDM*	0 - 15	0.148 Ba	0.089	60.1	0.179 Aa	0.112	62.6
	15 - 30	0.092 Bb	0.060	65.2	0.123 Ab	0.068	55.3
	30 - 45	0.060 Bc	0.048	80.0	0.088 Ac	0.039	44.3

* Averages followed by the same capital letter in the line and small letter in the column do not differ by the Scheffé test ($p < 0.05$)
** C.V. is the coefficient of variation

The values of RN in the Non-irrigated Treatment were significantly superior to the Irrigated Treatment in layers of 10 - 15 and 15 - 20cm. In the upper layers and in deeper layers there was no difference between treatments (Table 5). This finding may be justified based on the water regime of each treatment. After the ground moistening due to an event of irrigation or natural precipitation, starts a cycle of moisture reduction due to crop evapotranspiration, and this process occurs initially in the upper layers towards the deeper layers. In addition to this observation, according to KLEPPER (1991), plants cultivated without irrigation produces more roots and radicels to explore the profile of the soil and absorb the water that is strongly retained in the matrix of it. Thus, in the Irrigated Treatment the soil moisture was maintained around the field capacity by frequent irrigation and thus the radicular system of plants grew adequately along of the entire profile, since there existed humidity. However, in Non-irrigated Treatment the soil moisture was restored only by the precipitation and often the first layers of the soil were subjected to a lengthy period of humidity reduction. Thus, agreeing with KLEPPER (1991), the Non-irrigated Treatment plants increased root production in layers where humidity was often higher. However, even there was humidity in the deeper layers, this root production concentrated in the 10-20 cm layer.

It was also observed that in both treatments the layer with 0-10 cm depth showed the greatest RN, corresponding to 45.6 and 40.2% of the Irrigated and Non-irrigated Treatments, respectively. The layer of 10-20 cm showed an intermediate amount of roots, being responsible for 24.3 and 26.7% of the total treatments. Finally, the lower layers (20-45 cm) showed the lowest RN, responding for 30.1 and 33% of the total in treatments.

In all evaluated layers, the RDM values were significantly higher in Non-irrigated Treatment compared to the Irrigated Treatment (Fig. 5B, Table 5). This may be due to the relation between the soil moisture and the penetration resistance of it, since it is known that the drier soils have a higher resistance to penetration (CUNHA et al., 2002). Moreover, according to GREGORY (1994), under conditions of soil more resistant to penetration the diameter of the roots increases from the portion immediately after the root cap. According to the author, this increase in diameter reduces the resistance of the soil in the region below the root cap, facilitating the elongation of roots in previously unexplored ground areas. The authors discuss that this diameter increase is due to the increased volume of the root cortex cells, remaining unchanged the number of cells of the cortex and conductor vessels diameter. Thus, it is possible that the soil in Non-irrigated Treatment had a greater penetration resistance due to the lower moisture content in it. Therefore, to overcome this increased resistance to penetration, the Non-irrigated Treatment plants had to use part of the assimilates in the increase of root diameter to allow the continued elongation of them. This diameter increase may have been responsible for the increase in the mass of roots in the Non-irrigated Treatment as compared to Irrigated Treatment (Fig. 5B, Table 5), given that the mass increase was not due to differences in the number of roots between treatments (Fig. 5A, Table 5).

In both treatments the layer of 0-15 cm depth showed the greatest RDM, so that this corresponded to 49.4 and 46% of the total in Irrigated and Non-irrigated Treatments, respectively. The 15-30 cm layer presented intermediate RDM, being responsible for 30.6 to 31.5% of the total for the same treatments. Finally, the lowest layer (30-45 cm) was the one which showed a lower RDM, responsible for 20 and 22.5% of total treatments.

At PIRES et al. (1991) study it was noted that 83% of the total mass of wheat roots cultivated under center pivot irrigation was in the 0-40 cm layer. Based on this observation the authors recommended the use of this layer as the one corresponding to the effective depth of the radicular system used in irrigation projects. Although in the present study it was observed that 80% of the RDM of irrigated wheat were in the 0-30 cm layer, the authors do not recommend the use of this layer in irrigation projects. This is due to the fact that in this study it was evaluated only 45 cm of the soil profile, whereas in the PIRES et al. (1991) study they evaluated 60 cm of soil. The authors of this study believe that the best recommendation is that supplied by PIRES et al. (1991).

CONCLUSIONS

The irrigation increased three times the wheat productivity;

The water supplementation influenced the quality of the flour, however the produced flour was classified as bread type, the same to which IPR 118 cultivar is classified;

In general, plants cultivated under non-irrigated conditions showed equal or greater number of roots and root dry mass than in irrigated condition.

REFERENCES

AACC. *Aproved methods*. 9.ed. Saint Paul: AACC, 1995.

ALLEN, R.G.; PEREIRA, L.S.; RAES, D.; SMITH, M. *Crop evapotranspiration*: Guidelines for computing crop water requirements. Rome: FAO, 1998. 300 p. (FAO Irrigation and Drainage Paper, 56)

ALLEN, R.G. *REF-ET*: reference evapotranspiration calculation software. Version 2.0. Moscow: University of Idaho, 2000.

AOAC. *Official methods of analysis*. 15.ed. Washington: AOAC, 1990.

BÖHM, W. *Methods of studying root systems*. Berlin: Springer-Vela, 1979. 188 p.

BRASIL. Ministério de Agricultura, Pecuária e Abastecimento. Instrução normativa N° 91, jun. 2010. Regulamento técnico de identidade e qualidade da farinha de trigo. *Diário Oficial da República Federativa do Brasil*, Brasília, 01 mar. 2010, Seção 1, n.39, p.3-5.

CARAMORI, P.H.; FARIA, R.T. SMA - Sistema de Monitoramento Agroclimático para o Estado do Paraná. Londrina: Ia par, 2002. Disponível em: <http://www.iapar.br/modules/conteudo/conteudo.php?conteudo=900>.

CONAB. *Trigo – Brasil*: série histórica das safras 1976/77 a 2009/10. Brasília, 2010. Disponível em: <http://www.conab.gov.br/conabweb/download/safra/TrigoSerieHist.xls>. Acesso em: 31 jan. 2010.

COSTA, M.G.; SOUZA, E.L.; STAMFORD, T.L.M.; ANDRADE, S.A.C. Qualidade tecnológica de grãos e farinhas de trigo nacionais e importados. *Ciência e Tecnologia de Alimentos*, Campinas, v.28, p.220-225, 2008.

CUNHA, J.P.A.R.; VIEIRA, L.B.; MAGALHÃES, A.C. Resistência mecânica do solo à penetração sob diferentes densidades e teores de água. *Engenharia na Agricultura*, Viçosa, v.10, p.1-7, 2002.

ELIAS, M.C.; LOPES, V.; GUTKOSKI, L.C.; OLIVEIRA, M.; MAZZUTI, S.; DIAS, A.R.G. Umidade de colheita, métodos de secagem e tempo de armazenamento na qualidade tecnológica de grãos de trigo (cv. 'Embrapa 16'). *Ciência Rural*, Santa Maria, v.39, p.25-30, 2009.

EMBRAPA. *Sistema brasileiro de classificação de solos*. Rio de Janeiro: EMBRAPA-CNPS, 1999. 412 p.

EVERY, D.; SIMMONS, L.; AL-HAKKAK, J.; HAWKINS, S.; ROSS, M. Amylase, falling number, polysaccharide, protein and ash relationships in wheat millstreams. *Euphytica*, Wageningen, v.126, p.135-142, 2002.

FARIA, R.T.; MADRAMOOTOO, C.A. Simulation of soil moisture profiles for wheat in Brazil. *Agricultural Water Management*, Amsterdam, v.31, p.35-49, 1996.

FARIA, R.T.; MADRAMOOTOO, C.A.; BOISVERT, J.; PRASHER, S.O. A comparison of the performance of SWACROP and the versatile soil moisture budget models in Brazil. *Canadian Agricultural Engineering*, Ottawa, v.36, p.1-12, 1994.

FELÍCIO, J.C.; CAMARGO, C.E.O.; PEDRO JUNIOR, M.J.; FERREIRA FILHO, A.W.P. Avaliação de cultivares de trigo em duas regiões ecológicas do Estado de São Paulo. *Pesquisa Agropecuária Brasileira*, v.27, p.1243-1252, 1992.

FELÍCIO, J.C.; CAMARGO, C.E.O.; PEREIRA, J.C.V.N.A.; GERMANI, R.; GALLO, P.B.; CASTRO, J.L.; FERREIRA FILHO, A.W.P. Potencial de rendimento de grãos e outras características agronômicas e tecnológicas de novos genótipos de trigo. *Bragantia*, Brasília, v.65, p.227-243, 2006.

FRIZZONE, J.A.; MELLO JÚNIOR, A.V.; FOLEGATTI, M.V.; BOTREL, T.A. Efeito de diferentes níveis de irrigação e adubação nitrogenada sobre componentes de produtividade da cultura do trigo. *Pesquisa Agropecuária Brasileira*, Brasília, v.31, p.425-434, 1996.

GAJRI, P.R.; PRIHAR, S.S.; CHEEMA, H.S.; KAPOOR, A. Irrigation and tillage effects on root development, water use and yield of wheat on coarse textured soils. *Irrigation Science*, v.12, p.161-168, 1991.

GREGORY, P.J. Root growth and activity. In: BOOTE, K.J.; BENNETT, J.M.; SINCLAIR, T.R.; PAULSEN, G.M. (Ed.). *Physiology and determination of crop yield*. Madison: American Society of Agronomy, 1994. p.65-93.

GUERRA, A.F.; ANTONINI, J.C.A. Época de suspender as irrigações da cultura do trigo. *Pesquisa Agropecuária Brasileira*, Brasília, v.31, p.823-828, 1996.

GUTKOSKI, L.C.; JACOBSEN NETO, R. Procedimento para teste laboratorial de panificação - Pão tipo forma. *Ciência Rural*, Santa Maria, v.32, p.873-879, 2002.

GUTTIERI, M.; MCLEAN, R.; STARK, J.C.; SOUZA, E. Managing irrigation and nitrogen fertility of hard spring wheats for optimum bread and noodle quality. *Crop Science*, Madison, v.45, p.2049-2059, 2005.

IAPAR. *Cartas climáticas do Estado do Paraná*. Londrina: IAPAR, 1994. 49 p. (Documento, 18).

JOHANSSON, E. Effect of two wheat genotypes and Swedish environment on falling number, amylase activities, and protein concentration and composition. *Euphytica*, Wageningen, v.126, p.143-149, 2002.

KLEPPER, B. Crop root system response to irrigation. *Irrigation Science*, New York, v.12, p.105-108, 1991.

PASSIOURA, J.B. Roots and drought resistance. *Agricultural Water Management*, Amsterdam, v.7, p.265-280, 1983.

PIRES, R.C.M.; ARRUDA, F.B.; FUJIWARA, M.; SAKAI, E.; BORTOLETTO, N. Profundidade do sistema radicular das culturas de feijão e trigo sob pivô central. *Bragantia*, Campinas, v.50, p.153-162, 1991.

RIEDE, C.R.; CAMPOS, L.A.C.; OKUYAMA, L.A.; SCHOLZ, M.B.S.; SHIOGA, P.S.; POLA, J.N. IPR 118 - Bread wheat cultivar. *Crop Breeding and Applied Biotechnology*, Londrina, v.7, p.329-331, 2007.

SCALCO, M.S; FARIA, M.A.; GERMANI, R.; MORAIS, A.R. Produtividade e qualidade industrial do trigo sob diferentes níveis de irrigação e adubação. *Ciência e Agrotecnologia*, Lavras, v.26, p.400-410, 2002.

SILVA, M.S.; ANDRADE, J.M.V.; ALBRECHT, J.C.; SOARES SOBRINHO, J.; CANOVAS, A. No Brasil Central também dá trigo. *Cultivar*, Pelotas, v.27, p.18-23, 2001.

WARDLAW, I.F. Interaction between drought and chronic high temperature during kernel filling in wheat in a controlled environment. *Annals of Botany*, London, v.90, p.69-476, 2002.