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Yield components and crop estimation for wheat cultivars at different sowing times

Lorena Maia Noreto[1], Stefanie Lais Kreutz Rosa[2]*, Jorge Luiz Moretti de Souza[2], Élcio Silvério Klosowski[1], Cláudio Yuji Tsutsumi[1], Francisco de Assis Franco[3]

[1]Programa de Pós-Graduação em Agronomia, Universidade Estadual do Oeste do Paraná, Campus de Marechal Cândido Rondon. Rua Pernambuco, 1777 - Centro, Marechal Cândido Rondon, PR, Brasil.
[2]Programa de Pós-Graduação em Ciência do Solo, Universidade Federal do Paraná, Setor de Ciências Agrárias, Departamento de Solos e Engenharia Agrícola. Rua dos Funcionários, 1540 - Cabral, Curitiba, PR, Brasil.
[3]Coodetec Desenvolvimento, Produção e Comercialização Agrícola Ltda, Cascavel, PR, Brasil.

*Autor correspondente: skreutzrosa@gmail.com
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Abstract: The objective of this study was to evaluate the yield and yield components of wheat cultivars, and compare the productivity obtained in the field and estimated with Jensen model, at different sowing dates, in Cascavel and Palotina cities, Parana state, Brazil. The experiments were carried out in the field at the COODETEC Research Center, located in Cascavel and Palotina. The experiment was conducted in a randomized blocks design in a 7 × 3 factorial, with plots consisting of six lines spaced at 5 × 0.17 meters, with seven wheat cultivars and three sowing dates, with three repetitions. The pluvial precipitation higher than crop evapotranspiration in all cultivation cycles analyzed did not prevent water deficiencies, which occurred predominantly in the heading and physiological maturation stages. The smallest water deficiencies in Cascavel (31.2 mm; April 22) and Palotina (7.2 mm; March 31), from sowing to heading, reduced grain yield by 41.7% and 42.8%, respectively, in relation to the higher productivity of each location. Small differences in yield components (NEM, NGE and MMG) provide differences in grain yield between the cultivars tested. The sowing carried out at the end of April and in May tended to have a higher yield. The best performances with Jensen model to estimate wheat grains yield were obtained for CD 1440 and QUARTZO cultivars. The Jensen model overestimated the grain yield of the CD 108, CD 1104, CD 150 and CD 154 cultivars, since the model do not consider losses due to excessive rainfall and/or pests and diseases.

Key words: *Triticum aestivum* L.; water balance; yield components.

Estimativa da produtividade de grãos e componentes de produção para cultivares de trigo em diferentes épocas de semeadura

Resumo: O objetivo deste estudo foi avaliar o rendimento e os componentes de rendimento de cultivares de trigo e comparar a produtividade obtida no campo e estimada com o modelo de Jensen, em diferentes datas de semeadura, nas cidades de Cascavel e Palotina, Paraná, Brasil. Os experimentos foram realizados em campo no Centro de Pesquisa COODETEC, localizado em Cascavel e Palotina. O experimento foi conduzido em delineamento de blocos casualizados em esquema fatorial 7 × 3, com parcelas compostas por seis linhas espaçadas de 5 × 0,17 metros, com sete cultivares de trigo e três datas de semeadura, com três repetições. A precipitação pluviométrica superior à evapotranspiração das culturas em todos os ciclos de cultivo analisados não impediu as deficiências hídricas, que ocorreram predominantemente nos estágios de espigamento e maturação fisiológica. As menores deficiências hídricas de Cascavel (31,2 mm; 22 de abril) e Palotina (7,2 mm; 31 de março), da semeadura ao espigamento, reduziram o rendimento de grãos em 41,7% e 42,8%, respectivamente, em relação à maior produtividade de cada localidade. Pequenas diferenças nos componentes de rendimento (NEM, NGE e MMG) proporcionaram diferenças na produtividade de grãos entre as cultivares testadas. As semeaduras realizadas no final de abril e maio tiveram tendência de maiores produtividades. Os melhores desempenhos com o modelo de Jensen para estimar a produção de grãos de trigo foram obtidos para as cultivares CD 1440 e QUARTZO. O modelo de Jensen superestimou o rendimento de grãos das cultivares CD 108, CD 1104, CD 150 e CD 154, uma vez que o modelo não considera perdas por excesso de chuvas e/ou pragas e doenças.

Palavras-chave: *Triticum aestivum* L.; balanço hídrico; componentes de rendimento.

Introduction

Wheat (*Triticum aestivum* L.) is an annual crop, cultivated in autumn and winter in Brazil. In most parts of the world, wheat is mainly used to produce different types of flour, presenting genotypes with different genetic characteristics and adaptation to the soil and climate, enabling production in different growing regions (Silva et al., 2015).

In south Brazil, the states of Parana and Rio Grande do Sul stand out among wheat producers, being responsible for most of the national production. Compared to the previous harvest, Brazilian wheat production in 2017 harvest presented a decrease of 2.5 million tons, reaching 4.2 million tons, with an average yield of 2308 kg ha^{-1} in Parana and 1826 kg ha^{-1} in Rio Grande do Sul. The decline in national wheat productivity in the 2017 harvest was due to excessive rainfall and the occurrence of frost during flowering, impairing the wheat potential productive in the south of Brazil (CONAB, 2018).

Excessive rainfall and water deficit can interfere in the final grain yield. The water deficit causes a decline in the leaf area, stomatal closure, grain abortion and accelerated growing cycle, compromising the grain formation. However, excessive rainfall reduces the root system, in addition to favoring the incidence of root and leaf diseases that negatively affect final productivity (Souza et al., 2013).

Despite the complexity, wheat productivity can be stimulated before harvest, considering changes in grain yield components, influenced by environment condition, cultivar genetic characteristics and interaction between both. The yield components are defined in the pre-anthesis (number of spikes per square meter and number of grains per spike) and in the post-anthesis (grain weight), which determine the final grain yield (Qin et al., 2015).

Estimates of potential crop productivity or maximum crop yield can also be performed with mathematic models. For this purpose, information on leaf area index, gross photosynthesis, crop index and total length of the plant growth period is necessary, considering that there are no water nutritional and phytosanitary limitations during the entire cycle (Steduto et al., 2012). In addition, productivity estimate can be performed by penalizing the grain yield according to water deficit, obtaining values closer to the crop real productivity (Pereira et al., 2007). Souza et al. (2013) evaluating the water relations and the performance of the crop-water model to estimate the yield of the wheat crop in the Subtropical region of Brazil, after calibration, verified among the tested models that the Jensen model presented the best results for estimating yields.

The projection of grain yield from different cultivars information assists in the selection of the most suitable genotype for production in different locations (Junges and Fontana, 2011).

As the same wheat cultivar can present different productivity in different cultivation environment, the objective of this study was to evaluate the yield and yield components of wheat cultivars, and compare the productivity obtained in the field and estimated with the Jensen model, at different sowing dates, in Cascavel and Palotina cities, Parana state, south Brazil.

Material and methods

The experiments were carried out at the COODETEC Research Centers in the locations of Cascavel and Palotina, Parana State, south Brazil. The geographic coordinates of the areas are: 24º 56' S, 53º 32' W and altitude of 700 meters, in Cascavel; and, 24º 18' S, 53º 55' W and altitude of 310 meters, in Palotina. According to the Köppen's climate classification (Alvares et al., 2013), the locations are classified as Cfa (Humid subtropical, oceanic climate, without dry season and hot summer), with average air temperature in the coldest month between –3 and 18 °C and in the warmest month above than 22 °C. Cascavel and Palotina present average annual rainfall of 1234.8 mm and 978.8 mm, and average air temperature of 18.1 and 19.6 °C between March and October, respectively (IAPAR, 2017).

The experimental areas have adopted crop rotation system since 1997 with forage turnip preceding wheat in winter and soybean in summer. The experimental design was in randomized blocks (7 × 3), consisting of seven wheat cultivars and three sowing dates, with three replicates for each location. The plots were composed of six rows of 5 m in length, with spacing between rows of 0.17 m.

The soil is classified as Oxisol in both locations (Santos et al., 2013). According to chemical analyzes (Table 1), basic fertilization was performed with 300 kg ha^{-1} of 8–30–20 NPK fertilizer, and 100 kg ha^{-1} of urea fertilizer applied in cover at the beginning of tillering.

Cultivars were evaluated according to de cycle: *i*) Very early (CD 108), *ii*) Early (CD 150) and *iii*) Medium cycle (CD 154, CD 1104, CD 1550, CD 1440 and QUARTZO). The cycles average duration from emergence to tillering was up to 69 days for very early and early cycles, and between 69 and 84 days for medium cycle cultivars.

Table 1. Soil chemical characteristics of the experimental areas in the layer 0.0 – 0.20 m, in Cascavel and Palotina cities, Parana state, in 2015 harvest.

Location	P	K	Ca	Mg	Al	H+Al	CEC	V	O.M.	pH
	mg dm^{-3}	------------ cmol$_c$ dm^{-3} ------------						%	%	CaCl$_2$
Cascavel	14.11	0.32	4.20	2.16	0.09	3.75	6.45	64.11	4.14	5.1
Palotina	22.20	0.76	5.51	2.04	0.00	5.35	7.50	60.55	2.30	5.3

Source: COODETEC Soil Laboratory.

The seeds were treated before sowing with triadimenol (0.5 mg kg^{-1}) + Imidacloprid (0.48 g kg^{-1}). The tests were performed at the COODETEC Seed

Laboratory and showed an average germination rate of 94%. Mechanized direct seeding was carried out with 360 viable seeds per square meter for all cultivars. The sowings occurred on April 22, 2015, April 30, 2015 and May 21, 2015 in Cascavel, and on March 31, 2015, April 16, 2015 and April 27, 2015 in Palotina.

Phytosanitary control was carried out as: control of dicotyledonous weeds (Metallic metsulfurom; 4 g ha^{-1}; applying 200 L of syrup ha^{-1}); and annual poaceae, mainly oats and ryegrass (Clodinafop-propargyl, 200 Ml ha^{-1}, 50 L ha^{-1}); wheat caterpillars (*Pseudaletia adultera*) and cartridge caterpillar (*Spodoptera frugiperda*) (Lufenurom; 0.1 L ha^{-1}; applying 100 L of syrup ha^{-1}); fungal diseases (brown spot, yellow spot and glume blotch, caused by *Bipolaris sorokiniana*, *Drechslera spp*., and *Stagonospora nodorum* fungi, respectively) at the beginning of stem elongation, complete development and grain filling (Strobilurin + Triazole; 750 Ml ha^{-1}; applying 200 L of syrup ha^{-1}), according to CBPTT (2016) recommendations.

The estimation of Wheat Potential Productivity (P_P) was carried out with the Zone Agroecological method described by Doorenbos and Kassam (1994), in which all water, nutritional and phytosanitary needs are addressed. The potential productivity penalization as a function of water deficit was performed using Jensen equation (Jensen, 1968; Souza et al., 2013; Souza et al., 2015):

$$\frac{P_R}{P_P} = \prod_{i=1}^{n} \left(\frac{ETa}{ETc}\right)_i^{\lambda i} \qquad (1)$$

Where: P_R – wheat estimated yield (kg ha^{-1}); P_P – wheat potential yield in the region (kg ha^{-1}); ETa – actual crop evapotranspiration at each i-phenological stage (mm); ETc – crop evapotranspiration at each i-phenological stage (mm), determined by multiplying the reference evapotranspiration (ETo_i) by the respective crop coefficient for the stage (Kc_i); λ_i – crop relative sensitivity to water stress during different growth stages (dimensionless; Table 2); i – crop phenological stages; n – number of phenological stages.

Crop evapotranspiration (ETc), actual evapotranspiration (ETa), water deficit (DEF) and excess (EXC) were determined in a spreadsheet, using daily water balance, based on modified Thornthwaite and Mather (1955) methodology (Souza, 2017). The following input data were required for each location (Table 2): rainfall (P; mm day^{-1}), reference evapotranspiration (ETo; mm day^{-1}), crop coefficient (Kc; dimensionless), total available soil water (TAW; mm) and fraction of soil available water for wheat crop (p; dimensionless). The Co-sinusoidal equation was used to estimate soil water storage and/or "negative accumulation" (Souza and Gomes, 2008; Souza, 2017).

The reference evapotranspiration (*ETo*) was estimated by Penman-Monteith method parameterized by FAO (ASCE-EWRI 2005):

$$ETo = \frac{0.408 \cdot \Delta \cdot (R_n - G) + \gamma_{psy} \cdot \frac{900}{(T+273)} \cdot u_2 \cdot (es - ea)}{\Delta + \gamma_{psy} \cdot (1 + 0{,}34 \cdot u_2)} \qquad (2)$$

Where: ETo – reference evapotranspiration (mm day^{-1}); Δ – slope of the saturated water-vapor-pressure curve to the air temperature (kPa °C^{-1}); Rn – net radiation balance (MJ m^{-2} day^{-1}); G – soil heat flux (MJ m^{-2}

day^{-1}); γ_{psy} – psychrometric constant (kPa °C^{-1}); T – average air temperature (°C); u_2 – wind speed at two meters height (m s^{-1}); es – saturation vapor pressure (kPa); ea – actual vapor pressure (kPa).

The daily meteorological data required for the analysis in Cascavel and Palotina (average, minimum and maximum air temperatures, rainfall, relative humidity, solar radiation, wind speed) were obtained from the Parana Meteorological System (Simepar). The Kc values were obtained considering the Feekes scale (Large, 1954; Allen et al., 1998; Souza, 2017) phonological stage for wheat crop (Table 2).

Table 2. Phenological stages and average parameters used to estimate water balance and wheat yield in Cascavel and Palotina, Parana state: crop coefficient (Kc); rooting depth (z); total available soil water in the root zone (TAW); crop relative sensitivity to water stress during different growth stages (λ) and fraction of soil available water in function of the crop evapotranspiration ($p_{(ETo)}$).

				-------- TAW --------			
Phenological stages	Period	Kc	z	Cascavel	Palotina	λ	Fraction $p_{(ETc)}$ (2)
	(days)	(DI)	(m)	(mm)	(mm)	(DI)	(DI)
Tillering: 1.0 to 5.0 (1)	15	0.35	0.15	19	18	3.0565	0.71 to 0.73
Stem elongation: 6.0 to 9.0 (1)	30	0.68	0.30	26	24	−30.03	0.68 to 0.70
Heading stage: 10.0 to 10.5 (1)	60	1.10	0.30	26	24	3.9322	0.62 to 0.68
Physiological maturation: 11 (1)	35	0.71	0.30	26	24	−1.5270	0.64 to 0.72

(1) Feekes phenological scale (Large, 1954). (2) Fraction of soil available water for wheat crop p = 0.55 and $p_{(ETc)} = p + 0.04 . (5 - ETc)$ (Allen et al., 1998). DI is Dimensionless.

The field capacity was determined on a tension table using the EMBRAPA (2011) methodology. The permanent wilting point was obtained with a psychrometer WP4C model Dewpoint PotentiaMeter®, following the methodology described by Klein et al. (2010). The soil collection was realized at 0.30 m, corresponding to the wheat effective rooting depth during its development (Raes et al., 2018). The total available soil water (TAW) was determined by (Table 2; Steduto et al., 2012):

$$TAW = (\theta_{CC} - \theta_{PMP}) \cdot z \qquad (3)$$

Where: TAW – total available soil water in the root zone (mm); θ_{CC} – water content at field capacity (m^3 m^{-3}); θ_{PMP} – water content at permanent wilting point (m^3 m^{-3}); z – rooting depth (mm).

The wheat components assessed were: number of spikes per square meter, number of grains per spike, thousand grain weight (g), and grain yield (kg ha^{-1}). Yield data were analyzed separately for each location and submitted to analysis of variance, verifying significant interaction between cultivars and sowing dates. The cultivars were evaluated using Tukey's test at the 5% of significant level ($p < 0.05$). Statistical analyzes were performed by SISVAR statistical software (Ferreira, 2011).

The comparison between the estimated and real yield obtained in the field was carried out by linear regression analysis and correlation coefficient (R); index of agreement ("d", Willmott et al., 1981); and, performance index ("c", Camargo and Sentelhas, 1997). The "c" index has the following performances: "Excellent" ("c" > 0.85); "Very good" (0.75 < "c" ≤ 0.85); "Good"

(0.65 < "c" ≤ 0.75); "Medium" (0.60 < "c" ≤ 0.65); "Tolerable" (0.50 < "c" ≤ 0.60); "Bad" (0.40 < "c" ≤ 0.50); and "Terrible" ("c" ≤ 0.40).

Results and discussion

The absolute minimum and maximum air temperature (Figure 1a) recorded in Cascavel was 2.9 ºC (2nd ten-day period of June) and 36.6 ºC (2nd ten-day period of September), respectively. The absolute minimum air temperature in Palotina occurred in the 2nd ten-day period of June and September (1.7ºC), and the absolute maximum air temperature was 38.9 ºC, observed in the 3rd ten-day period of October (Figure 1b). The average air temperature values for the 1st ten-day period of July was 13.8 ºC in Cascavel (Figure 1a) and 15.6 ºC in Palotina (Figure 1b). Total rainfall ranged from zero (1st ten-day period of August) to 224.6 mm (1st ten-day period of July) in Cascavel (Figure 1a), and from zero (1st ten-day period of July and August) to 188 mm in Palotina (Figure 1b).

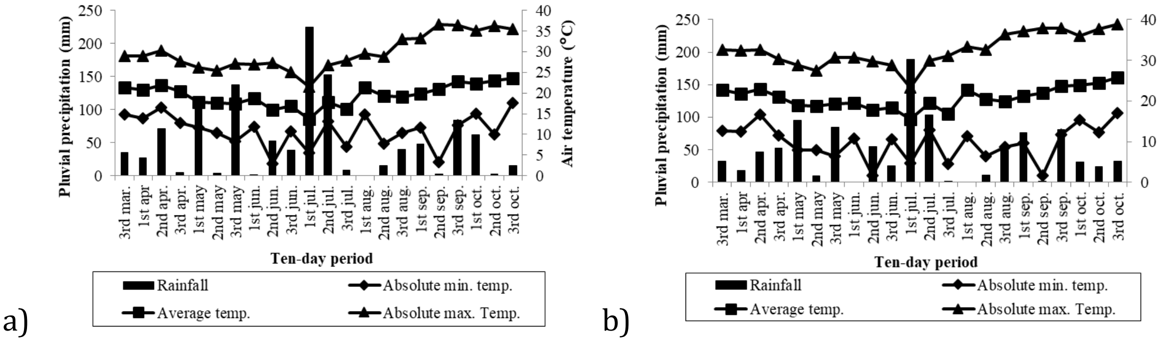

Figure 1. Rainfall and average absolute minimum and maximum air temperatures (ºC), for a ten-day period (°C), from March to October, 2015: a) Cascavel; and, b) Palotina.

For the photoperiod estimated as a function of latitude and solar declination, between the 3rd ten-day period of March and the 3rd ten-day period of October, in Cascavel there was reduction in the length of the day from March (11.9 hours; 3rd ten-day period) to June (10.5 hours; 2nd ten-day period), rising again to 12.8 hours in October (3rd ten-day period). In Palotina, the length of the day ranged from 10.5 hours (2nd ten-day period in June) to 12.7 hours (3rd ten-day period in October).

The minimum ETc estimated for wheat cultivars occurred in the crops sowed on April 16, 2015 (190.1 mm cycle^{-1}; Palotina) and April 22, 2015 (255.5 mm cycle^{-1}; Cascavel) (Table 3). The P values were higher than ETc values in all crop cycles. However, it did not prevent the occurrence of water deficit during the wheat cycle, regardless of sowing date in the studied locations.

Table 3. Averages of crop evapotranspiration (ETc), precipitation (P), real evapotranspiration (ETa), water deficit (DEF) and water excess (EXC) for wheat cultivars in Cascavel and Palotina, Parana state.

Location	Sowing date	ETc	P	ETa	DEF	EXC
		-------------------		(mm cycle^{-1})		-------------------
Cascavel	April 22, 2015	255.5	779.0	189.4	66.1	601.1
	April 30, 2015	261.3	791.9	173.9	87.4	617.7
	May 21, 2015	287.2	718.6	173.8	113.4	550.9
Palotina	March 31, 2015	199.9	680.3	192.0	8.0	494.5
	April 16, 2015	190.1	654.2	169.0	21.2	502.4
	April 27, 2015	213.2	586.2	152.7	60.5	436.8

At the beginning of wheat development (stage I) there was no water deficit for the locations and sowing dates evaluated (Table 4). There was a water deficit mainly in the developmental stages III (heading stage) and IV (physiological maturation). For sowing on May 21, 2015, in Cascavel, there was a water deficit of 111.9 mm during heading stage. In Palotina, the water deficit was 7.2 mm for sowing on March 31, 2015. At physiological maturation stage (IV) the water deficit values varied from 0.1 mm in Palotina (sowing on March 31, 2015) to 34.8 mm in Cascavel (sowing on April 22, 2015).

Table 4. Water deficit at tillering (I), stem elongation (II), heading stage (III) and physiological maturation (IV) of wheat phenological stages, for seven cultivars in Cascavel and Palotina, Parana state.

Location	Sowing date	Water deficit (mm stage^{-1})			
		I (1.0 to 5.0)*	II (6.0 to 10.0)*	III (10.0 to 10.5)*	IV (11.0 to 11.4)*
Cascavel	April 22, 2015	0.0	0.0	31.2	34.8
	April 30, 2015	0.0	0.0	80.7	6.7
	May 21, 2015	0.0	0.0	111.9	1.5
Palotina	March 31, 2015	0.0	0.7	7.2	0.1
	April 16, 2015	0.0	0.0	7.9	12.5
	April 27, 2015	0.0	0.0	42.8	18.9

*Feekes phenological scale (Large, 1954).

The period most sensitive to water deficit in the wheat crop is between the beginning of flowering (10.5.1) to milk grain stage (11.0). The water deficit in these stages can cause significant losses in the final grain yield (Steduto et al., 2012). Considering the higher productivity obtained in each location of the present study, lower water deficit values were found in Cascavel (31.2 mm; April 22, 2015) and Palotina (7.2 mm; March 31, 2015), from sowing to heading stage, resulting in a 41.7% and 42.8% grain yield reduction, respectively. The large amount of rain in the 1st and 2nd ten-day periods of July in Cascavel and Palotina, (Figure 1) may have contributed to the result.

The negative effect on wheat development and yield productivity, due to water excess in the soil and artificial shading, was also observed by Scheeren et al. (1995b). The authors observed reduction of 15% in the dry mass of wheat root system, 16% in the dry mass of aerial part, 24% in grain weight and 25% in the number of grains per spike. Losses in grain production at sowing on

April 22 (Cascavel, Table 6) and March 31 (Palotina, Table 8) are probably due to less water and nutrients absorption, caused by reduced volume of soil explored by the plants, as well as the photosynthetic rate, caused by the lower incidence of sunlight in the crop during the rainy season.

Experiment in Cascavel, Parana

The interaction between cultivars and sowing date was not significant ($p > 0.05$, Table 5) for number of spikes per square meter (NSSM) and number of grains per spike (NGS).

The CD 154 cultivar showed the lowest NSSM (410 spikes m^{-2}), but presented higher NGS (36 grains), along with CD 1104 (36 grains), CD 1440 (32 grains), CD 150 (35 grains), CD 1550 (31 grains) and QUARTZO (37 grains) cultivars. Similar results were observed for the sowing dates analyzed. There was less NSSM (499 spikes m^{-2}) and the cultivars produced higher average of NGS (45 grains) at sowing on May 21, 2015. Yield production is related to the plant's ability to partition biomass in pre-anthesis (Qin et al., 2015).

Table 5. Number of spikes per square meter (NSSM) and number of grains per spike (NGS) for wheat cultivars, in Cascavel, Parana, in the 2015 harvest.

Cultivars	NSSM	NGS
CD 108	553 a	29 b
CD 1104	542 a	36 a
CD 1440	613 a	32 ab
CD 150	532 a	35 ab
CD 154	410 b	36 a
CD 1550	590 a	31 ab
QUARTZO	530 a	37 a
Sowing date		
April 22, 2015	579 a	27 b
April 30, 2015	538 ab	29 b
May 21, 2015	499 b	45 a
Average	539	34
CV (%)	13.95	11.60

Means followed by the same letter in the column do not differ statistically between each other, by the Tukey test ($p < 0.05$).

The lower competition for photo assimilates favored the increase of NGS cultivar increment at sowing on May 21, 2015 (Table 5), confirming the plasticity capacity of wheat to alter the yield components to respond positively in grain (Fioreze and Rodrigues, 2014). Fioreze and Rodrigues (2014) evaluating the yield components in wheat affected by sowing density observed that the reduction in the number of plants per meter increased the number of grains per spike, as well as the number of fertile spikelet per spike, resulting in a 41% increase in the IAC 370 cultivar.

The grain weight had significant effect ($p > 0.05$) for cultivars and sowing dates interaction, but there was no alteration between cultivars at sowing on May 21, 2015 (Table 6). Although there is genetic variability among the cultivars, the environment during the analyzed period did not allow the cultivars to manifest a positive effect. Only CD 108 and CD 150 cultivars (Table 6) had lower thousand grain weight at sowing on April 22, 2015, when compared to April 30, 2015 and May 21, 2015 sowings.

The CD 108 cultivar (23.7 g) differed from others in terms of a thousand grain weight. As this cultivar has a very early cycle, the grain filling (sowing on April 22, 2015) coincided with the higher rainy season in Cascavel (Table 3), which contributed to the result. The sowing on April 22, 2015 in Cascavel (Table 4) damaged the grains filling, as a consequence of the 376.6 mm rainfall that occurred between 1st and 2nd ten-day periods of July, contributing to the 601.1 mm of water excess during the wheat cycle. The excess of water in soil damages mainly at physiological maturation stage, causing reduction in dry mass accumulation of the grain, due to the decrease of photosynthesis and nutrient absorption in wheat (Guarienti et al., 2005). Thus, CD 108 and CD 150 cultivars showed higher values of thousand grain weight at sowings on March 30, 2015 and March 21, 2015 (Table 6).

Table 6. Thousand grain weight (TGW) and grain yield for seven wheat cultivars in Cascavel, Parana, in the 2015 harvest.

Cultivar	------------------------------ Sowing date				-------------------------------		
	April 22, 2015		April 30, 2015		May 21, 2015		Average
------------------------------ Thousand grain weight (TGW; g) ------------------------------							
CD 108	23,70 b	B	33.20 ab	A	33.61 a	A	30.17
CD 1104	34.70 a	A	33.53 ab	A	34.76 a	A	34.44
CD 1440	31.50 a	A	30.90 b	A	31.92 a	A	31.44
CD 150	31.20 a	B	35.39 ab	A	34.91 a	A	33.83
CD 154	35.67 a	A	35.95 a	A	35.47 a	A	35.70
CD 1550	31.96 a	A	34.80 ab	A	33.85 a	A	33.54
QUARTZO	35.33 a	A	35.15 ab	A	35.22 a	A	35.23
Average	32.01		34.13		34.25		
CV (%)			5.39				
------------------------------------ Grain yield (kg ha^{-1}) ------------------------------------							
CD 108	2820 c	B	2998 c	B	5284 bcd	A	3701
CD 1104	3480 ab	B	5798 a	A	5441 bc	A	4906
CD 1440	3676 a	C	4579 b	B	5493 bc	A	4583
CD 150	2920 bc	B	5859 a	A	6226 a	A	5002
CD 154	1817 d	C	3111 c	B	4729 d	A	3219
CD 1550	3833 a	C	4657 b	B	5605 b	A	4698
QUARTZO	3468 ab	B	5046 b	A	4961 cd	A	4492
Average	3145		4578		5391		
CV (%)			5.5				

Means followed by the same upper case in the line and lower case in the column do not differ statistically between each other, by the Tukey test ($p < 0.05$).

The interaction between cultivars and sowing dates had a significant effect ($p < 0.05$) for grain yield. The CD 150 and CD 1104 cultivars showed higher averages yields in 66.7% of the evaluated environments (sowing dates, Table 6). The CD 150 cultivar obtained the highest grain yield at sowing on April 27, 2015 (6226 kg ha^{-1}) and April 16, 2015 (5859 kg ha^{-1}), the latter being statistically similar to CD 1104 cultivar (5798 kg ha^{-1}). As there were no major differences in yield components between the cultivars, the small positive interaction between NSSM, NGS and TGW provided significant effect on grain yield between the cultivars.

The CD 108, CD 1440, CD 154 and CD 1550 cultivars showed higher grain yield at sowing on April 27, 2015, compared to other sowing dates, with an average yield of 5284 kg ha^{-1}, 5493 kg ha^{-1}, 4729 kg ha^{-1} and 5605 kg ha^{-1}, respectively. Although there was a water deficit of 111.9 mm during heading stage (Table 4), lower rainfall and water excess values were observed during the cultivation on May 21, 2015 (Table 3). The reduction of rainy periods and clouds provided increase in incident solar radiation throughout the crop cycle, improving the wheat photosynthetic efficiency, in addition to allowing better chemical control of leaf diseases. Scheeren et al. (1995a) in an experiment carried out in Rio Grande do Sul considered that the decrease in luminosity reduces the liquid CO_2 assimilation rate causing less photosynthetic activity, besides that, the artificial shading on wheat cultivars reduced 34% of grain weight per plant compared to an environment without luminous restriction. Thus, it is considered that periods without rain observed in the present study were not long enough to cause grain yield loss. However, they contributed to increase incident luminosity on the crop, reflecting in higher productivity for the cultivars sown in the 3rd ten-day period of May in Cascavel (Table 6).

There was a lower average grain yield (3219 kg ha^{-1}) for CD 154 cultivar. Even with higher values of NGS (Table 5) and TGW (Table 6) the cultivar showed lower NSSM (Table 5), resulting in higher effect on the final grain yield reduction.

Experiment in Palotina, Parana

Among the evaluated variables, only the NSSM had no significant effect ($p > 0.05$) in the interaction between cultivars and sowing dates. In the three sowing dates (Table 7), the cultivars showed similar results for number of spikes per square meter.

Table 7. Number of spikes per square meter (NSSM) for wheat cultivars in Palotina, Parana, in the 2015 harvest.

Cultivar	Number of spikes per square meter (NSSM)
CD 108	456 bc
CD 1104	550 ab
CD 1440	560 a
CD 150	492 abc
CD 154	416 c
CD 1550	502 abc
QUARTZO	522 ab
Sowing date	
March 31, 2015	519 a
April 16, 2015	500 a
April 27, 2015	481 a
Average	500
CV (%)	13.73

Means followed by the same letter in the column do not differ statistically between each other, by the Tukey test ($p < 0.05$).

The CD 1440 cultivar obtained the highest NSSM (560 spikes m^{-2}), but the result did not differ statistically from CD 1104 (550 spikes m^{-2}), CD 150 (492 spikes m^{-2}), CD 1550 (502 spikes m^{-2}) and QUARTZO (522 spikes m^{-2}) cultivars. As in Cascavel, the cultivar CD 154 obtained smaller NSSM (416 spikes m^{-2}), and one of the highest NGS (27 grains, Table 8). However, excepting the CD 108, the CD 154 and QUARTZO cultivars (Table 8) presented the lowest grain yields.

Table 8. Number of grains per spike (NGS), thousand grain weight (TGW) and grain yield for seven wheat cultivars in Palotina, Parana, in the 2015 harvest.

Cultivar	Sowing date						
	March 31, 2015		April 16, 2015		April 27, 2015		Average
Number of grains per spike (NGS)							
CD 108	26 a	AB	28 ab	A	22 cb	B	25
CD 1104	26 a	AB	27 ab	A	22 cb	B	25
CD 1440	26 a	A	22 b	AB	21 cb	B	23
CD 150	24 a	AB	28 ab	A	20 cb	B	24
CD 154	24 a	B	30 a	A	29 a	AB	27
CD 1550	24 a	A	25 ab	A	26 ab	A	25
QUARTZO	26 a	A	23 b	AB	19 c	B	23
Average	25		26		23		
CV (%)			10.08				
Thousand grain weight (TGW; g)							
CD 108	23.50 a	A	17.21 a	B	18.56 b	B	19.46
CD 1104	23.89 a	AB	21.74 a	B	26.02 a	A	23.88
CD 1440	23.21 a	A	22.09 a	A	24.31 a	A	23.20
CD 150	20.95 ab	AB	19.36 a	B	24.78 a	A	21.70
CD 154	17.44 b	B	19.08 a	B	25.74 a	A	20.70
CD 1550	24.05 a	A	20.85 a	A	22.87 ab	A	22.59
QUARTZO	21.99 ab	B	22.48 a	B	27.71 a	A	24.06
Average	22.15		20.40		24.28		
CV (%)			9.57				
Grain yield (kg ha^{-1})							
CD 108	1669 cd	B	2507 c	A	1653 d	B	1943
CD 1104	2340 ab	B	4039 a	A	3678 a	A	3352
CD 1440	2243 ab	B	3869 ab	A	3707 a	A	3273
CD 150	1416 d	B	3591 ab	A	3868 a	A	2959
CD 154	1886 bc	C	2591 c	B	2993 b	A	2490
CD 1550	2546 a	B	3728 ab	A	2863 bc	B	3046
QUARTZO	1555 cd	C	3540 b	A	2474 c	B	2523
Average	1951	C	3409	A	3034	B	
CV (%)			6.58				

Means by the same upper case in the line and lower case in the column do not differ statistically between each other, by the Tukey test ($p < 0.05$).

There was a positive correlation (R = 0.875) between NSSM and grain yield in the analyzes performed with data from both locations together. The positive correlation (R = 0.8482) between the same variables was also reported by Vesohoski et al. (2011). Therefore, there is evidence that the increase in NSSM increases grain yield. In Palotina, negative consequences of NSSM reduction in final yields were very evident in the CD 108 and CD 150 cultivars.

Excepting CD 1550, the cultivars showed variations in the NGS after sowing on April 16, 2015 (Table 8). Sowing in the 3rd ten-day period of April provided a less favorable environment to increase grain yield, and cultivars had lower average number of grains at sowing on April 27, 2015 (23 grains per spike). The number of grains is determined before the anthesis, however, grains development may be limited by the availability of assimilates after this stage (Cunha et al., 2003). Especially at sowing on April 27, 2015 (Table 8), excessive rainfall in the rubber stage and water deficiency (42.8 mm) during the heading stage resulted in a decrease in NGS, probably reducing the photo assimilates production.

The cultivars presented the highest thousand grain weight when sown on April 27, 2015 (24.28 g, Table 8). However, there was a 33.4% reduction in the average value in Palotina when compared to Cascavel (Table 6). The CD 108 cultivar, in Palotina, showed the lowest value of thousand grain weight (19.46 g) and number of spikes (456 spikes m^{-2}), resulting in a 47.5% decrease in grain yield when compared to Cascavel (Table 8). The yield decrease probably occurred due to excessive rainfall, resulting in nutrient losses from the soil, and reduction of solar radiation and soil aeration in the wheat root system. The occurrence of leaf spots caused by fungi *Bipolaris sorokiniana* (brown spot), *Drechslera spp*. (yellow spot) and *Stagonospora nodorum* (glume spot) reduced the photosynthetic area, reflecting in a decrease in the thousand grain weight and grain yield for the cultivars, especially at sowing on March 31, 2015, in Palotina (Table 8).

Even in adverse environmental conditions, the CD 1104, CD 1440 and CD 150 cultivars expressed higher grain yield among the others, after sowing on April 15, 2015. The average yield was 38.4% higher than that reported by CONAB (2018) for Parana state (2308 kg ha^{-1}). The results showed higher adaptability and stability for these cultivars under conditions of excessive rains, water deficit and leaf diseases, considering sowing April 16 and 27, 2015 (Table 8).

Yields with Jensen equation for wheat cultivars

Excepting CD 154 cultivar, the associations between real and estimated yields were very close, with a determination coefficient of R > 0.81 (Table 9).

Table 9. Correlation coefficient (R), “d” and “c” indexes values, and performance between real (Y) and estimated (X) yields with Jensen equation for wheat cultivars, considering six sowing dates, in Cascavel and Palotina, in the 2015 harvest.

Cultivar	Linear regression	R	“d” index	“c” index	Performance
CD 108	Y = 2126 + 0.307 · X	0.82	0.69	0.56	“Tolerable”
CD 1104	Y = 2461 + 0.288 · X	0.89	0.68	0.60	“Tolerable”
CD 1440	Y = 2300 + 0.342 · X	0.95	0.71	0.68	“Good”
CD 150	Y = 2771 + 0.210 · X	0.81	0.56	0.45	“Bad”
CD 154	Y = 2605 + 0.287 · X	0.57	0.59	0.34	“Terrible”
CD 1550	Y = 1821 + 0.426 · X	0.87	0.75	0.65	“Medium”
QUARTZO	Y = 2044 + 0.445 · X	0.84	0.82	0.69	“Good”

The “d” indexes were between 0.56 (CD 150) and 0.82 (QUARTZO). The Jensen model (Equation 1) performance was classified as: “Good” for CD 1440 and QUARTZO cultivars; “Medium” for CD 1550; “Tolerable” for CD 108 and CD 1104; “Bad” for CD 150; and, “Terrible” for CD 154. The results obtained were interesting and promising, and were not better due to the “d” index values and the rigor of “c” index, since the results were obtained with the product “R · d”. The real productivity depends on many variables, and simplified models such as Jensen’s, which only considers water relations and penalizing factors in crop development stages, are not as sensitive to wide environmental variations. Thus, especially for the CD 108, CD 1104, CD 150 and CD 154 cultivars, high volumes of rainfall and elevation of average air temperature (Figure 1) caused by the El Niño phenomenon (2.2 °C in Cascavel and 1.5 °C in Palotina, in relation to the climatological normal of June, July and August of the locations), may have decisively interfered in the productivity estimates results.

Air temperature and relative humidity elevation also provided a favorable environment for leaf diseases emergence, such as brown spot (*Bipolaris sorokiniana*), yellow spot (*Drechslera spp*) and gluma spot (*Stagonospora nodorum*) in Cascavel and Palotina. As an aggravating factor, there was also the difficulty of control due to the waterlogging of the soil, making it impossible to apply fungicide. The loss of leaf area caused by the yellow spot in wheat reduces the crop photosynthetic rate, grain filling and number of grains per spike, negatively affecting the crop productivity (Ranzi et al., 2015). Due to leaf diseases, Barros et al. (2006) report a 66.5% reduction in grain yield for the IAC 370 cultivar, in Capão Bonito, São Paulo state.

The Jensen productivity estimation model (Equation 1) accounts the productivity loss due to the occurrence of water deficit, by the relation between ETa / ETc. Therefore, the penalty factor does not consider productivity losses due to water excess. Likewise, the model also does not consider the attack of pests and diseases, which can reduce the crop yield, causing differences between the real productivity values observed in the field and estimated in the model.

However, even influenced by adverse factors provided by the different adaptation regions and sowing dates, the CD 1440 and QUARTZO wheat cultivars showed yield compatible with the estimated productivity value of Jensen method. The result can be confirmed by the “Good” performance of the model in estimating the productivity of these cultivars (Table 9).

Conclusions

The pluvial precipitation higher than crop evapotranspiration in all cultivation cycles analyzed did not prevent water deficiencies, which occurred predominantly in the heading and physiological maturation stages.

The smallest water deficiencies in Cascavel (31.2 mm; April 22) and Palotina (7.2 mm; March 31), from sowing to heading, reduced grain yield by 41.7% and 42.8%, respectively, in relation to the higher productivity of each location.

The interaction between cultivars and sowing dates did not show higher differences in yield components (NEM, NGE and MMG), but did provide a difference in grain yield (mainly in CD 150 and CD 1104 cultivars). The sowing carried out at the end of April and in May tended to have a higher yield.

The best performances with Jensen model to estimate wheat grains yield were obtained for CD 1440 and QUARTZO cultivars. The Jensen model overestimated the grain yield of the CD 108, CD 1104, CD 150 and CD 154 cultivars, since the model do not consider losses due to excessive rainfall and/or pests and diseases.

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