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Yield response of canola (*Brassica napus* L.) to different inter-row spacings and sowing dates in northwest of Paraná, Brazil

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In Brazil, the cultivation of canola has increased as a result of higher demand for biodiesel production. However, the current knowledge on planting arrangement and sowing time to boost the crop's yield in the southern part of the country is limited. On this point, the goal of this work was to evaluate the yield potential of four canola hybrids submitted to different sowing dates and inter-row spacings in 2011 and 2012 crop years in Maringá, city located in the Brazilian state of Parana's Northwest area. The experiment was conducted with 16 treatments constituted of 2 sowing dates (April 08 and May 10), 2 inter-row spacings (0.17 and 0.45 m) and 4 hybrids (Hyola 76, Hyola 61, Hyola 433 and Hyola 411). The experimental design was a randomized complete block design with the treatments in a split-split plot design with four replications in the field. The yield potential of each hybrid was evaluated through the weight of a thousand seeds, the grain yield, and the oil content. From the results of grain and oil yields found, the canola hybrid Hyola 433 showed stable production in both crop years and, therefore, are indicated for sowing in early May. On the other hand, Hyola 61 and Hyola 71 can be recommended for sowing in early April. Mostly, the evaluated inter-row spacings did not affect the grain and oil yields over the two crop years.

Key words: Rapeseed, harvest, oilseed content and plant arrangement.

INTRODUCTION

Canola (*Brassica napus* L. var. *oleifera* DC.) is a winter oilseed crop originally derived from the breeding of rapeseed. The crop seeds contain about 40 to 44% of oil content and 23 to 35% of protein (Kandil and Gad, 2012) and currently ranked at second position in the world in edible oil consumption, after soybean (USDA, 2016).

With the growing interest in canola as feedstock, mainly for biodiesel production, it may become a profitable crop choice for winter cultivation in the Southern region of Brazil, such as corn or wheat (Kaefer et al., 2014).

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Table 1. Soil chemical properties in the 0-20 cm depth of the field area in 2011 and 2012, in Maringá-PR, Brazil.

Analysis	2011	2012	Unit	Extractor or Method
pH ($CaCl_2$)	4.7	4.8	-	$CaCl_2$
pH (H_2O)	5.5	5.6	-	H_2O
Al^{3+}	0.1	0.0	$cmol_c\ dm^{-3}$	KCl 1 mol L^{-1}
$H^{+}+Al^{3+}$	3.42	3.17	$cmol_c\ dm^{-3}$	SMP
K^{+}	0.54	0.38	$cmol_c\ dm^{-3}$	Mehlich
P	7.0	6.5	mg dm^{-3}	Mehlich
Ca^{2+}	2.82	3.41	$cmol_c\ dm^{-3}$	KCl 1 mol L^{-1}
Mg^{2+}	1.01	1.43	$cmol_c\ dm^{-3}$	KCl 1 mol L^{-1}
S	6.54	5.27	mg dm^{-3}	Monocalcium phosphate
SB	4.37	4.31	$cmol_c\ dm^{-3}$	-
CTC	7.79	15.20	$cmol_c\ dm^{-3}$	-
V	56.10	57.62	%	-
Ca	36.20	38.37	%	-
Mg	12.97	14.17	%	-
K	6.93	5.08	%	-
M	2.24	0.00	%	-

Source: Agrochemical Laboratory of UEM's Department of Chemistry (Maringá – PR, Brazil).

However, on one hand the country's demand is increased, but on the other hand, studies on canola seed production and technology with hybrids potentials which are useful in biofuel production are very limited.

Since there is little information available regarding the performance of canola growth in Northwest of Paraná, farmers mostly adopt cropping practices based on other species. On this point, the commercial inter-row spacings used in canola production are either of 0.17 or 0.45 m, which are, respectively, the same values used for wheat and soybean (Krüger et al., 2011; Bandeira et al., 2013).

Yan and Holland (2010) pointed out that the expression of crop yield potential depends on the genetic and environmental components and on the interaction between them. Therefore, as stated in Burton et al. (2008), an in-deep understanding of the phenological and physiological factors able to cause genotype-environment interaction could help growers to optimize grain yield and quality. In this context, the aim of this research was to evaluate the grain yield response and the oil content of four canola hybrids submitted to different sowing dates and inter-row spacings in the state of Parana Northwest area.

MATERIALS AND METHODS

The experiment was carried out during the crop years of 2011 and 2012 at Iguatemi Research Station (FEI) of the State University of Maringá (UEM), in Maringá in Northwestern Paraná state, located at latitude 23°25' south and longitude 51°57' west of Greenwich and with an average altitude of 540 m. The region's climate and soil are, respectively, classified as Cfa just as Köppen classification (Caviglione et al., 2000) and Typical Red Dystrophic Argisol according to the Brazilian Classification System (EMBRAPA, 2013).

In both crop years, the trials consisted of 16 treatments, comprising 4 different hybrids sown at two planting dates (08, April and 10, May) and grown using two distinct inter-row spacings (0.17 m and 0.45 m). The tested hybrids were the late-cycle Hyola 76, the medium-cycle Hyola 61 and the both short-cycle Hyola 411 and Hyola 433.

The experimental design was a randomized block factorial 4×2×2 (hybrid × sowing date × row spacing) with four replications arranged in a split-split plot layout, which is, according to Gomez and Gomez (1984), suited for a three-factor experiment where three different levels of precision are desired. The authors further stated that in this layout the main-plot is divided into subplots, which are further divided into sub-subplots. The less important factor is allocated at random to the main plot whereas the most important is allocated to the sub-subplot. In the present work, the main plot, the subplot, and the sub-subplot were, respectively, the dates of sowing, the inter-row spacings, and the hybrids.

The plots comprised either of six rows of 5 m × 0.45 m apart for the wider row spacing or of sixteen rows of 5 m × 0.17 m apart for the narrower row spacing. The harvesting area of each experimental unit consisted of only 3.6 m^2, since the lateral rows and the end boundaries of the central portion were not considered as a way of minimizing the border effect described in Peterson (1994).

After the chemical analysis (EMBRAPA, 2011), of which the results are shown in Table 1, soil correction and fertilization were adopted just as summarized in Tomm (2009). As seeds were sown manually into the soil, in order to reach the final population of about 40 plants m^{-2}, seedlings of all plots were thinned after the true leaf appeared as was updated in Ren et al. (2014).

As stated in Tomm (2009) and updated in Sanches et al. (2014), manual or chemical methods of control were carried out to deal with weeds and, later on, to control *Diabrotica speciosa* and *Brevicoryne brassicae* infestations. On this point, the active ingredients of the preemergence herbicide and the contact and ingestion insecticide used were, respectively, the fenoxaprop-P-ethyl + clethodim (Podium S®) and the alpha-cypermethrin (Cipermetrina Nortox 250 EC®).

The weather data were recorded at a nearby weather station within the FEI-UEM, located 3 km west of the field area (Figure 1). Adverse weather conditions such as low temperature and drought

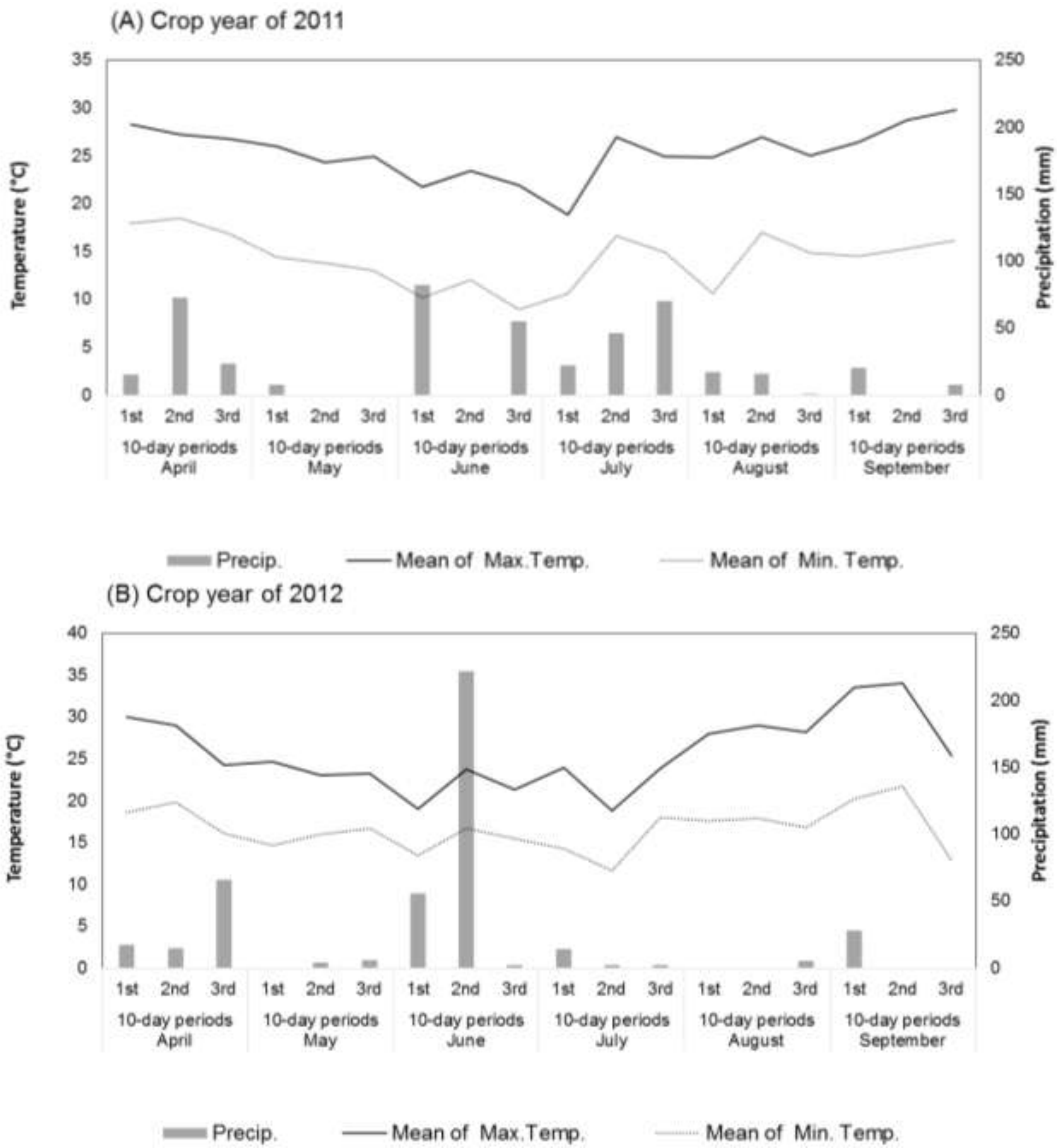

Figure 1. Climatic data indicating the means of the minimum and maximum temperatures and rainfall precipitation for the three 10-day period of each month from April to September for the years of 2011 (A) and 2012 (B) (FEI's weather station, Maringá-PR, Brazil).

were observed during the cropping seasons. On this point, in both crop years, the monthly rainfall total stood at around 100 mm in April, whereas the month of May was characterized by low precipitation, which was combined with the decrease of the temperatures along time (Figure 1).

A very high total precipitation was observed over the second 10-day period of June of 2012. However, June of 2011 showed reasonable regularity, with rain occurring during the first and second 10-days periods. Over July, 2011 the total rainfall observed was of 137.80 mm, which corresponds to about two and a half times above the seasonal average (56.2 mm). On the other hand, in August, 2011 the precipitation was of 33.8mm, remaining close to the monthly expected value (35 mm). Regarding 2012, the precipitation was very low in July (18.4 mm), and stayed below 5 mm in the course of August (INMET, 2014). The minimum temperature over the third 10-days period of July of 2011 (8.9°C) as well over the second 10-days period of July of 2012 (11.6°C) were out of the amplitude of 12-30°C, which is considered adequate for canola's growth (Zhang et al., 2015). Nevertheless, all the other means of the minimum temperature were within the crop's range of tolerance. Regarding the maximum temperature, only in the first 10-days period of September of 2012 it was noted a peak out of that range (33.5°C).

Manual harvesting took place when the main plant stem presented around 60% of the seeds with dark brown to black color (Portella and Tomm, 2007). The harvested plants from each plot were, then, packed, identified and transferred to a through-air drying process of 5 days. Once dried, the plants were threshed manually and then hand sieves and a digital impurities selector were used to obtain a very clean seeds. At the UEM's Seed Technology Laboratory, located at the Applied Research Center for Agriculture, the following assessments were carried out:

(i) Thousand seed weigh (TSW): it was determined by weighing 8 subsamples of 100 seeds for each field plot, with an analytical scale accurate to 1 mg. For all plots, the coefficient of variation was less than four, and the results were multiplied by 10 (Brasil, 2009).
(ii) Grain yield (GY): the GY of each plot was weighed after threshing and was converted into kg ha^{-1} after a proper moisture content adjustment of 9.5% as described in the Brazilian Rules for Seed Testing (Brasil, 2009).
(iii) Oil yield (OY): the quantification of total lipids involved Soxhlet extraction with hexane for 6h according to the analytical standards of the Adolfo Lutz Institute (IAL, 2008), but with the adjustments performed in Wang et al. (2010). Four sub-samples constituted of 2 g of canola bran from the seeds of each experimental unit were assessed. The results were shown based on the percentage of oil extracted, obtained by weighing difference. The total oil yields were calculated by multiplying the oil percentage with the mass of seeds from each plot. The results were shown in kg ha^{-1}.

The data obtained in this study were analyzed just as summarized in Perecin and Cargnelutti Filho (2008), in which the analytical framework adopted is the joint analysis of the experiments. The data were subjected to analysis of variance at 5% probability ($p < 0.05$) and when significant, the means were compared by the Fisher's LSD test (Least Significant Difference) ($p < 0.05$) according to Banzatto and Kronka (2006). When comparing the means from sowing dates and inter-row spacings the F test was conclusive. The computer package Sisvar (Ferreira, 2011) was used to perform all the statistical analyses.

RESULTS AND DISCUSSION

A significant first-order interaction was observed between hybrids and sowing dates for the variables GY and OY in both crop years, as well for the TSW regarding 2011. On the other hand, in 2012 the F-test at level of 5% showed a significant second-order interaction for TSW, which means that in the second crop year, besides the first-order interaction above mentioned, this variable revealed a significant contribution from the inter-row spacing (Banzatto and Kronka, 2006).

Thousand seed weight (TSW)

TWS is a suitable indicative parameter of seed physiological quality, as within the same lot high-density seeds tend to perform better in germination, vigor, seedling establishment and, thus in yield (Moshatati and Gharineh, 2012). Table 2 shows the first-order (sowing date × hybrid) and the second-order interactions (sowing date × hybrid × inter row spacing) of this variable in both years of 2011 and 2012, respectively. While at the first sowing date of the first crop year Hyola 433 presented the lowest value among the tested hybrids, no significant difference was found between the genotypes at the later sowing.

Just as Melgarejo et al. (2014) found, Hyola 433 performance was impaired as a result of limited water availability observed in May, 2011 (Figure 1), which could have compromised the flowering formation of this short-cycle hybrid.

Interestingly in 2011, even sharing with Hyola 433 similar maturation cycle, Hyola 411 did not perform the same, fact that may be related to the difference in the water requirement of each hybrid. Further, as documented in Tomm et al. (2009) and Marco et al. (2014), Hyola 433 is considered one of the tested hybrids with the highest sensitivity to water deficit, followed, in a decreasing sequence by Hyola 411, Hyola 76 and Hyola 61. At the second sowing date of 2011 (Table 2), no significant difference was found among the genotypes. On average, higher TSW values were found at the second sowing date regardless, of course, of the inter-row spacing. In 2012, Table 2 shows that at early sowing, the hybrids Hyola 61 and Hyola 411 grown using the row spacing of 0.17m had superior results than the others. Nevertheless using 0.45m as row spacing, Hyola 61 showed the lowest performance, while between the others no difference was observed.

Regarding the later sowing date of 2012 (Table 2), Hyola 61 was the only hybrid to present superior performance for TSW regardless of row spacing. However, when using the wider row spacing, Hyola 61 and Hyola 76 did not show statistical differences from each other. Overall, in 2012 Hyola 61 showed high stability performance for TSW, with an exception result at early sowing using the row spacing of 0.45 m. On the other hand, still in 2012, Hyola 433 presented the lowest TSW values, except when sown early and using the wider inter-row spacing.

Comparable results were documented in Marco et al. (2014), whom studying efficiency of water use of canola found that Hyola 433 showed higher values of evapotranspiration than Hyola 61 over the crop cycle. The authors further commented that Hyola 61 had a very high TSW stability even under conditions of water stress, albeit Hyola 433 needed high requirement of favorable environmental conditions to express its full productive potential. Conflicting responses to inter-row spacing between the tested years were recorded for TSW, as in 2011 no difference was found. Generally, at early sowing of 2012, while Hyola 411 showed greater TSW regardless of the row spacing, Hyola 61 performed the same at late sowing. Such variation between years could be attributed to the precipitation in 2012, in which the rainfall observed was very unevenly distributed with more than 90% of its total concentrated until June, albeit

Table 2. Partition for interaction of the variable thousand seed weight, in Maringá-PR, Brazil.

Thousand seed weight (g)		
Hybrids	**Sowing dates in 2011**	
	08 April	**10 May**
Hyola 76	2.595^{aB}	2.690^{aA}
Hyola 61	2.944^{aA}	2.837^{aA}
Hyola 411	2.647 a^{B}	2.744^{aA}
Hyola 433	2.343^{bC}	2.879^{aA}

Hybrids	**Sowing dates and inter-row spacings in 2012**			
	08 April	**08 April**	**10 May**	**10 May**
	0.17 m	**0.45 m**	**0.17 m**	**0.45 m**
Hyola 76	2.59^{ab}	2.72^{a}	2.66^{bc}	2.44^{a}
Hyola 61	2.64^{a}	2.21^{b}	3.11^{a}	2.37^{a}
Hyola 411	2.79^{a}	2.81^{a}	2.86^{ab}	2.32^{ab}
Hyola 433	2.34^{b}	2.79^{a}	2.48^{c}	2.10^{b}

Within each crop year, means followed by equal letters, uppercase in the column and lowercase in the line, do not differ significantly at 5% probability by LSD test and F test, respectively.

Table 3. First-order interaction (hybrid x sowing date) for the variables grain and oil yields in 2011 and 2012, in Maringá-PR, Brazil.

Hybrids	**Grain yield (kg ha^{-1})**		**Oil yield (kg ha^{-1})**	
	Sowing dates in 2011			
	08, April	**10, May**	**08, April**	**10, May**
Hyola 76	1304.25^{aBC}	870.74^{Bc}	465.36^{aAB}	303.15^{bC}
Hyola 61	1516.03^{aA}	1050.16^{bBC}	529.46^{aA}	357.39^{bBC}
Hyola 411	1385.20^{aAB}	1371.64^{aA}	495.45^{aA}	505.39^{aA}
Hyola 433	1168.71^{aC}	1234.44^{aAB}	402.37^{aB}	425.06^{aB}
Hybrids	**Sowing dates in 2012**			
	08, April	**10, May**	**08, April**	**10, May**
Hyola 76	1321.53^{aA}	793.05^{bC}	390.91^{aB}	268.58^{bC}
Hyola 61	1306.25^{aA}	1030.55^{bB}	453.76^{aA}	345.64^{bB}
Hyola 411	1122.57^{aB}	1281.59^{aA}	459.27^{aA}	390.28^{aB}
Hyola 433	977.08^{bB}	1147.91^{aAB}	331.20^{bC}	462.72^{aA}

Within each crop year, means followed by equal letters, uppercase in the column and lowercase in the line, do not differ significantly at 5% probability by LSD test and F test, respectively.

in 2011 this amount was of about 60%. Hence, these findings suggest that the TSW of canola is affected by the inter-row spacing, but only under water restriction from flowering.

Grain yield (GY)

Regarding the GY (Table 3), at the sowing date of 08 April, 2011, Hyola 61 presented superior performance than all of the others. Further, Hyola 411 presented higher results than Hyola 433 at this first sowing date. However, when sown on 10 May, 2011, Hyola 411 showed higher performance than Hyola 61, Hyola 76 and Hyola 433.

At the earlier sowing date of 2012 (Table 3), the late-cycle Hyola 76 and the medium-cycle Hyola 61 had both higher GY than that of the short-cycle hybrids Hyola 411 and Hyola 433. Such results were not observed at the later sowing period, in which Hyola 411 showed superior values than Hyola 61 and Hyola 76, whereas Hyola 433 had higher performance than Hyola 76. At the second sowing date of 2012, a non-significant difference was found (p>0.05) within the short- cycle group (Hyola 411 and Hyola 433) and between Hyola 433 and Hyola 61, but the first ones presented greater performance than the other two.

Comparing the GY data from both sowing dates of 2012, while the late and the medium-cycle hybrids (Hyola 76 and Hyola 61, respectively) presented productivity reduction, the short-cycle Hyola 411 and Hyola 433 maintained stable GY results. Additionally, it was noted that Hyola 433 showed productivity gain when sown on 10 May, 2012, performance that could be partly explained by the higher water availability observed on July, 2012 (Figure 1). Tomm et al. (2009) pointed out that the crop water needs range from 312 to 500mm over the plant cycle. In the present work, this requirement was met, but the uneven rainfall distribution regime, especially in 2012, appeared to be determinant on the hybrids yield response. On average, it is plausible to suggest that under the environmental conditions recorded at the first sowing date, the GY of Hyola 61 was positively correlated with its TSW, regardless of the crop year. However, considering the second sowing date no direct effect on GY was observed since Hyola 61 productivity was less than Hyola 433 and Hyola 433 in both growing seasons.

Oil yield (OY)

Concerning the variable OY (Table 3), Hyola 76, Hyola 61 and Hyola 411 presented higher oil content per hectare when sown on 08 April, 2011. Also, when sowing took place on 10 May, 2011, Hyola 411 showed superior values than all of the tested hybrids. Overall, in 2011 higher OY values were found for Hyola 76 and Hyola 61 at early sowing than at the late one. The short-cycle hybrids Hyola 411 and Hyola 433 did not differ significantly from each other, which mean that the tested sowing dates had no influence on their responses.

Now, regarding the OY in 2012 (Table 3), at the first sowing Hyola 61 and Hyola 411 presented superior performance, whereas at the second one Hyola 433 was superior among the other hybrids. Furthermore, at late sowing, Hyola 61 and Hyola 411 presented greater OY than Hyola 76. Comparing the OY data from both sowing periods in 2012 (Table 3), Hyola 76 and Hyola 61 presented both upper values when sown at the first sowing period than at the second one, whereas an opposite finding was observed for Hyola 433. Hyola 61, however, maintained a stable productivity regardless of the sowing date.

As discussed in Zhang et al (2015), canola achieves its full productive development at an optimal temperature of 20°C, with extreme limits ranging from 12 to 30°C. Further, Faraji (2012) summarized that the crop productivity compounds such as TSW, OY and GY are determined during seed filling period, which is highly linked to the environmental conditions. As a result, an increasing in temperature during that period decreases its duration and thereby the oil content, for instance.

In this trial, although few temperatures out of that range were observed (Figure 1), the uneven precipitation regime played the most important part in the yield results. In both crop years, regardless of row spacing, Hyola 61 and Hyola 76 decreased their GY and OY when sown at the later date, which indicates that for those hybrids 08, April is the best date for obtaining maximum yield in Parana's Northwest region.

It is believed that the water deficit measured at the beginning of cycle (May) could have adversely affected Hyola 61 and Hyola 76 growth, mainly, the seed emergency. However, as mentioned, all plots were conducted using a population of about 40 plants m^{-2}. On the other hand, as pointed out in Faraji (2012), here the low water availability observed from flowering seemed to impact negatively on the hybrids yield response, as for both the seed filing period initiated, on average, in the middle of July.

Conclusion

The short-cycle hybrid Hyola 411 showed stable production regardless of the sowing date. However, the variables GY and OY of Hyola 433, also a short-cycle hybrid, were impaired by the water restriction observed from flowering. Hybrids with late maturity such as Hyola 76 and Hyola 61 performed better when sown in early April. The tested inter-row spacings did not impact on the canola yield, including its oil content. On the other hand, to maximize the TSW it is recommended to sow Hyola 76 and Hyola 433 using the wider inter-row spacing, while Hyola 61 showed superior performance using the narrower one.

Conflict of Interests

The authors have not declared any conflict of interests.

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