Effects of different soil water tensions on rapeseed crops (*Brassica napus* L.)

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Abstract: Correct irrigation management aims to determine the right amount of water at the right time. Also, it is one of the available tools to reduce energy and water costs, enabling maximum crop production. Considering these aspects, a study was conducted to determine the effects of different soil water tensions on rapeseed crop. For this purpose, an experiment was carried out in Brazil, at the department of Agricultural Engineering at the Federal University of Lavras, from April to October 2008. The experimental design was completely randomised, with four treatments of different soil water tensions (20, 40, 80 and 120 kPa) and four replicates amounting to 16 experimental plots. Crop vegetative, productive parameters and qualitative grain parameters were evaluated. According to the variance analysis, different soil water tensions affected the number of pods, the number of branches, dry matter of the vegetative part, dry matter of pods, total dry matter and yield, by F test at 5% probability. While, the physical quality of the grains, the weight of 1,000 grains and specific matter were not affected by treatments. Water retained at 25 cm of depth and at 20 kPa tension proved to be a good indicator of the correct amount of water to start irrigation of rapeseed crop, as the highest grain yield was achieved with this treatment. Grain yield sensitivity to water deficit, represented by yield response factor ky, was lower than one, indicating that supplementary irrigation caused proportionally smaller yield decreases when compared to the reduction in applied water.

Keywords: water irrigation, rapeseed, yield, water tension on soil

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1 Introduction

Rapeseed (*Brassica napus* L.) from the family of crucifers is the third most cultivated oilseed crop worldwide, after palm and soybean (Istanbulluoglu et al., 2010; Mousavi- Avval et al., 2011; Takashima et al., 2013). Rapeseed can be used for human food, industry or as green manure (Pavlista et al., 2011; Sprague et al., 2014).

In Europe, rapeseed is mainly used for industrial purposes such as biodiesel production. In Brazil, however, rapeseed is used for food production (Milazzo et al., 2013) and livestock, as bran or grains (Heendeniya et al., 2010; Bergamin, 2011; França et al., 2011).

Rapeseed is grown in Brazil covering an area of 46,300 hectares concentrated mainly in the southern region, which accounts for 94% of the country´s production (Bergmann et al., 2013). Rapeseed can be introduced into the Brazilian cerrado (savannah), during the off-season, although water shortages in this period may compromise the crop development, leading to the need for irrigation.

Nevertheless, irrigation alone does not guarantee the increase in yield. Irrigation management is also fundamental to guarantee the expected crop yield, as lack

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or excess of water may be harmful to crop development (Resende and Albuquerque, 2002; Gomes and Testezlaf, 2004; Silva et al., 1999; Albuquerque and Durães, 2008).

The right time to perform irrigation may be determined by soil water tension, as this technique is closely related to yield rates, and proper equipment is available on the market (Silva et al., 1999). Currently, several studies are being carried out to determine crop irrigation management using tensiometers.

Silva et al. (2008) analysed the effect of two soil water tensions on wheat yield in the Brazilian savannah. The authors verified that irrigation performed with a tension of 50 kPa in the layer 0-0.20 m provided a higher grain yield.

Guerra et al. (2000) assessed the effects of different soil water tensions on bean plant (*Phaseolus vulgaris* L.) yields. Water was applied when soil water tension at 0.10 m reached levels of 41, 55, 75 and 300 kPa. Monitoring was carried out with tensiometers and plaster blocks. The highest yield was achieved when irrigation was applied at a tension of 41 kPa.

Amabile et al. (2004) suggest the tension of 60 kPa, monitored at 0.30m as the ideal time to start watering barley crops in the Brazilian savannah. Silva et al. (1998) recommend starting irrigation on corn crops under the tension of 40 kPa at 0.10 m of depth.

The purpose of this work was to determine the ideal time to start irrigating rapeseed crops through an experiment carried out at the Federal University of Lavras, Minas Gerais, Brazil. In addition, it assessed the effects of different soil water tensions under crop vegetative parameters, yield and physical quality of grains.

2 Materials and methods

2.1 Characterisation of the experimental area

The experiment was carried out in an experimental area of 325.6 m^2 (37 m × 8.8 m) at the Department of Engineering of the Federal University of Lavras, Brazil, from June to October 2008, during the off-season period in which the crop is called *safrinha* (winter crop).

The area is located in the Southern Minas Gerais State, at an altitude of 918 m above sea level, 21°14′ south latitude and 45°00′ west longitude. According to the Köppen classification, the region has a climate known as Cwa, i.e., mild temperate, rainy, with dry winters, average temperature in the coldest month less than 18ºC and over 3ºC and average temperature in the hottest month in summer over 22°C (Dantas et al., 2007).

Environmental conditions were monitored by an automatic weather station located near the experimental area. We collected daily data of weather variables, such as air temperature, relative humidity (UR), wind speed and precipitation.

The soil, classified as typical dystrophic Red Latosol (Empresa Brasileira de Pesquisa Agropecuária, 1999; Koetz, 2006), was prepared with subsoiling, ploughing and grading. The physical and chemical characterisation of the soil before the initiation of the experiment was carried out at the Department of Soil Science of the Federal University of Lavras, with a soil sample extracted from the layer 0-0.20 m.

The Chemical analysis was comprised of an examination of the pH level, organic matter, macro and micronutrients, sum of bases and cation exchange capacity at a ph level of 7.0 in base saturation rate (Table 1). In addition, the analysis of the particle's size consisted of the contents of clay, silt and sand (Table 2).

Table 1 Chemical analysis of soil in the experimental area

Symbol	Description	Unit	Determination
pH	H_2O	-	5.8
P	Phosphor	mg/dm^3	2.5
K	Potassium	mg/dm^3	69
Ca^{2+}	Calcium	$cmolc/dm^3$*	2.60
Mg^{2+}	Magnesium	$cmolc/dm^3$*	0.70
H+Al	Potential acidity	$cmolc/dm^3$*	2.10
SB	Sum of bases	$cmolc/dm^3$*	3.50
(T)	CEC at ph 7.0	$cmolc/dm^3$*	5.60
t	Effective cation exchange capacity	$cmolc/dm^3$*	3.5
V	Base Saturation	%	62.40
MO	Organic matter	dag/kg	3.00
Zn	Zinc	mg/dm^3	1.90
Fe	Iron	mg/dm^3	34.80
Mn	Manganese	mg/dm^3	45.60
Cu	Copper	mg/dm^3	6.00
B	Boron	mg/dm^3	0.30
S	Sulphur	mg/dm^3	33.50

Note: * Centimol per cubic decimetre.

Table 2 Particle size analysis of the experimental area

Layer/m	Sand	Silt	Clay	Texture class
	dag kg^{-1}			
0 – 0.20	10	21	69	Heavy clay

Retention curve of soil water was firstly built with the data of soil water content (%) corresponding to a given matric potential applied (kPa), as shown in Table 3.

Table 3 Retention curve of soil water in the experimental area

Sample/m	Matric potential applied/kPa							
	1500	500	100	33	10	6	4	2
	% of humidity corresponding to							
0-0.20	24.34	27.03	29.59	32.21	39.76	42.95	44.39	62.78

Table 4 shows parameters of the adjustment equation of the characteristic curve of soil water retention according to the Genuchten model (1980) obtained with the SWRC program (Soil Water Retention Curve), according to Dourado Neto et al. (2000).

Table 4 Parameters of the adjustment equation of characteristic curve of soil water retention according to Genutchten model (1980) with matric potential in kPa and water content in cm^3 for the experimental area

Layer /m	θr	θs	α 1/cm	M	n	Coefficient of adjustment
	cm^3 cm^{-3}					
0-0.20	0.243	0.628	0.3740	0.4046	1.6795	0.928

The mathematical model for retention curve description (Albuquerque and Durães, 2008) of soil water by Genuchten (1980) is shown in Equation (1):

$$\theta(\psi_m) = \theta r + \left(\frac{\theta s - \theta r}{[1 + (\alpha \psi_m)^n]^m} \right) \quad (1)$$

where, $\theta(\psi_m)$ = functional relationship between content of water (θ) in base volume, cm³/cm³; and matric potential, cm; θr = content of residual water, cm³/cm³; θs = content of soil water on saturation (equal to porosity), cm³/cm³; ψ_m = potential of soil water, cm; α = parameter with dimension equal to the inverse of the potential dimension, 1/m; m e n = non dimensional parameters.

Substituting the parameters of the mathematical model of the equation obtained with software SWRC, we arrived at Equation (2), which adjusted to the experiment soil.

$$\theta = 0.243 + \left(\frac{0.628 - 0.243}{[1 + (0.3740.\psi)^{1.6795}]^{0.4046}} \right) \quad (2)$$

Figure 1 shows the retention curve of soil water obtained with the Genuchten model (1980).

Total doses of NPK followed recommendations according to Tomm (2007) and Cordeiro et al. (1993): 150 kg/ha of N; 120 kg/ha of P_2O_5; 60 kg/ha of K_2O; 2 kg/ha of B; 2 kg/ha of Zn.

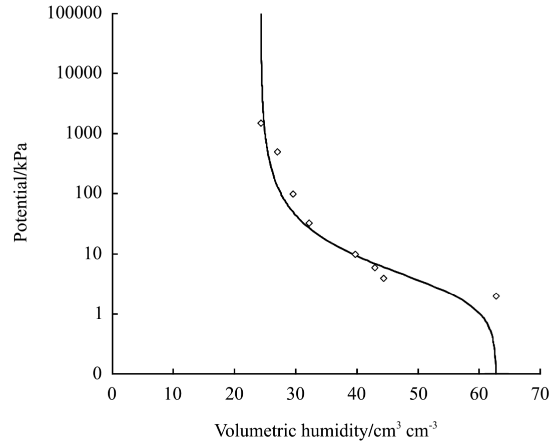

Figure 1 Retention curve of soil water to the layer assessed in typical dystrophic Red Latosol

2.2 Experimental design

The design was totally random with four treatments and four repetitions, amounting to 16 experimental plots. The treatments were comprised of four soil water tensions at 20, 40, 80 and 120 kPa (Silva et al., 1999).

The experimental plots were 4 m long and 1.6 m wide (6.4 m^2) with four planting lines, spaced out at 0.40 m and 0.0625 m. The assessed area was 2.4 m^2 (3 m × 0.8 m), corresponding to the plot central area, as shown in Figure 2. The plot borders comprised the rest of the plot.

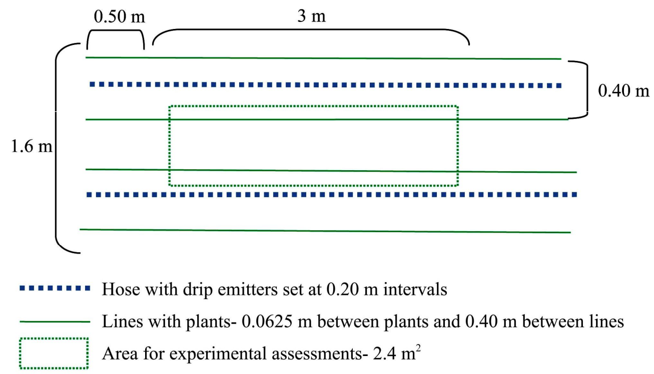

Figure 2 Experimental plot

2.3 Crop management

The hybrid chosen was Hyola 401, which shows high yield stability in many environments. Flowering starts at Day 44, lasting 19 to 33 days, and the crop cycle lasts 107 to 135 days. It is the most precocious hybrid grown in Brazil. Also, it is greatly resistant to lodging and susceptible to blackleg disease (Tomm, 2007).

Planting was carried out manually (Figure 3) on the June 20th 2008 with certified seeds provided by a local farmer. Sowing required a 0.05 m deep furrow to put down fertiliser. Later, seeds were placed in a 0.015 m deep furrow.

After emergence and establishment of the plants, we carried out two manual pruning treatments. The first was performed 15 days after sowing (from the 5th to the 8th of July 2008) and the second, 28 days after sowing (from the 18th to the 19th of July 2008), adjusting 15 plants per linear meter of row and 40 plants per square meter (Tomm, 2007).

Figure 3 Rapeseed planting (UFLA. Lavras-MG. 2008)

Treatments started 40 days after sowing, on July 31st 2008. The delay for starting treatments was due to the manifestation of Fusarium fungus (*Fusarium* spp), diagnosed by the Laboratory of Phytopathology at the Federal University of Lavras. It hampered crop establishment (growth, initiation), requiring weekly application of fungicide (commercial product: Derosal 500 SC at a dose of 1 mL/L, active ingredient Carbendazin) to recover plant stand. Weed control was performed manually and insect control was carried out with the application of insecticide according to need.

2.4 Assessment of parameters

2.4.1 Vegetative parameters

Vegetative parameters assessed fortnightly during the application of treatments were: the number of leaves; stem diameter (mm) with pachymeter; plant height (cm) with a measuring tape; the number of pods and branches.

Pod green matter (kg/ha), green matter of vegetative part (kg/ha) and total green matter of plants (kg/ha) were verified through the collection of plants corresponding to one linear metre in the centre of each experimental plot. Different parts of the assessed plants were separated, cut and weighed using a digital electronic scale.

Pod dry matter (kg/ha), dry matter of vegetative part (kg/ha) and total dry matter (kg/ha) were assessed in a ventilated greenhouse at a mean temperature of 65 - 75°C, where plants were kept in perforated paper containers until reaching a constant weight.

2.4.2 Grain yield

Grain yield was assessed by collecting pods in plants from the centre of the experimental plots, amounting to five linear metres. Grains were separated from pods, air-dried until they reached a level of 8% humidity, weighed and kept in a cold chamber at 10°C. The analysis of treatment effects on yield was carried out in kg/ha.

2.4.3 Physical quality of grains

Physical characteristics of grains assessed were: weight of 1000 grains (g) and specific matter (g/mL). The weight of 1000 grains was analysed with samples from each treatment, subdivided into eight repetitions of 100 grains. Later they were weighed on a digital electronic scale with the same decimal numbers. The result of the determination was calculated by multiplying the mean weight of 100 grains by 10. Grain specific matter was determined by a one-litre hectolitre scale.

All assessed parameters were submitted to an analysis of variance by F test significant at 5% probability, and the Tukey test was applied to compare means. The effect of treatments was verified through a regression analysis. Statistical analysis of data was performed with the computer System analysis of variance for balanced data (Sisvar), version 4.2 (Ferreira. 1999).

2.4.4 Sensitivity of rapeseed to water deficit

Quantification of the water deficit effect on grain yield was obtained with the relation between relative decrease of yield and relative decrease of irrigation depth applied, given by yield response factor ky (Doorenbosand and Kassan, 1994) – Equation (3) – adapted by the author. Response factor ky is <1 when fall in yield becomes proportionally lower than the water deficit applied; however, response factor ky >1 shows that relative fall in yield is higher than relative fall of water deficit applied.

$$\left(1-\frac{Yr}{Ym}\right)=Ky\left(1-\frac{Lr}{Lm}\right) \qquad (3)$$

where, *Yr* - real yield, kg/ha; *Ym* - potential yield, kg/ha; *Ky* - yield response factor; *Lr* – real irrigation depth, mm; and *Lm* – potential irrigation depth, mm.

Potential yield (*Ym*) and potential irrigation depth (*Lm*) were obtained from the treatments corresponding to soil water tension at 20 kPa, whereas real yield (*Yr*) and real irrigation depth (*Lr*) came from the other treatments.

2.4.5 Irrigation

Until the beginning of treatments, all plots were irrigated at a depth of 205 mm with laser-perforated hoses SANTENO®. Later, plots were irrigated by a drip irrigation system with compensating drippers of 3.9 L/h with a measured mean flow, set at 0.2 m intervals in 16 mm diameter polyethylene hoses. Each plot had two dripper lines set between planting lines.

Effective depth of root system was 0.25 m. Irrigation management was carried out by reading tension values on tensiometers set at a depth of 0.125 m in the experimental units of 20 and 40 kPa. At the tensions of 80 and 120 kPa, Watermark® was used, as shown in Figures 4 and 5.

Figure 4 Reading of soil water tension with tensiometer

Figure 5 Reading of soil water tension with Watermark®

Tensiometers were built at the Laboratory of Water and Soil Engineering at the Federal University of Lavras. Before being set in the field, the equipment underwent a careful test to check leakage.

Readings provided in bars by puncture tensiometer were transformed in kPa and adjusted by Equation (4).

$$\Psi = L + 0.098.h \qquad (4)$$

where, Ψ = matric potential, kPa; L = reading by tensiometer, kPa; h = height from tensiometer reading point to the centre of the porous capsule, cm.

Humidity values corresponding to the observed tensions were calculated by the characteristic retention curve of the mathematical model for description of retention curve of soil water. Based on the humidity value and the one corresponding to field capacity, 10 kPa (Koetz, 2006; Marouelli et al., 1996), along with the volume of soil in each plot (4 m × 1.6 m × 0.25 m), the relocation depth was calculated as shown by Equation (5).

$$V=\frac{(\theta_{cc}-\theta).V_s}{0.9} \qquad (5)$$

where, V: gross volume of water to be applied per plot, m^3; θ_{cc}: humidity at field capacity, m^3/m^3; θ: present humidity at volume base, m^3/m^3; V_s: total volume of soil, m^3; 0.90: efficiency of local irrigation system (Bernardo et al., 2006).

Irrigation time was determined by Equation (6).

$$T=\frac{V}{q_{40}} \qquad (6)$$

where, T - irrigation time, min; V - volume of water to be irrigated, m^3; q - flow of 40 drippers per plot, m^3/h.

Water applications stopped on October 11th, 2008, five days before the harvest, when grains in the middle third of plants turned brown.

3 Results and discussion

During experiment management, maximum and minimum mean temperatures were 27°C and 12.7°C, respectively (Figure 6). Maximum mean relative humidity was 69.4% and minimum was 45.24% (Figure 7).

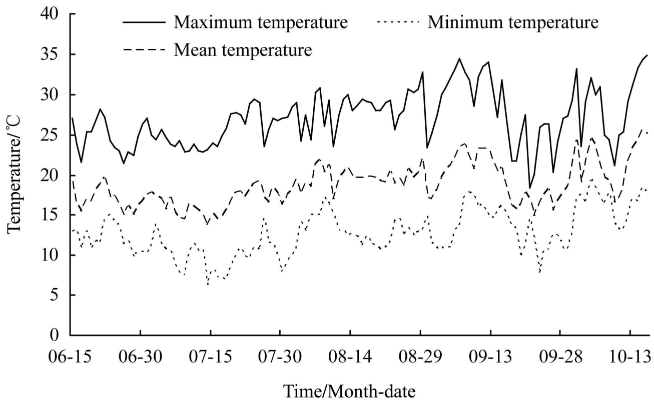

Figure 6 Maximum, minimum and mean temperature during the experiment management (2008)

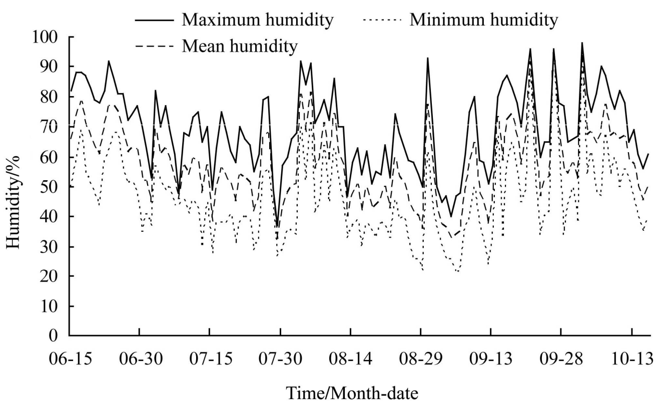

Figure 7 Maximum, minimum and mean relative humidity during the experiment management (2008)

The ideal temperature for good development of rapeseed ranges from 12 to 30°C (Canola Council of Canada, 2003). Therefore, the mean temperature value found during crop development, 19°C, is within the ideal limits for rapeseed.

3.1 Water management

Table 5 shows water depths applied (mm) regarding different soil water tensions and precipitation during crop development.

Table 5 Water depths applied regarding different soil water tensions and precipitation during crop development

Month	Water depths applied/mm				Precipitation /mm
	20 kPa	40 kPa	80 kPa	120 kPa	
June	50	50	50	50	7
July	155	155	155	155	-
August	180	160	123	67	14
September	183	120	94	70	88
October	41	24	-	-	34
Total/mm	609	508	422	342	142

All treatments received the same water depth, 205 mm, until the beginning of treatments on the 1st of August 2008 (Table 6). Later, differentiation of treatments caused a decrease of the applied depth as soil water tension increased. The irrigation depth applied during treatment management when tension reached 120 kPa was 66% lower than the depth applied with the tension of 20 kPa. Most of the precipitation, 95% equivalent to 135 mm, fell during the application of treatments, from August to October 2008.

The number of irrigations and intervals between irrigations performed in the treatments shown in Table 6.

Table 6 Parameters of irrigation obtained from water control in the different treatments

Treatment	Number of irrigations	Interval between irrigations
20 kPa	27	2.60
40 kPa	13	4.76
80 kPa	7	7.28
120 kPa	4	11.75

The numbers of irrigations were 27, 13, 7 and 4 for the treatments of 20, 40, 80 and 120 kPa, respectively. Intervals between irrigations or the watering schedule were 2.60, 4.76, 7.28, and 11.75 days for the treatments of 20, 40, 80 and 120 kPa, respectively. We verified that the highest number of irrigations and frequency was carried out when irrigation started under the tension of 20 kPa. The tension of 120 kPa, which showed higher soil water depletion, caused the lowest number of irrigations and longer watering intervals.

3.2 Analysis of vegetative parameters

Figure 8 shows the visual aspect of plants 34 days after the beginning of treatments, on September 4th, 2009. Visually, the treatment with tension of 120 kPa

(T4) shows weaker plants than plants from treatments of 20 kPa (T1), 40 kPa (T2) and 80 kPa (T3).

Vegetative parameters assessed at the end of the experiment were: the number of pods per plant, stem diameter (mm), the number of leaves per plant, the number of branches per plant and plant height (cm). The summary of the results of variance for crop vegetative parameters is shown in Table 7.

T_1 T_2 T_3 T_4

Figure 8 Visual aspect of rapeseed plants submitted to different soil water tensions

Table 7 Analysis of variance of the number of pods, stem diameter, number of leaves, number of branches and plant height regarding different soil water tensions

FV	GL	QM				
		Number of pods	Stem diameter/mm	Number of leaves	Number of branches	Plant height/cm
Treatments	3	4276.0*	2.39^{ns}	38.29^{ns}	19.32*	133.71^{ns}
Residue or error	12	357.3	1.25	14.03	4.35	206.10
CV/%	-	11.15	9.39	13.91	15.89	13.79
Mean	-	169.48	11.93	26.92	13.13	104.10

Note: ns - non significant by F test at 5% probability; * - significant by F test at 5% probability; FV: variation factor; GL: degree of freedom; QM: mean square; CV: coefficient of variation.

We verified that the number of pods per plant and number of branches per plant were significantly affected by different soil water tensions by F test at 5% probability.

Taylor et al. (1991) observed a significant decrease in the number of pods when rapeseed was submitted to different irrigation regimes. Champolivier and Merrien (1996) found a significant decrease in the number of pods when rapeseed was submitted to total water restraint in different stages of crop development. The authors also verified that plant height only decreased when a deficit was applied at the initial stage of crop development, between stem elongation and flowering.

Sinaki et al. (2007) verified that the number of pods was the yield compound which most decreased with water deficit applied on rapeseed, confirming the results obtained in the present experiment. Guerra et al. (2000), investigating the effect of different soil water tensions on bean crop, observed that the number of pods was significantly higher when irrigation was carried out at the lowest tension of 40 kPa.

Variation in the number of pods may be explained by linear regression, showing an adequate coefficient of determination (R^2) as shown in Figure 9. Thus, for each unit change of soil water tension there was a decrease of 0.72 pods per plant.

Similar behaviour was found by the Rapeseed Council of Canada (2003), which obtained the highest number of pods with high irrigation, when assessing yield compounds of rapeseed under three different crop conditions, without irrigation, low irrigation (282 mm) and high irrigation (369 mm).

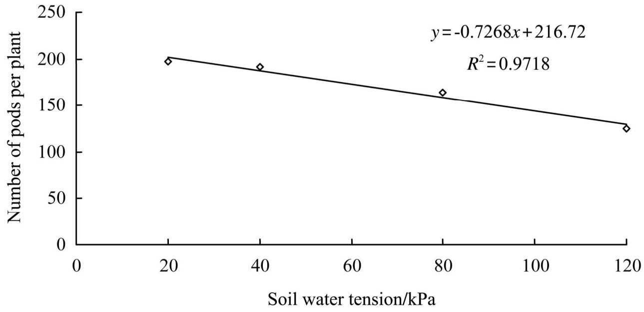

Figure 9 Effect of different soil water tensions on the number of rapeseed pods

Variation in the number of branches in relation to soil water tensions may be explained by linear regression, as shown in Figure 10, indicating that for each unit change of soil water tension there was a decrease of 0.0439 branches per plant.

The highest number of branches per plant under high irrigation was found by the Rapeseed Council of Canada (2003).

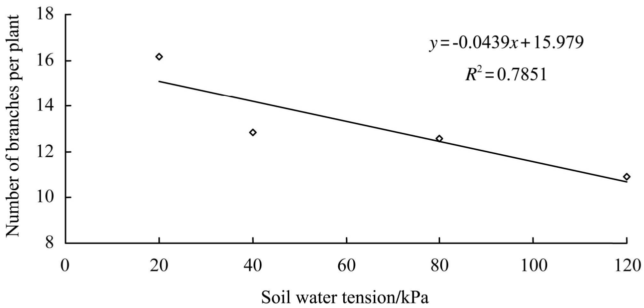

Figure 10 Effect of different soil water tensions on number of rapeseed branches

Table 8 shows the summary of results of the variance for green matter of the vegetative part, green matter of pods and total green matter.

Table 8 Analysis of variance for green matter of vegetative part, green matter of pods and total green matter regarding different soil water tensions

FV	GL	QM		
		Green matter of vegetative part	Green matter of pods	Total green matter
		kg ha^{-1}		
Treatments	3	61642532.89^{ns}	89471544.49^{ns}	298375273.75^{ns}
Residue	12	31004487.81	20777433.52	91675536.35
CV (%)	-	38.08	25.16	29.25
Mean	-	14621.37	18116.57	32737.94

Note: ns - non significant by F test at 5% probability; * - significant by F test at 5% probability; FV: variation factor; GL: degree of freedom; QM: mean square; CV: coefficient of variation.

Different soil water tensions showed no significant effect on crop green matter by F test at 5% probability. At harvest time, plants showed no leaf area due to natural senescence prior to harvest, which may have affected the experimental data.

Table 9 shows the summary results of the variance for dry matter of the vegetative part, dry matter of pods and total dry matter. F test at 5% probability shows that different soil water tensions significantly affected crop dry matter.

Table 9 Analysis of variance of dry matter of vegetative part, dry matter of pods and total dry matter regarding different soil water tensions

FV	GL	QM		
		Dry matter of vegetative part	Dry matter of pods	Total dry matter
		kg ha^{-1}		
Treatments	3	4256840.96*	17209382.87*	38243600.76*
Residue	12	945691.97	2957879.47	6687913.25
CV/%	-	29.22	24.14	24.74
Mean	-	3327.55	7124.50	10452.05

Note: ns - non significant by F test at 5% probability; * - significant by F test at 5% probability; FV: variation factor; GL: degree of freedom; QM: mean square; CV: coefficient of variation.

Banuelos et al. (2002) verified the potential of irrigated rapeseed in central California under different water relocation depths, equivalent to 25%, 50%, 100% and 125% of crop potential evapotranspiration. The authors reported that total dry matter of the vegetative part significantly increased until a depth equivalent to 125% relocation. Root dry matter showed no response to treatments.

Total dry matter (kg/ha), dry matter of pods (kg/ha) and dry matter of the vegetative part (kg/ha) showed linear response in relation to soil water tensions, as shown in Figures 11-13. For each unit change of soil water tension there was a decrease of 69.548 kg/ha of total dry matter; 46.571 kg/ha of dry matter of pods and 22.977 kg/ha of dry matter of the vegetative part.

Champolivier and Merrien (1996) and Sinaki et al. (2007) obtained a significant decrease of dry matter of rapeseed submitted to water stress, confirming data found in the present experiment.

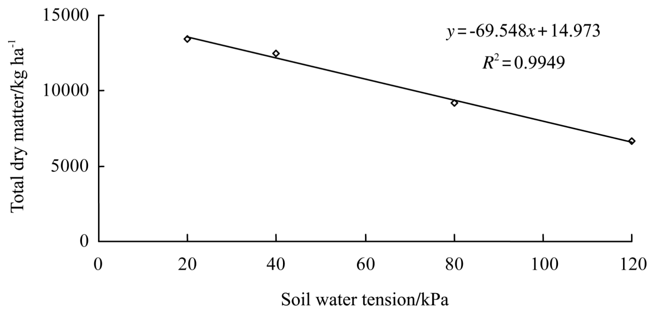

Figure 11 Effect of different soil water tensions on total dry matter of rapeseed

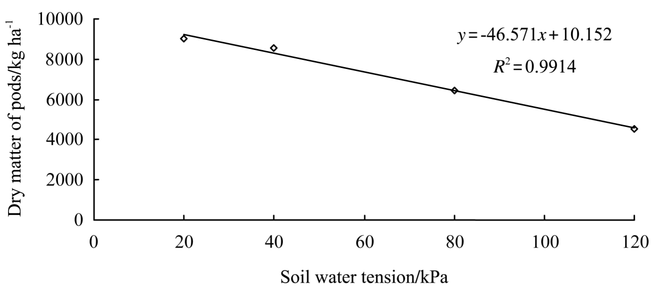

Figure 12 Effect of different soil water tensions on dry matter of rapeseed pods

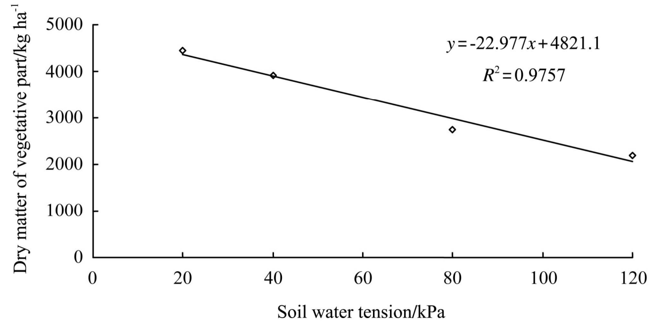

Figure 13 Effect of different soil water tensions on dry matter of vegetative partof rapeseed

3.3 Analysis of grain yield

The summary of results of the analysis of variance for grain yield (kg/ha) when the crop was submitted to different soil water tensions is shown in Table 10.

Table 10 Analysis of variance of grain yield regarding different soil water tensions

FV	GL	QM
		Yield
		kg ha^{-1}
Treatments	3	1388000.98*
Residue	12	343285.47
CV/%	-	14.08
Mean	-	4160.15

Note: ns - non significant by F test at 5% probability; * - significant by F test at 5% probability; FV: variation factor; GL: degree of freedom; QM: mean square; CV: coefficient of variation.

Table 10 shows a significant difference among treatments for grain yield (kg/ha) by F test at 5% probability. Similar results with rapeseed were verified by Taylor et al. (1991), Wright et al. (1988) and Faraji et al. (2009).

Grain yield (kg/ha) showed a linear response in relation to soil water tensions (Figure 14), indicating that for each unit change of soil water tension there was a decrease of 13.039 kg/ha.

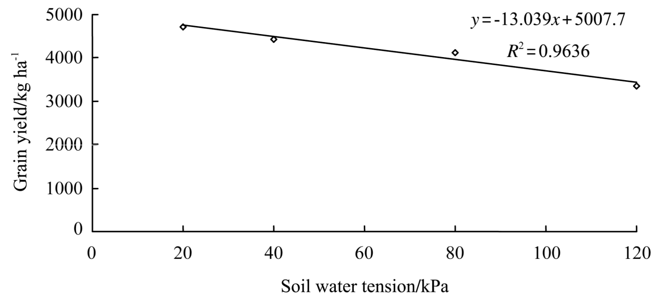

Figure 14 Effect of different soil water tensions on grain yield of rapeseed

The highest mean yield was 4,719.74 kg/ha, obtained with a tension of 20 kPa. The Rapeseed Council of Canada (2003) found a yield value of 2,463 kg/ha when rapeseed was cropped under optimum irrigation conditions (Table 1).

Wright et al. (1988) found a yield value of 3,800 kg/ha for irrigated rapeseed in Australia, higher than the value obtained in non irrigated crops, 1,700 kg/ha. Taylor et al. (1991) verified a yield value of 3,600 kg/ha of grains in irrigated rapeseed, whereas yield mean in non-irrigated treatment was 2,700 kg/ha.

3.4 Analysis of physical quality of grains

Effect of different soil water tensions was verified on the physical quality of grains, including grain specific matter (g/mL) and weight of 1000 grains (g).

Table 11 shows the summary of analysis of variance for specific matter and weight of 1000 grains. These parameters were not affected by different soil water tensions by F test at 5% probability.

Taylor et al. (1991) verified significant difference for weight of 1000 grains when comparing irrigated and non-irrigated rapeseed. Champolivier and Merrien (1996) found no significant differences for weight of 1000 rapeseed grains when the crop was exposed to different water deficit treatments. According to the authors, there was a compensation effect between the number of grains and weight of 1,000 grains.

Table 11 Analysis of variance for weight of 1000 grains and grain specific matter in rapeseed, regarding different soil water tensions

FV	GL	QM	
		Weight of 1000 grains/g	Specific Matter/g mL^{-1}
Treatments	3	0.015633^{ns}	0.000032^{ns}
Residue	12	0.014835	0.000154
CV/%	-	3.15	2.07
Mean	-	3.86	0.59

Note: ns - non significant by F test at 5% probability; * - significant by F test at 5% probability; FV: variation factor; GL: degree of freedom; QM: mean square; CV: coefficient of variation.

In the present experiment, lack of significance among data for physical quality of grains may be explained by 135 mm of precipitation during the application of treatments, preventing plots submitted to high soil water tensions from water stress.

3.5 Sensitivity of rapeseed to water deficit

Relative decrease of grain yield regarding relative decrease of water depth applied is shown in Figure 15. An equation of linear regression was adjusted passing by the origin, according to Stewart and Hagan (1973). The angular coefficient of the equation, which represents the factor of response ky, was 0.3699.

In the present experiment, the angular coefficient of the equation, ky, is 0.3699, which shows that yield relative decrease was lower than relative decrease of depth applied. Thus, regarding the conditions of the experiment management, grain yield did not show great sensitivity to water deficit.

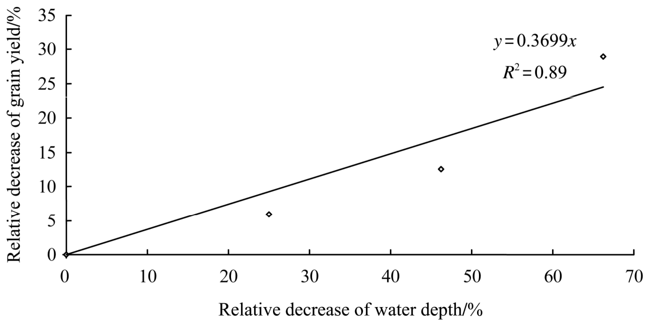

Figure 15 Relative decrease of grain yield of rapeseed regarding relative decrease of water depth applied

4 Conclusions

Different soil water tensions affected the number of pods, number of branches, dry matter of the vegetative part, dry matter of pods, total dry matter and yield. While the physical quality of grains was not affected by treatments.

Water retained at 25 cm of depth under tension of 20 kPa is a good indicator of the right time to start irrigating rapeseed crops, as these conditions provide maximum grain yield, 4,719.74 kg/ha.

Rapeseed yield under supplementary irrigation does not show sensitivity proportional to water deficit applied, as ky was lower than one (0.366).

References

Albuquerque, P. E. P., and F. O. M. Durães. 2008. Uso e manejo de irrigação. Brasília: Embrapa Informação Tecnológica, 528 p.

Amabile, R. F., D. B. da Silva, and A. F. Guerra. 2004. Cevada irrigada em áreas de cerrado no Brasil Central. Planaltina, Distrito Federal, Embrapa, Circular técnica, 26. 4 p.

Banuelos, G. S., D. R. Bryla, and C. G. Cook. 2002. Vegetative production of kenaf and canola under irrigation in central Califórnia. *Industrial Crops and Products,* 15(3): 237-245.

Bergamin, G. T. 2011. Fontes proteicas vegetais na alimentação da carpa húngara. *Ciência Rural,* 41(9): 1660-1666.

Bergmann, J. C, D. D. Tupinamba, O. Y. Acosta, J. R. M. Almeida, C. C. Barreto, and B. F. Quirino. 2013. Biodiesel production in Brazil and alternative biomass feedstocks. *Renewable and Sustainable Energy Reviews,* 21: 411-420.

Bernardo, S, A. A. Soares, E. C. Mantovani. Manual de irrigação. 8. ed. Viçosa: UFV, 2006. 625 p.

Canola Council of Canadá. Canola Growers Manual. 2003. Disponível em: < http://www.canolacouncil.org/canola_growers_manual.aspx> (accessed June 20, 2008).

Champolivier, L., and A. Merrien 1996. Effects of water stress applied at different growth stages to Brassica napus L. var. oleifera on yield, yield components and seed quality. *European Journal of Agronomy,* 5(3, 4): 153-160.

Cordeiro, D. S., E. P. Silveira, and A. N. Kichel. 1993. Resposta da *Brassica napus* a doses e épocas de aplicação de nitrogênio. *Pesquisa Agropecuária Brasileira,* 28(10): 1137-1142.

Dantas, A. A. A., L. G. de Carvalho, and E. FERREIRA. 2007. Classificação e tendências climáticas em Lavras, MG.

Ciência e Agrotecnologia, 31(6): 1862-1866.

Doorenbos, J., and A. H. Kassan. 1994. Efeito da água no rendimento das culturas. Tradução de Gheyi, H.R.; Souza, A.A.; Damasceno, F.A.V.; Medeiros, J.F. Campina Grande: UFPB, 306 p.

Dourado Neto, D., D. R. Nielsen, J. W. Hopmans, K. Reichardt, O. Bacchi. 2000. Software to model soil water retention curves (SWRC, version 3.00). *Scientia Agricola, Piracicaba,* 57(1): 191-192.

Empresa Brasileira de Pesquisa Agropecuária. 1999. Sistema brasileiro de classificação de solos. Rio de Janeiro: Embrapa Solos, 412 p.

Farajia, A., N. Latifi, A. Soltani, A. H. S. Rad2009. Seed yield and water use efficiency of canola (Brassica napus L.) as affected by high temperature stress and supplemental irrigation. *Agricultural Water Management,* 96(1): 132-140.

Ferreira, D. F. 1999. Sistema para análise de variância para dados balanceados (SISVAR). Lavras: UFLA.

França, J., F. M. O. B. Saad, C. E. P. Saad, R. C. Silva, and J. S. Reis. 2011. Avaliação de ingredientes convencionais e alternativos em rações de cães e gatos. *Revista Brasileira de Zootecnia,* 40: 222-231.

Genuchten, M. T. Van. 1980. A closed-form equation for predicting the hydraulic conductivity of unsaturated soils. *Soil Science Society of American Journal,* 44(1): 898-982.

Gomes, E. P., and R. Testezlaf. Manejo de irrigação na tomaticultura de mesa. Mogi-Guaçu, UNICAMP, São Paulo. 2004. Disponível em: <http://www.feagri.unicamp.br/tomates/pdfs/manejoirrig.pdf>. (acessed June 18, 2007).

Guerra, A. F., D. B. Da Silva, and G. C. Rodrigues. 2000. Manejo de irrigação e fertilização nitrogenada para o feijoeiro na região dos cerrados. *Pesquisa Agropecuária Brasileira, Brasilia,* 35(6): 1229-1235.

Heendeniya, R. G., D. A. Christensen, D. D. Maenz, J. J. Mckinnon, and P. Yu. 2010. Utilization of canola seed fractions for ruminants: effect of canola fibre-protein and can-sugar inclusion in dehydrated alfalfa pellets on palatability and lactation performance of dairy cows. *Canadian Journal of Animal Science,* 90(2): 279-283.

Istanbulluoglu, A., B. Arslan, E. Gocmen, E. Gezer, and C. Pasa. 2010. Effects of deficit irrigation regimes on the yield and growth of oilseed rape (*Brassica napus* L.). *Biosystems engineering,* 105(3): 388-394.

Koetz, M. Maracujazeiro-amarelo: cultivo protegido e natural, irrigação e adubação potássica. 2006. 130 p. Tese (Doutorado em Engenharia Agrícola) – Universidade Federal de Lavras, Lavras.

Marouelli, W. A., H. R. Silva, and W. L. C. Silva. 1996. Manejo da irrigação em hortaliças. 5. ed. Brasília: EMBRAPA-CNPH, 72 p.

Milazzo, M.F., F. Spina, A. Vinci, C. Espro, and J. C. J. Bart. 2013. Brassica biodiesels: Past, present and future. *Renewable and Sustainable Energy Reviews,* 18: 350-389.

Mousavi-Avval, S. H., S. Rafiee, A. Jafari, and A. Mohammadi. 2011. Energy flow modeling and sensitivity analysis of inputs for canola production in Iran. *Journal of Cleaner Production,* 19(13): 1464-1470.

Pavlista, A. D., D. K. Santra, T. A. Isbell, D. D. Baltensperger, G. W. Hergert, J. Krall, A. Mesbach, J. Johnson, M. O'neil, R. Aiken, and A. Berrada. 2011. Adaptability of irrigated spring canola oil production to the US High Plains. *Industrial Crops and Products,* 33(1): 165-169.

Resende, M., and P. E. P. de Albuquerque. 2002. Métodos e estratégias de manejo de irrigação. Sete Lagoas, MG: Embrapa, (Circular técnica, 19). Disponível em: <http://www.cnpms.embrapa.br/publicacoes/publica/2002/circular/Circ_19.pdf>. (acesso em: 20 ago. 2008).

Silva, E. M., J. A. Azevedo, A. F. Guerra, S. F. Figuerêdo, L. M. Andrade, J. C. Antonini. 1998. Manejo de irrigação para grandes culturas. In: FARIA, M. A. de. Manejo de irrigação. Poços de Caldas: UFLA/SBEA, cap. 3, p. 239-280.

Silva, E. M., J. A. Azevedo, A. F. Guerra, S. F. Figuerêdo, L. M. Andrade, J. C. A. Antonini. 1999. Manejo da irrigação por tensiometria para culturas de grãos na região do cerrado. Planaltina: Embrapa Cerrados, (Circular técnica, 6) 60 p.

Silva, M. R. R., O. ARF, and R. A. F. Rodrigues. 2008. Cultivares de trigo sob manejos de solo e água, na região de cerrado. *Ciência Rural, Santa Maria,* 38(4): 921-927.

Sinaki, J. M., E. M. Heravan, A. H. S. Rad, G. Noormohammadi, G. Zarei. 2007. The effects of water déficit during growth stages of Canola (Brassica napus L.). American-Eurasian Journal of Agricultural & Environmental Science, 2(4): 417-422.

Sprague, S. J., J. A. Kirkegaard, J. M. Graham, H. Dove, and W. M. Kelman. 2014. Crop and livestock production for dual-purpose winter canola(Brassica napus) in the high-rainfall zone of south-eastern Australia. *Field Crops Research,* 156(1): 30-39.

Stewart, J. I., and R. M. Hagan. 1973. Functions to predict effects of crop water deficits. *Journal of the Irrigation and Drainage Division,* 99(4): 421-439.

Takashima, N. E., D. P. Rondanini, L. E. Puhl, and D. J. Miralles. 2013. Environmental factors affecting yield variability in spring and winter rapeseed genotypes cultivated in the southeastern Argentine Pampas. *European. Journal of Agronomy,* 48: 88-100.

Taylor, A. J., C. J. Smith, and I. B. Wilson. 1991. Effect of irrigation and nitrogen fertilizer on yield, oil content, nitrogen accumulation and water use of canola (*Brassica napus* L.). *Fertilizer Research,* 29(3): 249-260.

Tomm, G. O. 2007. Indicativos tecnológicos para produção de canola no Rio Grande do Sul.Passo Fundo. Embrapa Passo Fundo, 32 p.

Wright, G. C., C. J. Smith, and M. R. Woodroofe. 1988. The effect of irrigation and nitrogen fertilizer on rapeseed (Brassica napus) production in south-eastern Australia: I. growth and seed yield. *Irrigation Science,* 9: 1-13.