

EFFECT OF DIFFERENT LEVELS OF WATER DEFICIT ON RAPESEED (*Brassica napus* L.) CROP

Efeito de diferentes níveis de déficit hídrico na cultura da canola

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ABSTRACT

Effects of different levels of water deficit applied during rapeseed crop development were assessed in a trial with metallic pots in greenhouse at the Department of Agricultural Engineering of Kassel University, Witzenhausen, Germany. A randomized block design was used with one cultivar (Ability Summer Rape) and three levels of water deficit (0, 30, and 60% of evapotranspiration) in three treatments and 20 replicates. Irrigation management was carried out through daily water balance, where $ET = I - D$; ET: evapotranspiration; I: irrigation; and D: drainage. The following evaluations were carried out weekly: stem diameter (mm); plant height (cm); number of leaves; number of branches and number of pods. At the end of the experiment, assessed total green matter (g plant⁻¹), total dry matter (g plant⁻¹), grain yield (g plant⁻¹), grain protein content (%) and grain oil content (%) were also assessed. Data were submitted to variance analysis and the effect of the treatments was assessed by regression analysis. Results showed significant differences between the treatments in all analysed variables except for plant height and grain protein content, by test F at 5% probability. Factor of response ky, indicator of crop sensitivity to water deficit, was lower than one for all assessed variables. Grain yield showed the highest sensitivity to water deficit.

Index terms: Water management, irrigation, water deficit.

RESUMO

Os efeitos de diferentes níveis de déficit hídrico, aplicados durante o desenvolvimento da canola, foram avaliados por meio de um experimento conduzido em vasos de metal no interior de uma casa de vegetação, no Departamento de Engenharia Agrícola, da Universidade de Kassel, Alemanha. Foi utilizado um delineamento inteiramente casualizado, com a cultivar Ability (Summer Rape), e três níveis de déficit de água, 0%, 30%, 60% da evapotranspiração da cultura, totalizando três tratamentos com 20 repetições. O manejo da irrigação foi realizado por meio do balanço hídrico diário, em que $ET = I - D$, onde ET é evapotranspiração, I é irrigação, D é drenagem. Foram realizadas semanalmente as seguintes avaliações: diâmetro do caule (mm), altura da planta (cm), número de folhas, número de ramos e número de síliquas. No final do experimento, foram avaliadas a matéria verde total (g planta⁻¹) e matéria seca total (g planta⁻¹), produtividade de grãos (g planta⁻¹), além do teor de proteína (%) e de óleo (%) dos grãos. Os dados foram submetidos à análise de variância, sendo o efeito dos tratamentos estudado por meio de análise de regressão. Os resultados mostraram diferenças significativas entre os tratamentos para as variáveis analisadas, exceto para a altura das plantas e teor de proteína dos grãos, pelo teste F a 5% de probabilidade. O fator de resposta ky, indicador da sensibilidade da cultura ao déficit hídrico, foi menor que um para todos os parâmetros estudados. A produtividade de grãos apresentou a maior sensibilidade ao déficit hídrico.

Termos para indexação: Manejo de água, irrigação, déficit hídrico.

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INTRODUCTION

Water shortage in some regions of the world (RIJSBERMAN, 2006; KHAN et al., 2009) definitely increases interest in carrying out studies on development of crops showing acceptable yield under water deficit (ZWART; BASTIAANSEN, 2004; FARRE; FACI, 2006; PAYERO et al., 2006; SINAKI et al., 2007). Understanding the behaviour of every crop, regarding different amounts of applied water, is absolutely necessary to determine when lack or excess of water may cause production fall, thus enabling appropriate irrigation management (BERNARDO et al., 2006).

Local studies on the relationship between fall of relative yield and relative deficit of evapotranspiration are recommended (GEERTS; RAES, 2009), as production conditions during crop cycle depend on the place and variety chosen (DOORENBOS; KASSAN, 1994).

Deficit irrigation is performed differently from supplementary irrigation, as in deficit irrigation we reduce depth of application while irrigation frequency is maintained. Supplementary irrigation aims at meeting crop water requirements during critical development stages without natural precipitation (ZHANG et al., 2006).

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Deficit irrigation does not always decrease yield, as deficit properly applied in some development stages may even increase crop yield. Many research studies have been carried out to verify the effect of water deficit on crops (DETAR, 2008; GEERTS; RAES, 2009).

Farre e Faci (2006) compared corn (*Zea mays* L.) and sorghum [*Sorghum bicolor* (L.) Moench] response to water deficit through an experiment carried out in north-eastern Spain. Plant vegetative part, total biomass and grain yield were affected by the treatments in both crops. Corn grain yield was higher than sorghum grain yield under optimum irrigation conditions, although sorghum showed higher yield under moderate or severe water deficit. The authors concluded that sorghum could be a good alternative to replace corn under limited water supply in the semi arid north-eastern Spain.

Sinaki et al. (2007) assessed rapeseed response to different levels of groundwater depletion equivalent to 20%, 50% and 75% of water available in soil concluding that, among yield compounds, number of pods was the most sensitive to water deficit.

The objective of this study was to assess the effect of different levels of water deficit applied during rapeseed crop development on vegetative parameters, grain yield, grain protein content and grain oil content of rapeseed, Hybrid Ability.

MATERIAL AND METHODS

The experiment was carried out in acclimatised greenhouse at the Department of Agricultural Engineering of Kassel University, Witzenhausen, Germany. A meteorological station inside the greenhouse monitored environmental conditions concerning temperature and relative air humidity.

Soil used for pot fulfilment was extracted from subsurface layer until 20 cm depth, and samples were collected for physical and chemical analyses. Soil was air-dried, broken into small pieces and sieved through a 1 cm mesh. Pots were set on metal bench. A mixture was made with 80% of soil from the field and 20% of sand, in order to facilitate irrigation management. Granulometric analysis of prepared soil showed the following rates: sand: 32.37%; silt: 53.76%; clay: 13.88%.

Fertilization used 4 g pot⁻¹ with concentration of 7% nitrogen; 6% phosphorus; and 10% potassium. Later we performed fertilization with nitrogen cover, using 1 g pot⁻¹ of urea diluted in water to meet the nutrient dose of 150 kg ha⁻¹ nitrogen recommended by Cordeiro et al. (1993) and Tomm (2007).

We used randomized block design with three treatments and 20 repetitions, corresponding to three levels of water deficit, 0%, 30%, 60% of crop evapotranspiration, amounting to 60 experimental units. Hybrid Ability, widely grown in Germany, was sowed in 6.5 dm³ capacity metallic pots (Mitscherlich-Gefäßen) on 7 April 2009, in 0.02 m depth, with 10 seeds per pot. Later we carried out pruning to adjust one plant pot⁻¹. It was necessary to tutor plants with bamboo stakes in order to keep plants from falling over. Weed and disease were controlled according to need, in continuous monitoring.

We assessed vegetative parameters, productive parameters and grain quality from all experimental units, 60 crops. As treatments started we assessed stem diameter (mm) with digital pachymeter; plant height (cm) with tape measure; number of leaves plant⁻¹; number of branches plant⁻¹ and number of pods plant⁻¹ on a weekly basis.

Total dry matter (grams plant⁻¹) was assessed at the end of the experiment in forced ventilated oven at 105°C (WANG et al., 2007; ARABHOSSEINI et al., 2009), where plants were kept during 24 hours. Total green matter (grams plant⁻¹) was assessed through weighing of leaves, branches and pods in electronic scale. Leaves were collected daily according to their natural senescence. Afterwards, they were weighed and stored in paper bags to assess dry matter.

Harvest was carried out manually when pod grain colour of the central part turned brown. Oil content (%) and protein content (%) of grains of each experimental unit were assessed at the specialised laboratory Landesbetrieb Hessisches Landeslabor, in Kassel, Germany.

Quantification of water deficit effect on yield was achieved with the relationship between relative decrease of grain yield and relative decrease of evapotranspiration, given by the coefficient of response k_y (Doorenbos e Kassan, 1994), according to Equation 1:

$$\left(1 - \frac{Y_r}{Y_m}\right) = K_y \left(1 - \frac{ET_r}{ET_m}\right) \quad (1)$$

in which: Y_r – real yield; Y_m - potential yield; K_y – crop coefficient of response; ET_r – real evapotranspiration and ET_m - potential evapotranspiration.

Potential yield (Y_m) and potential evapotranspiration (ET_m) were obtained in the treatments corresponding to 0% of water deficit, whereas real yield (Y_r) and real evapotranspiration (ET_r) were found in the other treatments.

All assessed parameters were submitted to analysis of variance by F test, significant at 5 % probability, while

Tukey test was applied to compare means. The effect of treatments was assessed by regression analysis. Data statistic analysis was performed with the system of variance analysis for balanced data (Sisvar) version 4.2 (FERREIRA, 1999).

Irrigation

Treatments started 16 days after sowing. Volumes of water replacement in deficit irrigation treatments were obtained through the percentile of water evapotranspired (consumed) by the control treatment, which received 100% of replacement water. To manage control treatment irrigation we used the equation of water balance: $ET = I - D$, in which ET is the evapotranspiration (volume of consumed water, ml pot⁻¹), I is the volume of applied water (ml pot⁻¹) and D is the volume of drained water (ml pot⁻¹).

RESULTS AND DISCUSSION

During the experiment, maximum and minimum temperatures observed were 33.8° C and 15.3° C (mean 21.9° C), respectively, and average humidity was 69%. Greenhouse temperature during rapeseed development

remained within the range recommended for the crop, 12-30° C (CANOLA COUNCIL OF CANADA, 2003).

Water management

Table 1 shows the volumes of water applied in each treatment. It is observed that until the beginning of treatments, which started 16 days after sowing, all plants received the same volume of water, 1.9 l plant⁻¹. Later, the volume applied was proportional in each treatment: plants with 0% of water deficit received 28.2 l plant⁻¹ during application of treatments; plants with 30% of water deficit received 19.6 l plant⁻¹; and plants with 60% of water deficit received 11.2 l plant⁻¹.

Analysis of vegetative parameters

Table 2 shows the summary of results of variance analysis for crop vegetative parameters. Significant differences is observed in the following variables: volume of water applied (l plant⁻¹), (stem diameter (mm), number of branches, number of leaves and number of pods. However, there were no significant differences between treatments in the variable plant height (cm).

Table 1 – Volume of water applied in each treatment. UNIKASSEL, Witzenhausen, Hessen, 2009.

Treatment	Volume of water	Volume of water	Total volume
	applied until the beginning of treatments	applied during treatments	
	----- l plant ⁻¹ -----		
0% of deficit	1.9	28.2	30.1
30% of deficit	1.9	19.6	21.5
60% of deficit	1.9	11.2	13.1

Table 2 – Variance analysis of volume of water applied (l plant⁻¹), plant height (cm), stem diameter (mm), number of branches, number of leaves and number of pods regarding different levels of water deficit applied during rapeseed development. UNIKASSEL, Witzenhausen, Hessen, 2009.

FV	GL	QM					
		Volume of water applied (l plant ⁻¹)	Plant Height (cm)	Stem diameter(mm)	Number of branches	Number of leaves	Number of pods
Treatments	2	1446.6*	664.86 ^{ns}	90.65*	151.66*	1081.05*	186114.05*
Residue or error	57	1.91	323.31	2.63	13.70	302.51	11129.11
CV (%)		0.00	15.30	12.39	37.91	36.50	29.81
Mean		21.66	117.53	13.10	9.76	47.65	353.85

in which: 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: variance coefficient.

Significant differences for volume of water applied can be explained by the application: the treatment with 60% water deficit received a water volume equivalent to 43.5% evapotranspiration, whereas the one with 30% water deficit received a volume equivalent to 71.4% evapotranspiration. Consequently, such decrease in volume of water applied should explain the significant decrease in crop vegetative parameters.

Sangtarash et al. (2009) verified rapeseed response in two irrigation regimes: daily irrigation to keep soil at field capacity and irrigation when plants showed symptoms of water deficit. The authors concluded that water deficit caused decrease in plant height, stem diameter and total dry matter. Taylor et al. (1991) assessed the effect of irrigation on yield components of rapeseed crop, verifying

that water deficit significantly affected number of pods per m². A similar result was found by Confalone e Dujmovich (1999) when studying the effect of water deficit on soybean crop. The authors verified that number of pods was the yield component mostly affected by water deficit.

Figures 1-4 show regression analysis for rapeseed vegetative parameters. The assessed variables showed linear response in relationship with the water deficit applied.

Maximum diameter of middle stem was verified in the treatment with 0% of water deficit (15.45 mm). Later there was decrease of 0.0692 mm plant⁻¹ for each unit change in water deficit. Maximum average number of branches was verified in the treatment with 0% of water deficit (11.6). Later, there was decrease of 0.0833 branches plant⁻¹ for each unit change in water deficit.

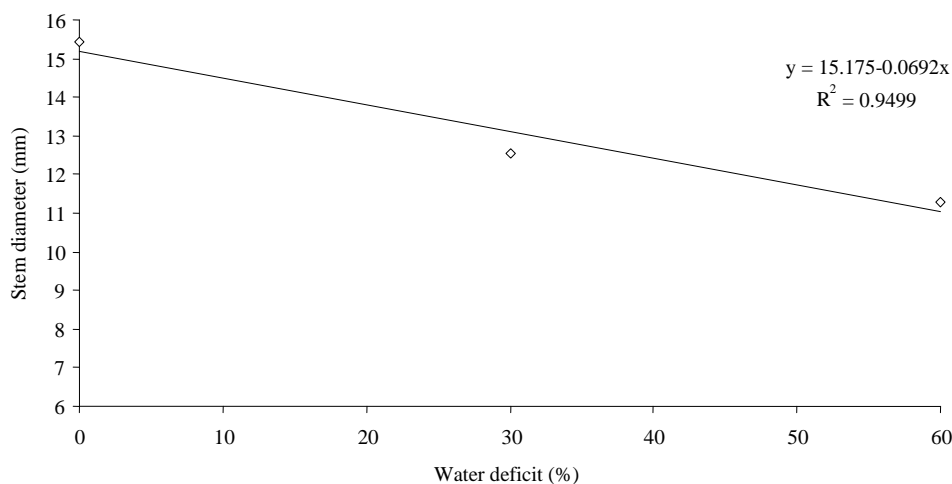


Figure 1 – Effect of water deficit on rapeseed stem diameter (mm). UNIKASSEL, Witzzenhausen, Hessen, 2009.

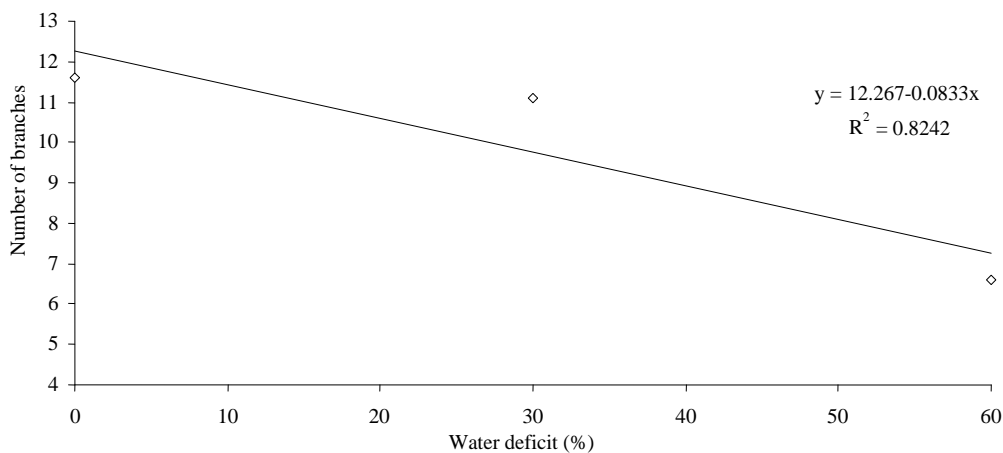


Figure 2 – Effect of water deficit on number of rapeseed branches UNIKASSEL, Witzzenhausen, Hessen, 2009.

Maximum average number of leaves was observed in the treatment with 0% of water deficit (55.1). Later, there was decrease of 0.245 leaves plant^{-1} for each unit change in water deficit. Maximum average number of pods was observed in the treatment with 0% of water deficit (451.9). Later, there was decrease of 3.21 pods plant^{-1} for each unit change in water deficit.

Variance analysis for total green matter and total dry matter in each treatment is shown in Table 3. Significant differences for the assessed variables by F test at 5% of probability. Were observed.

Figure 5 and Figure 6 show regression analysis for total green matter and total dry matter. The assessed variables showed linear response in relation to the water deficit applied.

Maximum total average green matter was observed in the treatment with 0% of water deficit (285.3 grams plant^{-1}). Later, there was decrease of 2.25 grams plant^{-1} for each

unit change in water deficit. Maximum total average dry matter was observed in the treatment with 0% of water deficit (51.25 grams plant^{-1}). Later, there was decrease of 0.33 grams plant^{-1} for each unit change in water deficit. Such result can be explained by decrease in the volume of water applied to treatments, corresponding to evapotranspiration deficit. Similar results were found by Frizzone (1995) and Banuelos et al. (2002).

Analysis of grain yield

Table 4 shows a summary of variance analysis data for grain yield (grams plant^{-1}) when crop was submitted to different levels of water deficit. According to the results, there were significant differences between treatments.

Decrease in crop yield can be explained by decrease in the volume of water applied to treatments, corresponding to evapotranspiration deficit, which significantly reduced number of pods and grain yield.

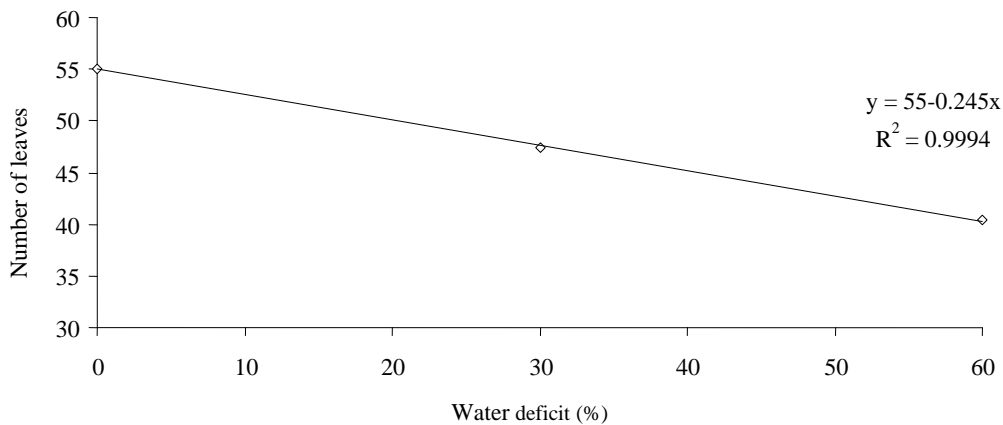


Figure 3 – Effect of water deficit on number of rapeseed leaves. UNIKASSEL, Witzenhausen, Hessen, 2009.

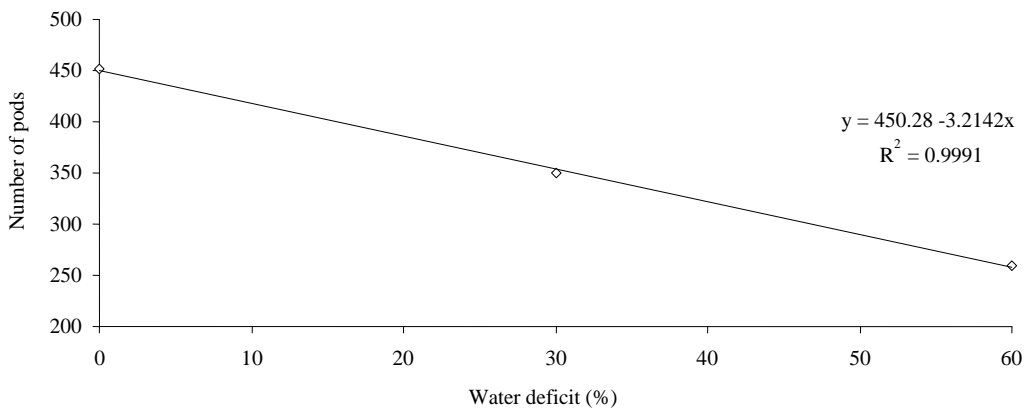


Figure 4 – Effect of water deficit on number of rapeseed pods. UNIKASSEL, Witzenhausen, Hessen, 2009.

Table 3 – Variance analysis of total green matter (g plant⁻¹) and total dry matter (g plant⁻¹) under different levels of water deficit applied during development of rapeseed crop. UNIKASSEL, Witzenhausen, Hessen, 2009.

FV	GL	QM	
		Total green matter	Total dry matter
----- grams plant ⁻¹ -----			
Treatments	2	91789.65*	1962.21*
Residue or error	57	1159.57	28.74
CV (%)	-	15.84	12.91
Mean	-	214.95	41.53

in which: 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: variance coefficient.

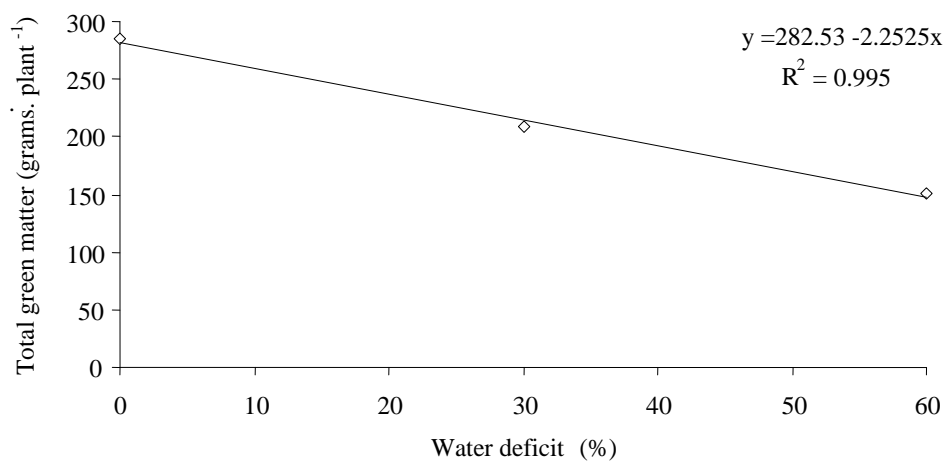


Figure 5 – Effect of water deficit on total green matter of rapeseed crop. UNIKASSEL, Witzenhausen, Hessen, 2009.

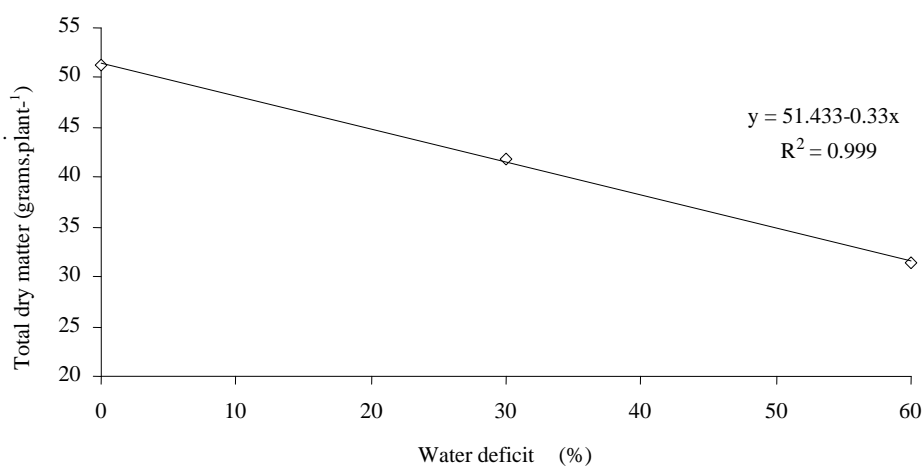


Figure 6 – Effect of water deficit on total dry matter of rapeseed crop. UNIKASSEL, Witzenhausen, Hessen, 2009.

Table 4 – Variance analysis of grain yield (grams plant⁻¹) regarding different levels of water deficit applied during development of rapeseed crop. UNIKASSEL, Witzzenhausen, Hessen, 2009.

FV	GL	QM
		Grain yield (grams plant ⁻¹)
Treatments	2	222.14*
Residue or error	57	5.19
CV (%)	-	28.87
Mean	-	7.89

in which: 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: variance coefficient.

Regression analysis for grain yield is shown in Figure 7. We verified that grain yield showed linear response in relation to the water deficit applied.

Maximum grain yield was observed in the treatment with 0% of water deficit (10.74 grams plant⁻¹). Later, there

was decrease of 0.1085 grams plant⁻¹ for each unit change in water deficit.

Analysis of grain quality

Table 5 shows the effect of different levels of water deficit on grain quality with the summary of variance analysis for protein content (%) and oil content (%) of rapeseed grain.

There was a significant difference for oil content between treatments. Protein content, however, showed no significant change.

Decrease in rapeseed oil content was also assessed by Sinaki et al. (2007) in an experiment carried out in Iran. The authors verified significant decrease in grain oil content in non-irrigated treatments. Similar results were found by Bouchereau et al. (1996), who assessed the effect of water deficit on rapeseed protein and oil content in a greenhouse experiment carried out in France. The authors verified significant decrease in oil content and increase in protein content.

Maehler et al. (2003) assessed grain quality of two soybean cultivars regarding soil water availability by performing two treatments, with and without irrigation. The

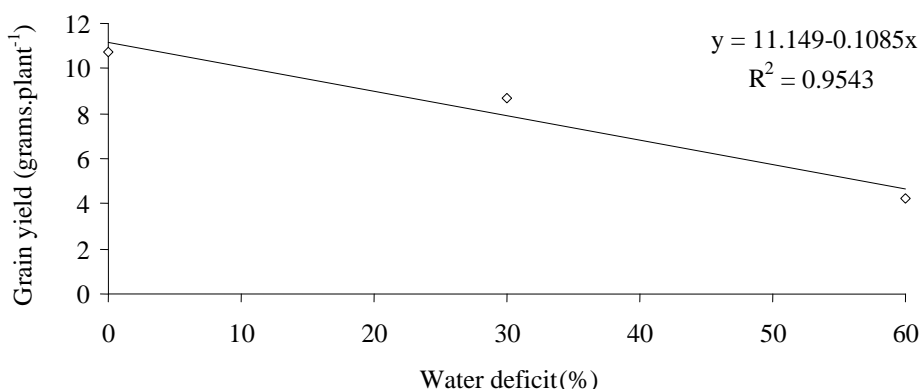


Figure 7 – Effect of water deficit on grain yield of rapeseed crop. UNIKASSEL, Witzzenhausen, Hessen, 2009.

Table 5 – Variance analysis of grain protein content (%) and grain oil content (%), regarding different levels of water deficit applied during development of rapeseed crop. UNIKASSEL, Witzzenhausen, Hessen, 2009.

FV	GL	QM	
		Protein content (%)	Oil content (%)
Treatments	2	17.76 ^{ns}	96.70*
Residue or error	57	17.092	29.67
CV (%)	-	5.16	6.03
Mean	-	29.33	37.75

in which: 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: variance coefficient.

authors observed increase of 39% in grain yield and protein content of irrigated soybean, but no significant differences in oil content.

Regression analysis for grain oil content is shown in Figure 8.

Maximum average oil content of grain was observed in the treatment with 0% of water deficit, 39.57%. Later, there was decrease of 0.0709% in oil content for each unit change in water deficit.

According to Bouchereau et al. (1996), decrease in oil concentration in rapeseed grain exposed to water deficit is justified by changes in availability of precursors to fulfil the grain, as reproductive organs and grains are built of resources either recently achieved or previously amassed in the vegetative part. This could have happened in the experiment, as number of leaves, green matter and dry matter significantly decreased according to the treatments, which could have led to a decrease in oil content.

Analysis of rapeseed sensitivity to water deficit

Sensitivity to water deficit in rapeseed vegetative parameters

Table 6 shows the percentile decrease of stem diameter, number of branches, number of leaves, number of pods, total green matter, total dry matter, grain yield and grain oil content of rapeseed according to each water deficit applied.

The treatment with 30% of deficit shows total green matter reduction (27%) as the most sensitive to water deficit, followed by number of pods (22%), grain yield (19%), total dry matter (18%), number of leaves (14%), grain oil content (8%), number of branches (4%) and stem diameter (2%).

The treatment with 60% of water deficit shows decrease namely in grain yield, 60% when compared to the control plant, followed by total green matter (47%), number

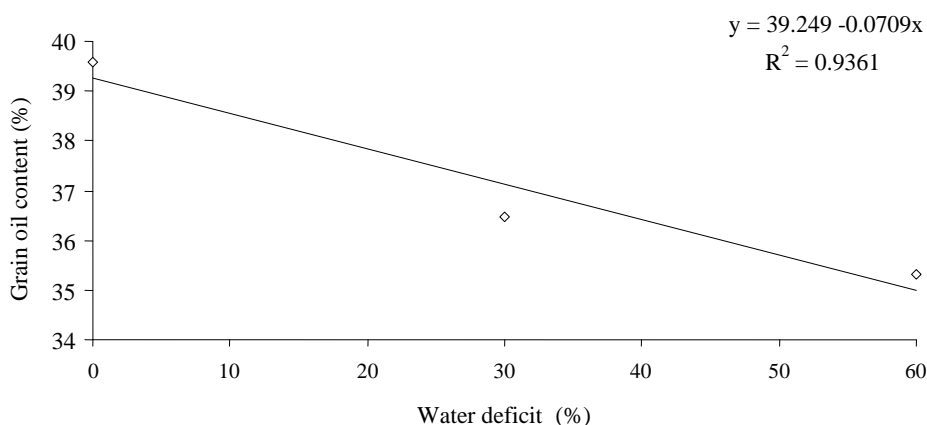


Figure 8 – Effect of water deficit on grain oil content of rapeseed crop. UNIKASSEL, Witzzenhausen, Hessen, 2009.

Table 6 – Relationship between water deficit applied and decrease in vegetative parameters (%), grain yield and grain oil rate of rapeseed. UNIKASSEL, Witzzenhausen, Hessen, 2009.

Assessed parameters	Water deficit applied		
	0%	30%	60%
Stem diameter (mm)	0%	2%	18%
Number of branches	0%	4%	43%
Number of leaves	0%	14%	27%
Number of pods	0%	22%	26%
Total green matter	0%	27%	47%
Total dry matter	0%	18%	39%
Grain yield	0%	19%	60%
Grain oil content	0%	8%	11%

of branches (43%), total dry matter (39%), number of leaves (27%), stem diameter (18%) and grain oil content (11%), respectively.

Water deficit of 60% decreased all assessed parameters, owing to water deficit amassment since the beginning of treatments, as shown in Figures 9-12.

Figures 13 and 14 show relative fall of vegetative parameters, grain yield and oil content of rapeseed grain according to the water deficit applied. The indicator of crop sensitivity to water deficit, ky , was lower than one for all assessed variables, which shows that crop sensitivity to water deficit is proportionally lower than the water deficit applied.

Grain yield was the parameter most sensitive to water deficit, ky of 0.934 (Figure 14), followed by total green matter, ky of 0.809 (Figure 14); total dry matter, ky of 0.6367 (Figure 14); number of branches, ky of 0.6034 (Figure 13); number of pods, ky of 0.4976 (Figure 13); stem diameter, ky of 0.4833 (Figure 13); number of leaves, ky of 0.4483 (Figure 13); and oil content, ky of 0.1954 (Figure 14).

Decrease in grain yield owing to water deficit in rapeseed crop was also verified by other authors, such as Taylor et al. (1991), Bouchereau et al. (1996), Champolivier e Merrien (1996) and Sinaki et al. (2007), thus corroborating our findings.

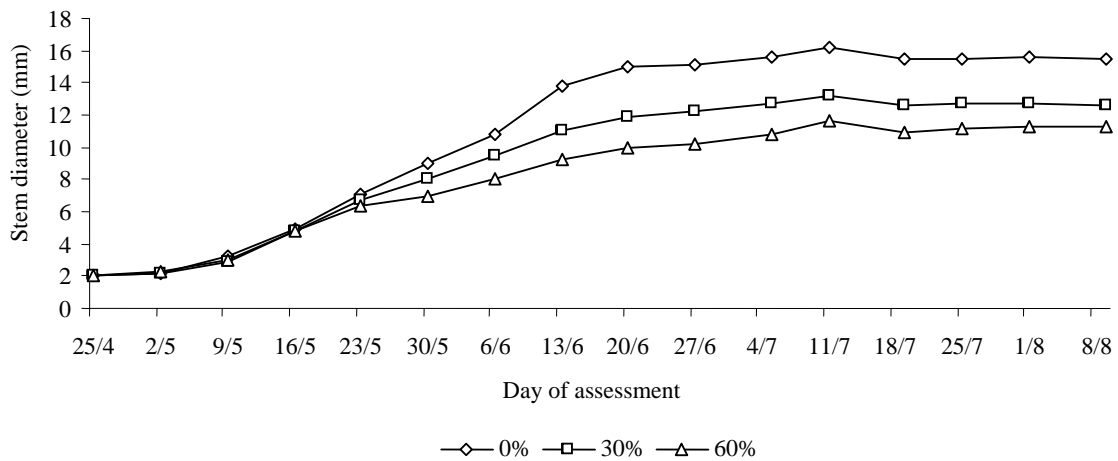


Figure 9 – Effect of water deficit on stem diameter during development of rapeseed crop. UNIKASSEL, Witzenhausen, Hessen, 2009.

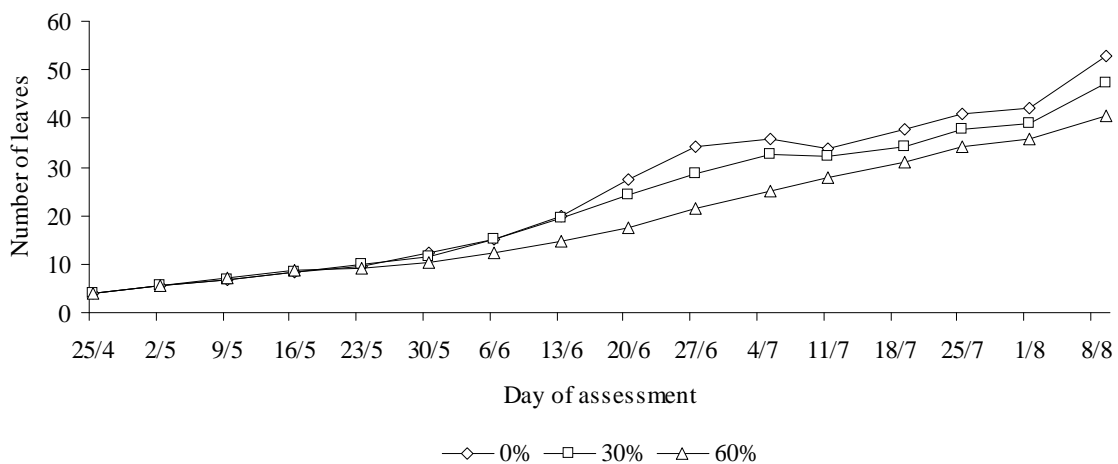


Figure 10 – Effect of water deficit on number of leaves during development of rapeseed crop. UNIKASSEL, Witzenhausen, Hessen, 2009.

Payero et al. (2008) assessed the effect of different levels of water deficit in corn crop in Nebraska (USA), finding the yield factor of response, ky , of 1.58. Oktem (2008) assessed yield sensitivity of sweet corn in Turkey, applying water deficit from 10% to 30% evaporation of

class A tank, finding yield factor of response to water deficit from 0.82 to 1.43. Calvache et al. (1997) achieved bean factor of response (ky) of 2.2 when water deficit occurred during fulfilment of pods, proving this is the period of highest crop sensitivity to water deficit.

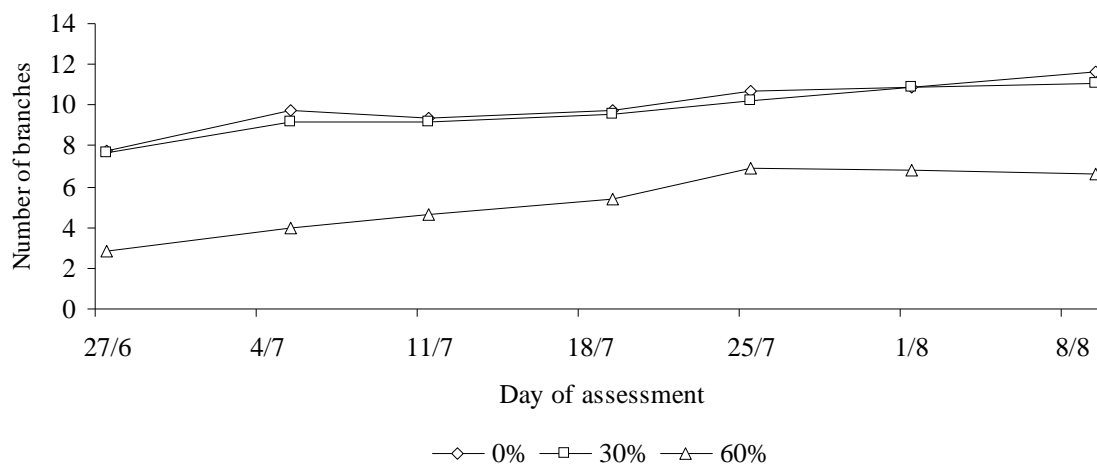


Figure 11 – Effect of water deficit on number of branches during development of rapeseed crop. UNIKASSEL, Witzzenhausen, Hessen, 2009.

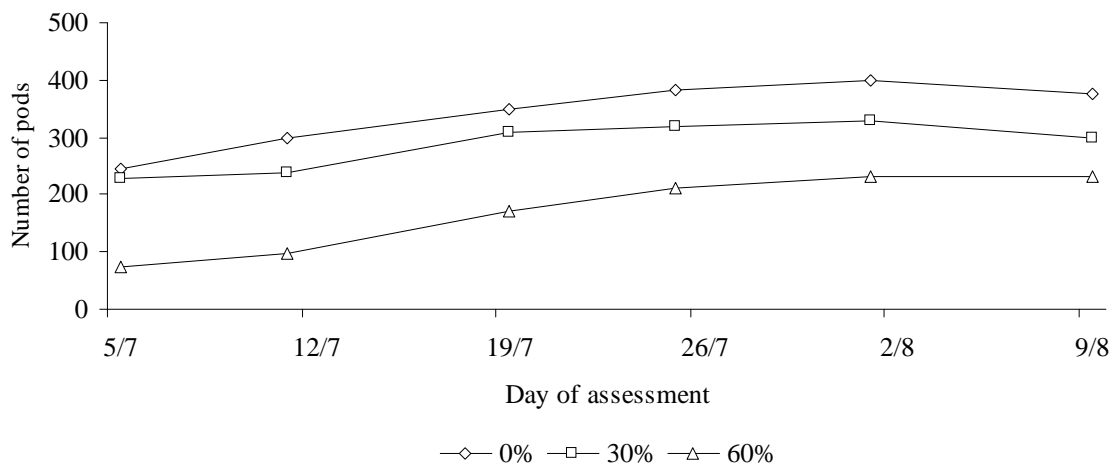
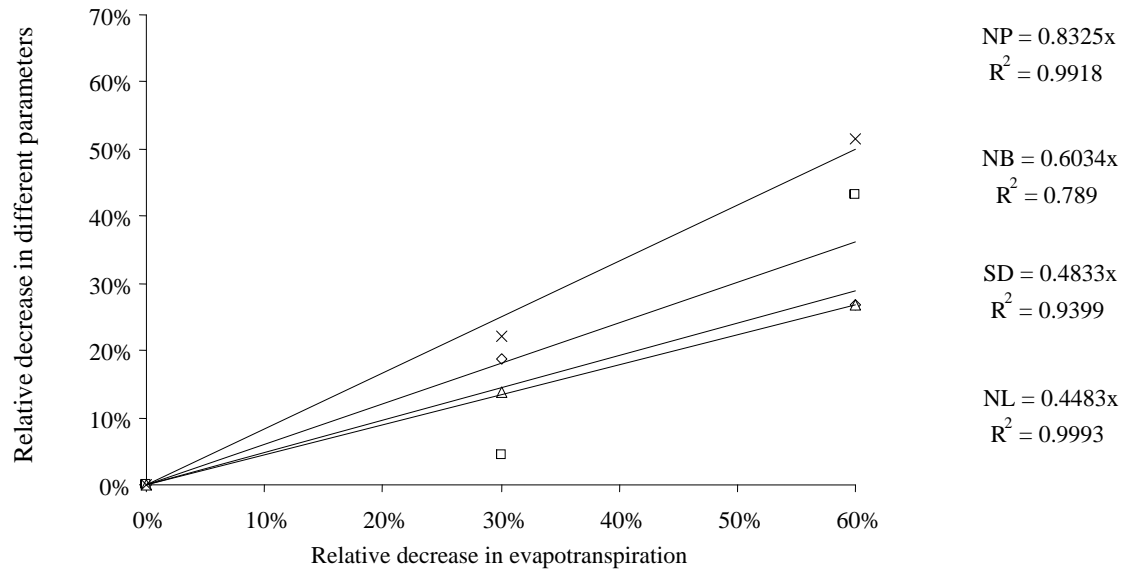
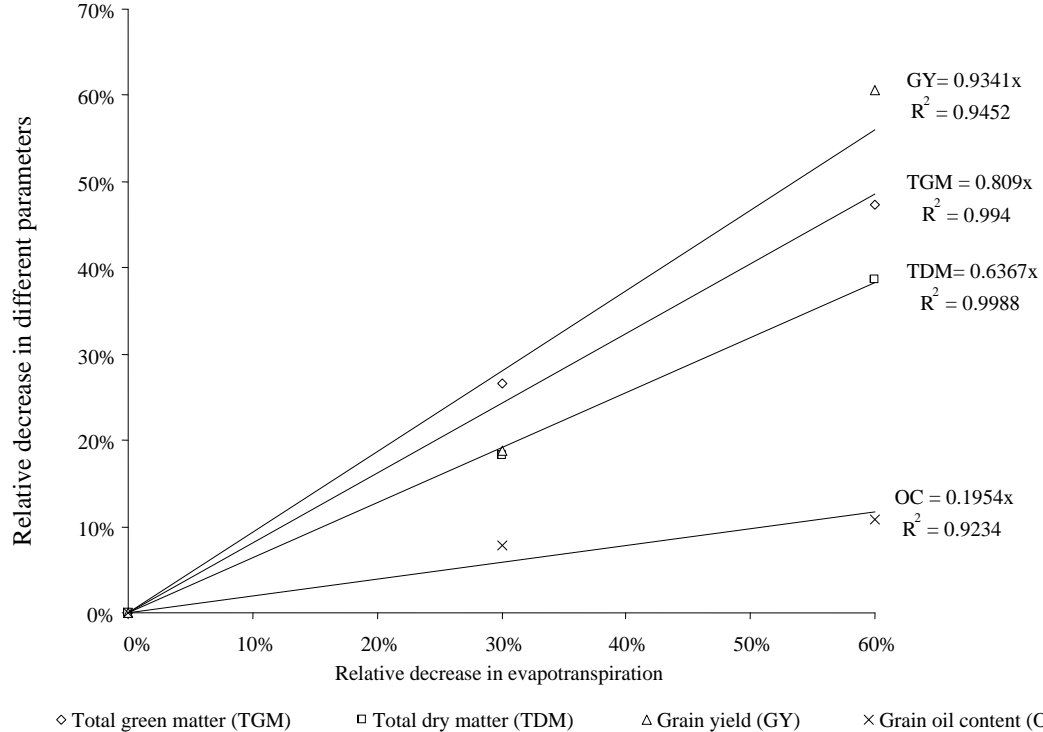


Figure 12 – Effect of water deficit on number of pods during development of rapeseed crop. UNIKASSEL, Witzzenhausen, Hessen, 2009.



◇ Stem diameter (SD) □ Number of branches (NB) △ Number of leaves (NL) × Number of pods (NP)

Figure 13 – Relative decrease in stem diameter, number of branches, number of leaves and number of pods according to relative decrease in evapotranspiration in rapeseed crop. UNIKASSEL, Witzenhausen, Hessen, 2009.



◇ Total green matter (TGM) □ Total dry matter (TDM) △ Grain yield (GY) × Grain oil content (OC)

Figure 14 – Relative decrease in total green matter, total dry matter, grain yield and grain oil content according to relative decrease of evapotranspiration in rapeseed. UNIKASSEL, Witzenhausen, Hessen, 2009.

CONCLUSIONS

Irrigation deficit decreases all aspects of growth parameters, with major reductions in levels of 60% of water deficit.

The relationship between fall of relative yield and relative evapotranspiration deficit (k_y) was lower than one for all analysed variables, showing that the assessed factors decrease less than the percentile decrease of applied water.

Grain yield showed high sensitivity to water deficit, proving that irrigation can definitely benefit crop grain yield.

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