DOI: https://doi.org/10.55302/JAFES18721183m

RAPESEED (*BRASSICA NAPUS*, L.) – BIOLOGICAL REQUIREMENTS, GROWING CONDITIONS AND NEED FOR IRRIGATION

Milena Moteva[1], Antoaneta Gigova[2], Totka Mitova[2], Vjekoslav Tanaskovik[3], Romina Kabranova[3], Zoran Dimov[3], Joanna Krużel[4]

[1]University of Architecture, Civil Engineering and Geodesy, Sofia, Bulgaria
[2]Institute of Soil Science, Agro-Technology and Plant Protection "N. Pushkarov", Sofia, Bulgaria
[3]University Ss. Cyril and Methodius, Faculty of Agricultural Sciences and Food, Skopje, Macedonia
[4]University of Agriculture in Krakow, Poland

Corresponding author : milena_moteva@yahoo.com

Abstract
Rapeseed is one of the most important energy and food crops. The European agricultural producers are highly interested in it due to the obligations under the EU Directive for replacing the fossil fuels with biofuels as much as 20% by 2020, which has drawn the purchase prices considerably up. Rapeseed is widely used for production of cooking oil and rich in protein feed too. As regards to the environment, it contributes for restoration of degraded and contaminated lands owing to its capability for improving soil structure and leaving the area free of weeds. Rapeseed is one of the best pre-crops of winter wheat and contributes for some 20-30% increase of its yield. The paper contains an overview of different aspects of rapeseed growing: its biological requirements and the abiotic stressing factors in the Balkan geographic region; its sensibility to water and the impact of the water deficit on the yield and yield structural components; its yearly and monthly evapotranspiration and crop coefficients at different empirical evapotranspiration calculation methods; world data on its yields and the agricultural practices such as proper irrigation scheduling for its yield increase. The conclusions show that the soil and the climatic conditions on the Balkans are suitable for rapeseed growing and irrigation can contribute for obtaining sustainable yields from this crop.

Keywords: rapeseed, abiotic stressing factors, irrigation scheduling, yield and yield components.

Introduction

A number of research programs in Europe and in the world are devoted to rapeseed. It is known as a an energy crop rich in oil content. The interest in it grows in Bulgaria due to high purchasing prices and obligations of Bulgaria under the EU Directive on replacement of transport petroleum products by 2020 with biofuels up to 20%. Rapeseed is widely used for producing of household oil and high-protein fodder. Ecologically, it contributes to recultivation of eroded and contaminated terrains, improving the structure of the soil and leaving areas free of weeds. Rape is one of the best precursors to wheat. It contributes for increase of wheat yield by about 20-30%. The climatic conditions for growing winter oil rapeseed (*Brassica napus* L.) in Bulgaria are favorable but in some years they are risky. There is a potential risk of frost during the winter period and from drought during sowing, blooming and grain formation. World studies on the dynamics of rapeseed water consumption and its irrigation response are small in number, mostly in the countries with semi-arid and arid climate where drought is a constant or periodic phenomenon with a high probability. For the conditions of a moderate-continental climate, such as our country's climate, there is less research work, mostly for the US and Canadian conditions. In our country, such studies have not been made because the crop has been cultivated only in recent years and because of the presumption that its vegetation period is and the spring season, it is largely waterproofed by the autumn-winter spring rainfalls. However, our studies show that in 75% of the years the spring and summer rainfall totals are expected to be between 150 and 300 mm, while the rapeseed evapotranspiration, according to data in the literature, is 300 to 400 mm. Therefore, there are years in which the atmospheric precipitation provides only 50% of the water needed for the normal crop development. In addition, the average annual rainfalls in the spring season are 190-200 mm with a 55-65% variation. The large variation shows the instability of the phenomenon and the risk of drought, resulting in yield instability. Under these conditions, it is logical to think of increasing the yield and stabilizing it by further introducing water by irrigation. For this purpose, we need knowledge about the evapotranspiration of the crop in the soil-climatic conditions of our countries, the sensitivity of its phenological stages to a water stress and the water use efficiency. The establishment of a proper irrigation scheduling is a step towards optimizing the farming practices to this crop, to controlling the management of the production process and is a basis for obtaining the desired economic results.

Rapeseed as a crop

Rape is an important oil crop with specific and favorable agronomical features: it is adaptable to different climatic conditions, has a good impact on wheat crops in field crop rotations and has high oil content. Rapeseed increases the crop yields in crop rotations by inhibiting the growth of weeds, diseases and pests, by reducing root disease, by improving soil structure (Hang et al., 2009). The yield of wheat, sawn after oil rapeseed is higher by 19 to 24-30% compared to the yields of wheat, sawn yield after wheat (Scott et al., 1999, Zentner et al., 1986, Larney, Lindwall, 1994, Brandt, Zentner (1995), cited by Johnston et al., 2002; Angus, 2002, cited by North, 2010). There are two types of winter rape - edible and industrial. The edible type contains less than 2% erucic acid and less than 30 µmol/g glycosinate. The average oil content of the seeds is 42% and the protein is 21% (DeClercq, Daun, 1999, cited by Johnston et al., 2002). The industrial rape contains 40% erucic acid and is used for the production of lubricants, rubber products, fibers, plastics, surfactants and others. (Gilliland, Hang, 2003).

Biological requirements and abiotic stressing factors

The crop has low resistance to extreme temperature impacts. The yields of winter rapeseed, however, are 1.3 times higher than those of the spring rapeseed (Bauder, 2006). Some authors have found that the seed yield when the crop is sawn in autumn is 3.0-4.0 Mg/ha, while the yield of a spring sawn crop is half of it (Evans and Luden (1987), Stefanova (1990), Slavankov (1991) cited by Ivanova, 2010). Rapeseed demonstrates the highest resistance to low temperatures during the rosette stage, with developed 6-8 leaves and when is well rooted. The temperature tolerance threshold of fully hardened plants is -15°C. It is essential that the autumn sowing date has to be chosen so as to enable the plants to grow up to the phenological stage required for successful wintering (Sovero, 1993). The temperatures during the spring vegetation have limiting effect on the yield, while the rainfalls have an increasing effect (Mailer and Cornish, 1987, Walton et al., 1999, Angadi et al., 2003, Faraji and Soltani, 2007, cited by Daneshvar et al., 2008). Rapeseed develops best at an air temperature of 21°C, and during its flowering and ripening, its requirements increase to 23°C (Ivanova, 2010). Plants are stressed at temperatures between 27°C and 30-32°C, which causes abortion of the flowers, the seed quality becomes poor, with low oil content (Sovero, 1993; Rahnema and Bakhshandeh, 2006). The thermal stress during flowering causes accelerated premature flowering, which limits the yield (Johnston et al., 2002). Negative effect was observed as a result of drought stress during flowering and seed maturing (Johnston et al., 2002). The rapeseed yield is mostly influenced by the temperature factor during flowering and by the rainfalls during seed ripening. Rapeseed has high requirements for soil and air humidity. In order to germinate and start their development, it is necessary to have about 20 mm available water in the upper soil layer (Tesfamariam, 2004; Masoud Sinaki et al., 2007). Rapeseed transpires a large amount of water. Its transpiration coefficient is in the range of 500-700 mm and 400-500 mm of precipitation is desirable to fall during the vegetation season (Ivanova, 2010). To obtain high yields, the air humidity during flowering should be high. Excessive rainfall and low temperatures during the reproduction stage are also unfavorable - they reduce the number of flowers, the number and size of the siliques and seeds in them. (Fabry, 1996, cited by Ivanova, 2010). The root system of winter oilseed rape extracts water from the deep soil layers - 115 to 165 cm. About 92-95% of the evapotranspiration is provided by the water in the 0-120 cm layer. The most favorable soils for rapeseed production are the chernozems and the dark gray forest soils with clay-sandy mechanical composition. An important condition to be met by soils is not to form a soil crust. Sandy, over-wetted, marshy and acidic soils are inappropriate (Ivanova, 2010).

Rapeseed yields and factors for increasing the yields

According to a study by Istanbulloglu et al. (2010), the seed yields from different parts of the world (Australia, India, Iran in irrigated and rain-fed conditions are in the range of 1.0-5.3 Mg/ha (Taylor and Smith, 1992; Robertson et al., 2001; Rahnema and Bakhshandeh, 2006). According to Alberta Agriculture (1980) the rapeseed yields without irrigation are considered good when ranging from 1.0 to-2.6 Mg/ha, and with irrigation: when ranging from 3.2 to 4.0 Mg/ha. In order to be profitable, at an average multi-year price of $370/Mg, a yield of not less than 1.7 Mg/ha should be ensured. Yields without irrigation at NSW Central Murray (Australia) averaged 1.8 Mg/ha and farmers used to give up rapeseed growing. The best farmers there obtained 1.8-3.6 Mg/ha in conditions of irrigation, while the yields from the experimental fields were 3.8-5.2 Mg/ha (Wright et al., 1988; Taylor et al., 1991). The seed yield of irrigated winter canola in Nebraska was 2600 lb/A (=3 Mg/ha) (Aiken and Lamm, 2006). The average oil content of the seeds, according to the study of (Istanbulluoglu et al., 2010) varies between 31.0% and 46.4%. Henry & McDonald (1978) found that drought is a factor for reducing the seed oil content and increasing the protein content. A negative correlation between the oil content and the protein content has been demonstrated (Asare and Scarisbrick, 1995; Brennan et al., 2000; Danesh-Shahraki, 2008). Naderikharadji et al., 2008 established multiple regression where yield is a parameter and factors are different elements of yield:

$$Y = -21 + 0.32 \text{ (silique length)} + 0.045 \text{ (100-seeds weight)} + 0.13 \text{ (number of seeds in a silique)}$$

From the equation we can see that the yield is mainly formed on the account of the length of the pods and the number of seeds in them. Irrigation and fertilization increase the seed yield. Canola reacts more strongly to nitrogen fertilization when irrigated. The dry matter and seed yield increase when irrigated and increased nitrogen fertilization. The oil content increases with irrigation and decreases with increasing the nitrogen fertilization (Smith et al., 1988). Under irrigation, Wright et al., 1988 obtained 1.2 Mg/ha oil yield and without irrigation: 0.8 Mg/ha. The maximum oil yield (about 1.6 Mg/ha) was obtained by irrigation combined with fertilization with 100 kg N/ha at sowing. Numerous studies have shown that the application of potassium in the form of fertilizer mitigates the negative impact of drought on growth (Fanaei et al., 2009). Irrigation has a greater impact on the number of seeds in a silique than on the other components of the yield (Masoud Sinaki et al., 2007). A feature of canola is that it uses soil moisture until the end of maturing (Bauder, 2006).Robertson et al. (2001) describe a model for the growth and development of winter rape as a module to the Australian Simulation Model of Agricultural Production (APSIM). Husson (1998) and Gabrielle et al. (1998), cited by Robertson et al. (2001) also developed simulation models from the family of CERES models. The Robertson model describes both dry and irrigation conditions. It simulates with sufficient accuracy the yields under different conditions, sowing dates, water supply, and nitrogen supply. Yields of 30 to 500 g/m^2 are simulated with 15% standard deviation.

Response to water. The effect of water deficit on the yield and the structural elements of the yield.

Drought is one of the most powerful abiotic stressors for rapeseed's growth and productivity. According to Fanaei et al. (2009), the relative yield reduction in abiotic stress conditions compared to optimum conditions ranged from 54 to 82%. The time of occurrence of drought stress is much more important than its intensity. Gan et al. (2004) found that plants undergoing drought stress in the early stages are easily recoverable while the drought stress during the formation of siliques causes substantial and irreversible reduction in the structural elements of the yield. The drought stress during flowering and seed maturing causes reduction in dry matter, seed yield and oil content (Nuttall et al., 1992; Mansour et al., 2005; Muhammad et al., 2007; Datesh-Shahraki et al., 2008;

Ahmadi and Bahrani, 2009). Colton and Sykes (1992) (cited by North, 2010) recommended that irrigation starts in spring without allowing drought stress. Bernadi (1996) recommends that full irrigation be applied. By applying drought stress during stem elongation and flowering, Richards, Thurling, 1978, cited by North, 2010) obtained seed yields 1.51 g/plant and 1.43 g/plant, respectively, while the yield at fully meeting the crop's water needs, was 3.30 g/plant. Tahir et al. (2007) obtained the highest yield when irrigating during the early vegetative stage, flowering and seed maturing. Masoud Sinaki et al. (2007) found that the reduction in yield was greatest at water stress during flowering, then during the siliques formation. Irrigation after the flowering stage by fully meeting the plant water needs, significantly increases the yield (North, 2010). Wright et al. (1988) recommended that rapeseed has to be irrigated, especially after flowering, in combination with high nitrogen fertilizers. The drought stress during flowering results in deviations in the leaf area index (LAI) and the photosynthetic potential (LAP) due to leaf wilting and dropping. This is accompanied by abortion and dropping of the flowers and the siliques (Gunasekara et al., 2003). According to observations by Gunasekara et al. (2006), the yield of biomass under moderate and strong water stress during the reproductive stage decreased by 17.9% and 32.1%, and the seed yield by 18.5% and 38.7%. Watering during the seed maturing has the greatest effect on the yield (Gilliland and Hang, 2001). The drought stress during late season does not affect the number of seeds but it affects the weight of seeds. It reduces the seed size, shortens the period of their maturing, and reduces the ability of plants to recover (Mendham, Salisbury, 1995). In Germany, Bilibio et al., 2009b found that the yield factor K_y, which is indicative of the sensitivity of the crop to water deficit, was low: <1. The most sensitive to water deficit is the seed yield. Water stress significantly influences the net productivity of the photosynthesis, the mouth cell conductivity and the cell concentration of CO_2 both during the vegetative and the flowering stage (Naderikharadji et al., 2008). According to Nasri et al. (2008), the irrigation scheduling at a 75% maximum allowable deficit provides for 43.1% seed oil content, while without irrigation or allowing 25% available water deficit provide for 40.2% seed oil content. With an increase of the drought stress from 75% to the maximum allowable deficit (without irrigation), the yield decreased from 3.3 to 1.8 Mg/ha, the amount of saturated fatty acids and glucosinolates in the seeds increased and the quality of the oil deteriorated. Brandt and McGregor (1997), cited by Johnston et al. (2002) have established an equation for the yield of spring canola as dependent on the meteorological factors:

Yield of *B. napus* L. = 4323 + 5.90 Precip. - 187.7 Temp.
R^2=0.76; SE = 221

where: Precip. - the precipitation total of the period from 21 June to 20 August (R^2=0.82), Temp. - the temperature total of the period 15 June to 15 August (R^2=0.58). The relationship showed that for each increase of the average daily temperature by 1°C, the yield was reduced by 188 kg/ha. For each mm increase of water in the soil, the yield increased by 5.9 kg/ha. The studies of Champolivier and Merrien (1996), cited by Moaveni et al. (2010) showed that the yield and the structural elements of the yield were significantly affected by the water shortages from the beginning of flowering to the end of seed maturing. The 1000-seeds weight was also affected by the smallest drought stress during the period of seed coloring. The same authors have found that the oil content decreased when the crop developed under water deficit conditions from flowering to maturity.

Evapotranspiration and crop factors

The requirements of rapeseed to water and the need for irrigation are well studied for different soil and climatic conditions (Choudhury et al., 1990, Francois, 1994). The potential rapeseed evapotranspiration during the spring period is around 300-400 mm. According to McKenzie (2009), rapeseed spends about 100-125 mm from germination to reaching the reproductive stage. In the initial stages it consumes 2-3 mm/d, during stem elongation: 3-5 mm/d. During flowering, which coincides with the summer period, from mid-June to late July or early August, spring rapeseed consumes 7-8 mm/d. The 24-hour water consumption remains high throughout the flowering and seed formation period. It goes cuttingly down to the end of the seed stage when the maturing process is over. Spring canola grown under optimum conditions in South Alberta, Canada (well-watered, well-fertilized, on well-drained soils, by even stand and optimal density, weed-free) spends 400 to 480 mm of water for evapotranspiration. The average daily evapotranspiration ranges from 0.1 mm up to 7.0 mm during the flowering and seed-filling stage. Canola extracts 70% of the required water from the layer 0-50 cm. FAO 56 crop coefficients for canola in the southern hemisphere are 0.35, 0.36, 0.60, 0.93, 1.0, 0.95, 0.56 respectively in April, May, June, July, August, September and October (Allen et al., 1998). At plant height of maximum 0.60 cm, the coefficients K_c by stages are as follows: vegetative - 0.35, flowering - 1.00-1.15, maturation - 0.35. K_p to E_{pan} for the whole canola vegetation period is 0.75 (Nodson, 1978, cited by North, 2010), which corresponds to 0.94, converted to FAO PM (K_p=0.8K_c). The FAO Penman-Meyer coefficients for the months from April to November for two areas of Australia are: for Murray Valley - 0.3, 0.4, 0.6, 0.9, 1.0, 1.0, 0.9, 0.6 and for Griffith - 0.3, 0.4, 0.6, 0.75, 0.75, 0.7, 0.4 respectively (North, 2010).

Irrigation scheduling

Winter oil rapeseed is relatively new and unexplored in terms of the irrigation scheduling in the Balkan countries. Recent studies showed that in our soil-climatic conditions this crop is threatened by: 1) the negative effects of low winter and high summer temperatures, and 2) droughts in both autumn and spring seasons. In this case, irrigation must be applied to overcome these impacts and produce high yields. According to Krogman and Hobbs (1975), when increasing the soil moisture, both the leaves and the siliques increase their photosynthesizing area, resulting in an increased yield. Irrigation contributes for creation of a uniform crop stand, which is difficult to achieve in dry conditions. Because of the trends of climate warming and drought it is necessary to apply good irrigation management with high water use efficiency. Water availability is crucial for rapeseed the stages: germination, vegetative stage (before flowering: rosette formation, stem elongation and jointing), flowering and silique formation. Ideally, soil water should be maintained within 60-100% of the total available water, be readily available so as not to be a limiting factor for the formation of the yield. This is valid for the period of sowing too. The first irrigation application after sowing should be 15 mm for the 0-50 cm layer. The soil moisture during the vegetative stage should be monitored in the 0-100 cm layer. The irrigation application depths for the 0-100 cm layer should be 50 mm for sandy soils and up to 90 mm for sandy clayey and clayey soils. The last application should be given when the earliest siliques start to mature. Niazi and Fooladmand, 2006 concluded that the most favorable inter-application period for the experimental conditions was 10-12 days. In a field experiment of Sultana et al., 2009, the best results, i.e. the highest yield and the highest harvest index, were obtained under the largest number of applications. Irrigation contributes to formation of higher plants, more branching, much more and longer siliques, which automatically increases the yield of the biomass mass. According to Mondul et al (1988), cited by Sultana et al. (2009) the highest yield obtained was when giving an application during flowering and another one when silique forming (2.56 Mg/ha). In Tasmania, a 100 mm irrigation depth, given through two applications after flowering, increased the yield from 3.5 to 5.2 Mg/ha (Mendham and Salisbury 1995). Mendham and Salisbury (1995) cite authors who have obtained through 1, 2 and 3 applications of 50 mm respectively 275, 287 and 420 g/m^2. In Southern Brazil, it was concluded that establishing the soil moisture pressure of 20 kPa was a good indicator of starting irrigation. A factor of greater importance for increasing the rapeseed yield is the frequency of irrigation rather than the amount of water delivered (Bilibio et al., 2009a). According to Bauder (2006), maintaining a water supply of more than 75% of the available water content can cause to waterlogging.

Conclusions

The seed yield from different parts of the world under rain-fed conditions is in the range of 1.0-2.6 Mg/ha, and under irrigation: 3.2-4.0 Mg/ha. In experimental conditions the yield reaches 5.2 Mg/ha.

The average seed oil content ranges between 31.0% and 46.5% and the protein content is between 20% and 20.5%. Oil yield is 0.8-1.2 Mg/ha, and the yield of raw protein: up to 2.3 Mg/ha. Under good agricultural practices, the biomass can be 7.0 Mg/ha and the dry matter: 1.1 Mg/ha. The yields are mainly accumulated on account of the number and length of the siliques and the number of seeds in a silique. The water factor is crucial for releasing the productive potential of winter oil rapeseed as well as drought is one of the most powerful abiotic stressors for rape growth and productivity. Depending on the climatic and meteorological conditions, irrigation of rapeseed provides for an increase in the yields from several percent to several times: up to 560% in plant height, 116% in branching, 300% in silique number, 70% in silique length, 50% for seen number in a silique, 42% in 1000-seeds weight, 80% in oil yield. The leaf area, when meeting the crop needs in water, increases with 50%, the photosynthetic potential - up to 16%, the growth rate - up to 85% and the productivity of the photosynthesis - up to 50%. The most critical to water is the flowering stage, followed by the maturing stage (seed maturing) and the seed formation stage. Most affected by water deficiency during flowering are the seed and oil yields as well as the structural elements of the yield: silique number, seed number in a silique and the biometric features - plant height and number of branches per plant. The 1000-seeds weight is most affected by the water deficiency during seed maturing. Moderate and strong drought stress results in 14.5% and 32.0% reduction in the biomass yield and 18.5-38.0% reduction in seed yield. The seed number is mast affected. The drought stress has a stronger effect on seed yields than on the biomass yields. The drought stress after flowering reduces the oil content. The strong drought stress influences the negative relationship between oil and protein in the seeds in favor of fat. As the water stress increases, the harvest index decreases. With increasing of the water deficit, the amount of saturated fatty acids and glucosinolates in the seeds increases and the quality of the oil deteriorates. Waterlogging is harmful to rapeseed. It can occur if the water supply maintains the available water content over 75%. The rapeseed water requirements and its need in irrigation are well studied in the world. Under the conditions of the Mediterranean climate, evapotranspiration without irrigation is some 465 mm, and when meeting the crop water needs by irrigation, it is some 715 mm. The seasonal evapotranspiration during the spring period is around 300-400 mm. The maximum average daily evapotranspiration rate of 5 mm/d occurs during the flowering stage. In the same phenological stage, the spring rapeseed consumes 7-8 mm/d. In our countries there is no research on the water requirements of rapeseed. The FAO coefficients K_c have been established. At plant height of maximum 0.60 cm, FAO recommends the following coefficients per stages: vegetative - 0.35, flowering - 1.00-1.15, maturation - 0.35. A coefficient for the transition from evaporation from a class A evaporator to evapotranspiration of canola K_p=0.75 was established for the whole growing season. The elements of the irrigation scheduling for different climatic conditions have been estimated. The readily available water is within the 60-100% of the total available water. The first irrigations should be 15 mm for the 0-50 cm layer. If the water is readily available, watering can cause over-wetting, which is detrimental to the crop. If autumn is extremely dry, it is good to deliver an irrigation application to create a uniform crop. Some authors recommend that the first application be carried out before the leaf's water potential has fallen below 0.4 MPa. In spring vegetation, irrigation must be reintroduced from mid-April, when the crop is vegetative growing and continue during flowering. It is recommended that irrigation be carried out while the water potential of the soil is 20 kPa. Depending on the weather conditions, the water needs of the crop in moderate climates are met by 3-5 spring irrigation applications with an irrigation depth of 250-300 mm. The irrigation depths for the 0-100 cm layer are 50 mm for sandy and 90 mm for sandy clay and clayey soils. The last application should be given when the earliest siliques begin to mature. In case of water deficiency, it is advisable to irrigate during flowering, since irrigation can double the yield. The most favorable duration of the inter-application period is 10-12 days.

References

1. Ahmadi, M. and Bahrani, M.J. (2009). Yield and yield components of rapeseed as influenced by water stress at different growth stages and nitrogen levels. American-Eurasian J. Agric. & Environ. Sci., 5 (6): 755-761
2. Aiken, R. M. and Lamm, F. R. (2006). Irrigation of oilseed crops. In: Proc. Central Plains Irrigation Conference, Colby, K.S., Feb. 21-22, 2006. Available from CPIA, 760 N. Thompson, Colby, KS: 162-172.
3. Alberta Agriculture (1980) Irrigated oilseed rape production. Agdex No. 149/561-1. Edmonton, Alberta: Alberta Agriculture.
4. Allen, R.G., Pereira, L.S., Raes, D. and Smith, M. (1998). Crop evapotranspiration. Guidelines for computing crop water requirements. FAO Irrig. and Drainage Paper No. 56, Rome, 300 pp.
5. Asare, E. and Scarisbrick, D.H. (1995). Rate of nitrogen and sulfur fertilizers on yield, yield components and seed qualit of oilseed rape (*Brassica napus,* L.). Field Crop Res., 44: 41-46
6. Bauder, J.W. (2006). The right strategy for irrigating your canola crop. http://waterquality.montana.edu/docs/irrigation/canolastrategy.shtml 4 pp.
7. Bilibio, C., Hensel, O., Carvalho, J. A., Martins, M., Rezende, F. and de Freitas, W. A. (2009a). Optimizing water use in irrigated rapeseed areas in Brazil. Tropentag, October 6-8, 2009, Hamburg "Biophysical and Socio-economic Frame Conditions for the Sustainable Management of Natural Resources"
8. http://www.tropentag.de/2009/abstracts/links/Bilibio_hEnwN4GC.pdf
9. Bilibio, C., Hensel, O., de Assuncao Carvalho, J., Richter, U. and Martins, M. (2009b). Effect of different levels of water deficit on yield parameters of rapeseed crop Bioenergy Engineering, 11-14 October 2009, Bellevue, Washington, BIO-098000,
10. https://elibrary.asabe.org/abstract.asp?aid=28875&t=2
11. Brennan, R.F., Mason, M.G. and Walton, G.H. (2000). Effect of nitrogen fertilizer on the concentrations of oil and protein in canola (*Brassica napus*, L.) seed. J. Plant Nutr., 23: 339-348
12. Choudhury, A.K. (1990). Response of rapeseed (*Brassica napus*, L.) to irrigation and nitrogen levels under sandy-loam soils of Assam. Indian Journal of Agricultural Sciences, 60, 5: 347-349
13. Danesh-Shahraki, A., Nadian, H., Bakhshanden, A., Fathi, G., Alamisaied, K. and Gharineh, M. (2008). Optimization of irrigation and nitrogen regimes foe rapeseed production under drought stress. Journal of Agronomy, 7(4): 321-326
14. Daneshvar, M.Z., Sarvestani, Z.T. and Savani, S.A. (2008). Different irrigation and nitrogen fertilizer treatments on some agro-physiologic traits in rapeseed (*Brassica napus*, L.). Pak. J. Biol. Sci. 11(2): 1530-1540
15. Fanaei, H.R., Galavi, M., Kafi, M. and Ghaari Bonjar, A. (2009). Amelioration of water stress by potassium fertilizer in two oilseed species. International Journal of Plant Production 3 (2): 41-54
16. Francois, L.E. (1994). Growth, seed yield, and oil content of canola grown under saline conditions. Agronomy Journal, 86, 2: 233-237.
17. Gan, Y., Angadi, S.V., Cutforth, H., Angadi, V.V. and McDonald, C.L. (2004). Canola and mustard response to short periods of temperature and water stress at different developmental stages. Can. J. Plant Sci., 84: 697-704.
18. Gilliland, G.C. and Hang, A.N. (2003) Oilseed rape keeps irrigated land productive during drought. Drought Advisory, EM4833, http://pubs.wsu.edu
19. Gunasekara, C.P., Martin, L.D., French, R.J., Siddique, K.H.M. and Walton, G.H. (2003). Effect of water stress on water relations and yield of Indian mustard (*Brassica juncea*, L.) and canola (*B. napus*, L.). Proc. 11th Australian Agronomy Conference, 2-6 Febr., Geelong, Victoria, Australia
20. Gunasekara, C.P., Martin, L.D., French, R.J., Siddique, K.H.M. and Walton, G. (2006). Genotype by environment interactions of Indian mustard (*Brassica juncea*, L.) and canola (*Brassica napus*, L.) in Mediterranean-type environments: I. Crop growth and seed yield. Euro. J. Agron. 25: 1-12.
21. Hang, N., Collins, H.P. and Sowers, K.E. (2009). WSU Extesion Manual EM006E http://pubs.wsu.edu

22. Henry, J.L. and McDonald, K.B. (1978). The effects of soil and fertilizer nitrogen and moisture stress on yield, oil and protein content of rape. Can. J. Plant Sci., 58: 303-310
23. Istanbulluoglu, A., Arslan, B., Gocmen, E., Gezer, E. and Pasa, C. (2010). Effects of deficit irrigation regimes on the yield and growth of oilseed rape (*Brassica napus*, L.). Biosystem Engineering, 105: 388–394
24. Ivanova, R. (2010). Rapeseed – a crop of the future. Videnov & Son, 210 c.
25. Johnston, A.M., Tanaka, D.L., Miller, P.R., Brandt, S.A., Nielsen, D.C., Lafond, G.P. and Riveland, N.R. (2002). Oilseed crops for semiarid cropping systems in the Northern Great Plains. Agron. J. 94: 231–240
26. Krogman, K.K. and Hobbs, E.H. (1975). Yield and morphological response of rape (*Brassica campestris*, L., Cv. Span) to irrigation and fertilizer treatments. Can. J. Plant Sci., 55: 903-909.
27. Mansour, H.Z., Shiranirad, A.H., Naderi Darbaghshahi, M.R., Majd Nasiri, B. and Hamid, M. (2005). Effect of drought stress on yield and yield components of autumn rapeseed varieties. Journal of Agriculture, 7(2): 17-24
28. Masoud Sinaki, M.J., Majidi Heravan, E., Shirani Rad, H., Noormohammadi, G.and Zare, G.H. (2007). The effects of water deficit during growth stages of canola (*Brassica napus*, L.). Am-Euras. J. Agric. Environ. Sci., 2: 417-422.
29. McKenzie, R.H. (2009). Crop water use and requirements. Agri-Facts - Practical Information for Alberta Agriculture Industry. Agdex 100/561-1
30. Mendham, N.J. and Salisbury, P.A. (1995). Physiology, crop development, growth and yield. In: Kimber, D.S. and D.I. McGregor. (Ed.). Brassica Oilseeds: Production and utilization. CAB International, London: 11-64.
31. Moaveni, P., Ebrahimi, A. and Farahani, H.A. (2010). Physiological growth indices in winter rapeseed (*Brassica napus,* L.) cultivars as affected by drought stress at Iran. Journal of Cereals and Oilseeds, 1(1): 11-16
32. Muhammad, T., Ali, A., Nadeem, M.A., Tanveer, A. and Sabir, Q.M. (2007). Performance of canola (*Brassica napus* L.) under different irrigation levels. Pak. J. Bot., 39: 739-746.
33. Naderikharadji, R., Pakniyat, H.and Biyabani, A.R. (2008). Effect of drought stress on photosynthetic rate of four rapeseed (*Brassica napus*, L.) cultivars. J. Applied Sci., 8 (23): 4460-4463
34. Nasri, M., Zahedi, H., Tohidi Moghadam, H.R., Ghooshchi, F.and Paknejad, F. (2008). Investigation of water stress on macro elements in rapeseed genotypes leaf (*Brassica napus*, L.). American Journal of Agricultural and Biological Sciences 3 (4): 669-672
35. Niazi, J. and Fooladmand, H. R. (2006). Irrigation Frequency and Irrigation Requirement of Three Different Rapeseed Cultivars in Zarghan Area, Fars Province. Journal of Science and TEC of Agriculture and Technology Natural Resources, Water and Soil Science, 10, 3: 71-82
36. North, S. (2010). Tactical Irrigation Strategies for Maximizing Farm Profitability in Mixed Cropping Enterprises. Irrigation Matter Series No. 03/10, Cooperative Center for Irrigation Futures.
37. Nuttall, W. P., Molin, A.P. and Townley-Smith, L.J. (1992). Yield response of canola to nitrogen, phosphorus, precipitation, and temperature. Agronomy Journal, 84: 765-768.
38. Rahnema, M. and Bakhshandeh, A.M. (2006). Determination of optimum irrigation level and compatible canola varieties in the Mediterranean environment. Asian J. Plant Sci., 5: 543-546.
39. Robertson, M. J., Holland, J.F. and Kirkegaard, J.A. and Smith, C. J. (2001). Simulating growth and development of canola in Australia. Proc. 10th Intern. Rapeseed Congress, Сабр.erra, Australia, 27-29 Sept., 2001, Internet
40. Smith, C.J., Wright, G.C. and Woodroofe, M.R. (1988). The effect of irrigation and nitrogen fertilizer on rapeseed (*Brassica napus*, L.) production in south-eastern Australia. II. Nitrogen accumulation and oil yield. Irrig. Sci. 9: 15-25
41. Sovero, M. (1993). The biology of *Brassica napus*, L. Canola/Rapeseed. Cultural and environmental requirements. In: Rapeseed, a new oilseed crop for United States (Ed., J. Janick): 302-307.

42. Sultana, S., Ruhul Amin, A.K.M. and Hasanuzzaman, M. (2009). Growth and yield of rapeseed (*Brassica campestris*, L.) varieties as affected by levels of irrigation. American-Eurasian Journal of Scientific Research, 4(1): 34-39
43. Tahir, M. Ali, A., Nadeem, M.A., Tanveer, A. and Sabir, Q.M. (2007). Performance of canola (*Brassica napus*, L.) under different irrigation levels. Pak. J. Bot., 39(3): 739-746
44. Taylor, A. J., Smith, C. J. and Wilson, I. B. (1991). Effect of irrigation and nitrogen fertilizer on yield, oil content, nitrogen accumulation and water use of canola (*Brassica napus*, L.). Nutrient Cycling in Agroecosystems, 29, 3: 249-260
45. Taylor, A. J. and Smith, C. J. (1992). Effect of sowing date and seeding rate on yield and yield components of irrigated canola (*Brassica napus*, L.) grown on a red-brown earth in south-eastern Australia. Aust. J. Agric. Res. 43: 1629-41.
46. Tesfamariam, E.H. (2004). Modelling the soil water balance of canola Brassica napus L (Hyola 60). PhD Thesis, University of Pretoria etd., 120 pp.
47. Wright, G.C., Smith, C.J. and Woodroofe, M.R. (1988). The effect of irrigation and nitrogen fertilizer on rapeseed (*Brassica napus*, L.) production in south-eastern Australia. I. Growth and seed yield. Irrig. Sci. 9: 1-13.