Available online: www.notulaebiologicae.ro
Print ISSN 2067-3205; Electronic 2067-3264
Not Sci Biol, 2015, 7(3):361-366. DOI: 10.15835/nsb.7.3.9554
AcademicPres
Notulae Scientia Biologicae

Effects of Super-Absorbent Polymer Application on Yield and Yield Components of Rapeseed (*Brassica napus* L.)

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Abstract

Limitation of water resources and its great impact on agricultural and natural resources play a crucial role in the efficiency of water use. Applying super absorbent polymer to the soil may be one of the methods to minimize the stress of weather dryness in arid and semi-arid regions. In order to evaluate the effects of hydrophilic polymer application on yield and water use efficiency of rapeseed plants, an experiment was conducted under field condition in 2012 at the Research Farm of the Faculty of Agriculture, University of Maragheh. Treatments' factors were: (i) 3 super absorbent polymers (SAP) (Taravat A200) levels of 0 (without application), 75 and 150 kg ha^{-1} A200 application, (ii) three irrigation levels of 80, 120 and 180 mm evaporation from class A basin in main plots, (iii) two cultivars 'Hyola 401' and 'RVS' in sub plots as factorial split plot combination based on completely randomized block design with three replications. The results showed that in all of the measured traits within the experiment there were significant differences between SAP levels. Furthermore, increasing irrigation interval led to an increase in a thousand seeds' weight, but decreased seed yield. Increasing water stress raised seed oil percent and infertile silique and subsequently resulted in reduced oil yield. 'Hyola 401' was more susceptible to embryo abortion compared with 'RVS'. As a conclusion of the research, SAP (A200) application in quantities smaller than 75 kg ha^{-1} may be recommended for rapeseed production under field condition.

Keywords: drought, hydrogel, irrigation, oil yield, water-holding capacity, water stress

Introduction

Synthetic polymers in the form of crystals or tiny beads are available under several trade names as super absorbent polymers, root watering crystals and drought crystals; they are collectively known as hydrogels. They can absorb and retain 1,000 times more water or aqueous solutions than their original size and weight (Farrell *et al*., 2013). The incorporation of super absorbent polymers (SAPs) into soil improved soil physical properties (El-Amir *et al*., 1993), enhanced seed germination, plant emergence, crop growth and yield (Yazdani *et al*., 2007) and reduced the irrigation requirement of plants (Taylor *et al*., 1986).

In arid and semiarid regions, drought stress is the main factor limiting crop growth and productivity (Todorov *et al*., 1998). Efficient management of soil moisture is critical for agricultural production in areas with scarce water resources (Eneji *et al*., 2013). Iran contains both arid and semiarid regions and drought stress is one of the major environmental stresses, restricting crop production in the country (Jabbari *et al*., 2013). The amelioration of drought stress by application of SAPs has been documented in several studies (Yazdani *et al*., 2007; Islam *et al*., 2009; Li *et al*., 2014). The SAPs improved soil porosity, structure and water-holding capacity (Karimi *et al*., 2009). Also, the use of hydrophilic polymer materials as carrier and regulator of nutrient release minimized undesired fertilizer losses and sustained considerable plant growth (Mikkelsen, 1994). SAPs also significantly increased the soil water content (SWC) and soil maximum hygroscopic moisture (SMHM) in the booting and filling stages, but had no effect on the soil available water-holding capacity (AWC) compared with the control in the filling stage (Li *et al*., 2014). Ahmad and Verplancke (1994) reported an improvement in germination and biomass production of clover, lettuce and ryegrass in dune sand with gel amendment. Seedling emergence rate and dry seedling weight in lettuce, tobacco and cotton increased in soil amended with hydrogel (Wallace and Wallace, 1986). Woodhouse and Johnson (1991) have shown varying degrees of improvement in the germination and establishment of different plant species. The highest increase in seed yield, total dry matter (TDM), leaf area index (LAI), crop growth rate (CGR) and harvest index (HI) were achieved by Yazdani *et al*. (2007) with a dose of 225 kg ha^{-1} polymer compared with the control (without polymer). These results indicated that the application of super absorbent polymer increased all the above growth and yield attributes (Yazdani *et al*., 2007).

Rapeseed (*Brassica napus* L.) is a cosmopolitan oil bearing plant. Its oil is used primarily for human foods, but has also some industrial applications. Worldwide, rapeseed production is of approximately 62.4 million tons and covers a

Received: 17.03.2015. Received in revised form: 02.08.2015. Accepted: 21.08.2015. Published online: 24.09.2015.

total area of 33.6 million hectares (FAO, 2011). Rapeseed is one of the most important industrial crops in Iran. A major challenge for the production of rapeseed in Iran is the lack of uniform stand establishment of the plants due to poor water resources and dry soil conditions (Mwale *et al*., 2003). Two overlapping growth stages are considered to influence rapeseed yield and yield components: silique formation and seed number per silique. Several factors, including low water availability, during those critical periods negatively influence siliques number per plant and the number of seeds per silique. There is evidence that apart from environmental factors (such as drought stress), limited photosynthate had great impact on seed number per silique for rapeseed plants (Puma and Panin, 1999).

In a previous study, water deficit stress either in the vegetative growth stage or during flowering and/or seed filling stage, led to a significant decline in seed number per unit area and reduced yield (Ahuja *et al*., 2008). Seed weight per unit area is a more variable factor of rapeseed, genotypes being easily influenced by environmental factors. Commonly, there is a linear relationship between time course from flowering (beginning to ending of this stage) and seed weight. Seed development period of rapeseed is between 35 to 55 days. This period is mainly dependent on water and photosynthate availability (Rao and Mendham, 1991).

Due to the extension of drought in Iran and the importance of rapeseed cultivation in the country, the objective of this study was to evaluate the effect of super absorbent application in order to reduce the effects of drought stress. Recently, due to high efficiency, low cost and easy availability of Taravat A200, as common SAP in Iran, the use of this material is more spread. It should be noted that the A200 used in this research composed of acryl amide (AM), acrylic acid (AA) and potassium acrylate.

Materials and Methods

The experiment was conducted at the Research Farm of the Faculty of Agriculture, University of Maragheh, Iran, during 2012-2013 (from autumn of 2012 to spring of 2013). Two rapeseed (*Brassica napus* L.) cultivars namely 'Hyola 401' and 'RVS' (sub plots) were employed for evaluation of combinations of 0, 75, 150 kg ha^{-1} soil based with Taravat A200 (1-2 mm granular size) and application of three irrigation levels: 80, 120 and 160 mm evaporation from class A pan, as factorial split plot based on randomized complete block design with three replications. Main plots (strips) were irrigation levels of I_1=80 mm, I_2=120 mm and I_3=160 mm evaporation from class A pan. Water penetration value was determined by double ring and irrigation duration was calculated by the Blaney-Criddle method. Three levels of SAP (A200) at S_1= Control (without application of SAP), S_2 = 75 kg ha^{-1}, S_3 = 150 kg ha^{-1} super absorbent, were applied into 15 cm depth of furrows prior to planting. Physical and chemical characteristic of super absorbent polymer were as presented in Table 1. The SAP amendment used in this study was produced by the Rahab Resin Co. Ltd., under license of the Iran Polymer and Petrochemical Institute. It was a white granular powder with 90% active ingredient, 75-1,000 μm particle size and 0.60 g cm^{-3} bulk density, which swells to form a gel in water. After calculation, the necessary super absorbent amounts were poured separately into each pail and sufficient water was added. Thirty minutes later, the super absorbent had already absorbed completely the water and was slowly and accurately poured on the whole plot. Each plot was consisted of 5 rows of 5 m in length and 3 m width. There was a distance of 1.8 m between strips and 3 m between sub plots.

The soil of the experimental site was a clay loam, with a montmorillionite clay type, 10% of neutralizing substances low in nitrogen (0.06-0.07%), low in organic matter (0.56-0.60%), and alkaline in reaction with a pH of 7.2 and EC = 0.66 dSm^{-1}.

The method of irrigation was siphons and the amount of water used was measured by 2 inch contour.

Planting of rapeseed was done after the application of super absorbent. Plant density was 150 seed per m^2. All common tillage practices such as weeding and disease control were carried out on plants. Plants harvest was carried out on July 2013. Observations were carried out on 2 central rows and 0.5 m from both ends of the rows was left not studied as it represented the border effect.

The following measurements were carried out: seed yield (seeds were separated and weighted from individual plots (14% moisture)), the number of siliques per plant (18 plants of every individual plot were selected and the number of siliques in every plant were countered (with at least one seed)), the number of seeds per silique (18 plants of every individual plot selected and the number of seeds were countered from 5 siliques in every plant) and 1,000-seed weight (seed counter was used to count the number of 100-seed). Seed oil quantity was determined by succelet method.

All data were analyzed by using the SAS software (SAS Institute Inc., 1997). Each treatment was analyzed in three replications. When ANOVA showed significant treatment effects, the Duncan's multiple range test was applied to compare the means, at $p < 0.05$.

Table1. Super absorbent polymer (Taravat A200) characteristics

Color	Humidity (%)	Toxics	Density (g/cm^3)	pH	Water soluble	Dimension (micrometer)
White	3-5	No	1.5	6-7	No	50-150

Results and Discussion

The results showed that super absorbent application had significant effects on yield and yield components of rapeseed (Table 2). The results of the current study showed that super absorbent application under control condition and moderate stress (80 and 120 mm evaporation from class A basin, respectively) led to prominent increase of the siliques number per plant, while under severe stress (160 mm evaporation from class A pan), only the application of 75 kg ha^{-1} of super absorbent could increase this trail amount significantly (Table 3). Li *et al*. (2014) noted that the addition of SAPs promoted the formation of macro soil aggregates (particle size > 0.25 mm) and soil bacterial abundance under winter wheat cultivation. The results showed that the application of SAPs did not lead to detectable adverse effects on the soil microbial community and might even enhance soil microbial activity.

Probably in the current experiment also, A200 as a super absorbent, had positive effects upon increasing soil water availability and concomitantly improved siliques number per plant. Application of 150 kg ha^{-1} super absorbent significantly increased siliques number per plant for 'Hyola 401' cultivar, but not for 'RVS' (Table 4). There was no significant difference between cultivars with low amounts of super absorbent application, but for the higher quantity of super absorbent application the difference between cultivars was significant.

Table 2. Analysis of variance of *Brassica napus* seed characteristics

F-value						
Seed oil yield	Seed yield	1,000-seed weight	Seed per silique	Siliques per plant	D.F	S. O. V.
ns	*	ns	*	Ns	2	Replication
*	**	ns	ns	**	2	Irrigation
*	*	*	*	Ns	2	SAP
ns	ns	**	**	**	4	SAP*Irrigation
					16	Error A
ns	ns	ns	ns	Ns	1	Cultivar
ns	ns	ns	ns	*	2	Cultivar*SAP
ns	ns	ns	**	Ns	2	Cultivar*Irrigation
ns	ns	ns	ns	Ns	4	Cultivar*SAP*Irrigation
					18	Error B

^{ns}, * and **: no significant, significant at the 5% and 1% levels of probability, respectively

Table 3. Siliques number per plant, seed number per silique and 1,000-seed weight as influenced by super absorbent rate and irrigation level

1,000-seed weight (g)	Seed per silique	Siliques per plant	Treatments	
			Irrigation levels (mm)	Super absorbent (kg ha^{-1})
3.85^{cd}	25.2^{e}	130^{e}	80	
3.80^{d}	25.8^{de}	135de	120	Non-application
3.93^{bcd}	27.0^{cd}	137^{cd}	160	
3.86^{cd}	28.3^{bc}	140^{bc}	80	
3.98^{bc}	30.3^{a}	160^{a}	120	75
4.01^{b}	29.0^{ab}	150^{ab}	160	
3.97^{bc}	30.8^{a}	165^{a}	80	
4.04^{b}	30.2^{a}	180^{a}	120	150
4.32^{a}	27.0^{cde}	136^{cde}	160	

Means within a column followed by the same letters are not significantly different based on Duncan's test at 5% probability level

There was an association between siliques number per plant and seed number per silique. Water deficit during silique formation period considerably reduced siliques number/plant. On the contrast, any delay in water deficit treatment beyond silage formation stage resulted in substantial decline of seed number per siliques. Meanwhile, complementary or regular irrigation of rapeseed fields increased siliques numbers per plant due to increased leaf area during flowering period, and thus more assimilates availability for leaves and/or shoot development and therefore raised silique formation.

Several studies revealed that in rapeseed plants there is strong competition for assimilates partitioning between developing siliques and seeds (Aljaloud *et al.*, 1996; Nielson, 1997; Leilah *et al.*, 2000; Zarei *et al.*, 2010). This competition is more severe during stress conditions, leading to seed yield loss due to siliques shedding. The higher number of siliques/plant under shorter stress intervals could be attributed to higher number of flowers/plant (Zarei *et al.*, 2010). The constant stress in flowering and silique development stages caused the loss of fertility, no siliques formation and higher percent of siliques abscission to some extent (Ardestani *et al.*, 2011). McPherson *et al.* (1987) noted that water deficit stress during late season went to shedding of up to 50% of siliques.

Under control irrigation treatment any increase in super absorbent level resulted in increased silique seed content (Table 3). In 120 mm evaporation from class A basin (moderate water deficit) there was no difference between the two super absorbent application levels and the least seed number per silique belonged to control treatment (without super absorbent application). Under severe water stress conditions, application of 75 kg ha^{-1} super absorbent enhanced seed number, but no statistical difference was observed between control (without super absorbent employment) and 150 kg ha^{-1} super absorbent application.

Water availability especially during flowering and silique development period is favorable for raising siliques' seed content and consequently seed yield per unit area. Complementary, irrigation of rapeseed is favored for seed number in silique as well (Nielsen, 1996). Pazuki (1996) reported that under stress conditions, reduced flower formation, decreased number of fertile flowers, as well as increased respiration rates were the main reasons for lessened seed number in siliques.

Thousand seed weight had a positive relationship with the super absorbent levels. Furthermore, any increase in irrigation interval led to increased thousand seed weight. Interactive effects of super absorbent × irrigation levels showed that any increase in super absorbent level under severe stress condition (160 mm evaporation from class A basin) raised one thousand seed weight (Table 3).

The beneficial effects of hydrophilic polymers on plant drought tolerance are due to the supplementary water derived from the hydrophilic polymer granules that improved water availability in the drying soil (Shi *et al.*, 2010). As a consequence, the plant roots can take up water from the polymer fragments. Hence, the soil drying-induced leaf injury was consequently alleviated (Shi *et al.*, 2010). At the same time, 75 kg ha^{-1} super absorbent level combined with acute water stress produced a low number of large seeds. Pazuki (1996) noted that in rapeseed production, reduction of irrigation from 85 mm to 45 mm and/or decrease in water availability led to diminished one thousand seed weight. The scientist claimed reduced water and nutrients absorption and hence weakened photosynthesis and assimilates partitioning were the principle support for reduced thousand seed weight under water deficit condition.

Super absorbent application substantially influenced seed yield of rapeseed plants (Table 5). Seed number per silique was positively influenced by super absorbent application (Table 5). 'Hyola 401' cultivar within the 80 mm irrigation level had significant less seeds per silique than the rest of the treatments in the experiment (Table 6). Leaf stomatal conductance (Gs), transpiration rates (TRN) and net photosynthetic rates (P_n) of the plants markedly increased with super absorbent application (Shi *et al.*, 2010). The current results were consistent also with those of Arbona *et al.* (2005) and Viero and Little (2006), in which the application of hydrophilic polymers improved the growth performance of Eucalyptus (Viero and Little, 2006) and Citrus (Arbona *et al.*, 2005) under water-deficient conditions. However, no significant difference was observed between 75 and 150 kg ha^{-1} super absorbent application. In contrast, seed yield was negatively related with the increase in irrigation intervals (Table 7). In order to reach the optimum yield of rapeseed plant it is essential to restore irrigation immediately after 80 mm evaporation from class A basin.

Seed yield was strongly correlated with seed oil content and yield. Enlarged irrigation intervals led to the reduction of seed oil content and yield. Puma and Panin (1999) reported that growing season precipitation and temperatures were the appropriate indices for prediction of rapeseed yield potential. Deep root distribution and simultaneously high potential of rapeseed roots for utilization of sub-soil level water resources, as well as low dependence of this plant upon precipitation, are the main advantages of rapeseed production systems in arid regions. There is evidence that rapeseed has the potential to produce suitable yields only with soil moisture resources (Puma and Panin, 1999). The main irrigation needed stages of rapeseed production under arid regions are during seed sowing time, plantlets emergence and flowering periods. Nilsen (1996) studied the effect of draught on rapeseed and reported that water deficit during seed filling periods resulted in minimum seed yield, due to low branching potential, reduced silique number per branches and lessened seed number per siliques. Moreover, competition for water, nutrients and photosynthates between developing silique walls and maturing seeds, are another yield restrains that lead to silique abscission (McPherson *et al.*, 1987). In general, adequate water availability especially during flowering period and silique development time would be the most effective criterion towards the improvement of seed yield by increasing seed number per silique (Rao and Mendham, 1991).

Super absorbent supply enhanced seed oil yield of plants. There was no statistical difference between 75 and 150 kg ha^{-1} super absorbent application (Table 5). Oil yield decreased in response to the increase in irrigation intervals (Table 7). Morgan (1995) observed that irrigation cease during reproductive growth stage substantially reduced oil content. Furthermore, oil yield of rapeseed increasingly diminished under water deficit conditions.

There was a positive strong correlation between seed yield and seed oil content and yield, so that any decrease in seed yield under water stress conditions lead to seed oil content and yield loss and *vice versa* (Table 7). The results showed that low evaporative demands (2-4 mm) of rapeseed plants had no significant impact on seed and oil yield. Contrarily, high evaporative demands (4-5 mm) meaningfully reduced seed and oil yield. It has been reported that water deficit during silique filling period increased seed oil yield in both loam and sandy soils (Nielsen, 1996).

Table 4. Siliques number per plant as influenced by super absorbent rate and cultivar

Siliques per plant	Treatments	
	Cultivar	Super absorbent (kg ha^{-1})
140^{b}	'Hyola 401'	Control
142^{b}	'RVS'	
141^{b}	'Hyola 401'	75
140^{b}	'RVS'	
210^{a}	'Hyola 401'	150
141^{b}	'RVS'	

Means followed by the same letters are not significantly different based on Duncan's test at 5% probability level

Table 5. Number of seeds per silique, seed yield and seed oil yield by super absorbent rate

Seed oil yield (t ha^{-1})	Seed yield (t ha^{-1})	Seed number per silique	Super absorbent (kg ha^{-1})
1.30^{b}	3.31^{b}	26.5^{b}	Control
1.46^{a}	3.79^{a}	28.4^{a}	75
1.49^{a}	3.85^{a}	28.5^{a}	150

Means within a column followed by the same letters are not significantly different based on Duncan's test at 5% probability level

Table 6. Interaction effect between irrigation level (mm) and cultivars on seed number per silique

Seed number per silique	Treatments	
	Cultivar	Irrigation (mm)
23.9^{b}	'Hyola 401'	80
28.5^{a}	'RVS'	
29.8^{a}	'Hyola 401'	120
28.8^{a}	'RVS'	
29.2^{a}	'Hyola 401'	160
29.3^{a}	'RVS'	

Means followed by the same letters are not significantly different based on Duncan's test at 5% probability level

Table 7. The effect of irrigation (mm) level on seed yield and seed oil yield

Seed oil yield (t ha^{-1})	Seed yield (t ha^{-1})	Irrigation level (mm)
1.68^{a}	3.69^{a}	80
1.33^{b}	3.32^{b}	120
1.28^{b}	3.09^{b}	160

Means within a column followed by the same letters are not significantly different based on Duncan's test at 5% probability level

Conclusions

Based on the results of this study it can be concluded that super absorbent polymer application in rainfed agriculture increased the quantity and quality of yield. Soil based super absorbent application improved yield components and subsequently seed yield and oil content of rapeseed plants. Also, severe stress led to more infertile siliques due to negative effects of water deficit on seed formation, and hence reduction of seed number per silique and final yield loss. This phenomenon led to the increased partitioning of photo assimilates towards the remaining seeds and production of heavier seeds, with higher one thousand seeds' weight. Moderate to severe water deficit increased oil content, but decreased seed production and seed oil yield. This is in conformity with previous findings that water stress impacts seed yield, but it improves oil percent in consequence of increased one thousand seeds weight. There was a significant difference between the two cultivars in the study regarding studied traits. 'Hyola 401' was more susceptible to embryo abortion compared with 'RVS'. Taking into account the overall results of the present experiment, it is worthy of recommendation that similar experiments, with other cultivars, are needed, in order to optimize the rapeseed production dynamics under water deficit conditions of Northwest Iran, as a model region for other dry and semi-dry areas of the world. Additionally, it is advisable that under the geographical and edaphic conditions from Northwest Iran and similar conditions, super absorbent levels smaller than 75 kg ha^{-1} are adequate for soil amendment regarding optimum water use efficiency of rapeseed plants. However, this claim needs more detailed and comprehensive studies.

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