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The effects of planting arrangement and phosphate biofertilizer on soybean under different weed interference periods

G. R. Mohammadi[1,*], S. Chatrnour[1], S. Jalali-honarmand[1] and D. Kahrizi[1]

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ABSTRACT

This study was conducted to evaluate the effects of planting arrangement and phosphate biofertilizer on soybean yield and yield components under different weed interference periods at the Agricultural Research Farm of Razi University, Kermanshah, west Iran. The experiment was a factorial with three factors arranged in a randomized complete block design with four replications. The first factor was planting arrangement (50 and 5 cm (P1) or 25 and 10 cm (P2) for inter-row and inter-plant spacings, respectively), the second factor was phosphate biofertilizer (no-inoculation (I0) and inoculation (I1)) and the third factor was weed treatment (full season weed-free condition (W0), weedy condition until soybean 4-trifoliate stage (W1), weedy condition until soybean flowering stage (W2) and full season weedy condition (W3)). Results revealed that the highest soybean yield occurred when weeds were controlled throughout the growing season and soybean was planted at the inter-row and inter-plant spacings of 25 and 10 cm, respectively (P2) whether phosphate biofertilizer was used or not. For both planting arrangements, full season weedy condition at the lack of the biofertilizer led to the lowest soybean yield produced. Weed biomass was not significantly affected by use of biofertilizer. The highest weed biomass was established in plots without weed control throughout the whole growing season and soybean was planted in a wider row spacing and a less uniform spatial arrangement (P1). Moreover, For W2 and W3 treatments, soybean planted in a narrower row spacing and a more uniform spatial arrangement (P2) produced a notable lower weed biomass, so that, this planting arrangement reduced weed biomass by 31.8 and 31.7 % in W2 and W3, respectively as compared to the P1 planting arrangement. It can be concluded that soybean planting in a more uniform spatial arrangement via a narrower row spacing can significantly improve soybean yield and suppress weeds. Phosphate biofertilizer had no significant effect on soybean yield when soybean was planted as the P2 and weeds were controlled throughout the growing season.

Key words: *Glycine max*, phosphate biofertilizer, planting arrangement, soybean yield, weed control

IZVLEČEK

UČINKI NAČINOV SETVE IN UPORABE FOSFORJEVIH BIO-GNOJIL NA PRIDELEK SOJE OD ČASOVNO RAZLIČNIH ZATIRANJ PLEVELOV

V raziskavi, ki je bila izvedena na Agricultural Research Farm, Razi University, Kermanshah, zahodni Iran, so bili ovrednoteni učinki prostorske razporeditve rastlin (načinov setve) in uporabe fosforjevih bio-gnojil na pridelek soje in njegove komponente pri različnih zapleveljenostih. Poskus je bil zasnovan kot naključni bločni, trifaktorski poskus s štirimi ponovitvami. Prvi preučevani dejavnik je bila razporeditev rastlin v odvisnosti od načina setve, 50 in 5 cm (P1) ali 25 in 10 cm (P2), kot razdalji setve med vrstami in znotraj vrste. Drugi dejavnik je bila uporaba fosforjevih bio-gnojil (brez inokulacije (I0) in z inokulacijo (I1)) in tretji je bilo obravnavanje s pleveli (cela sezona brez plevelov (W0), zapleveljeno do stopnje razvoja, ko ima soja 4 trojnate liste (W1), zapleveljeno do začetka cvetenja soje (W2) in zapleveljeno celo rastno sezono (W3). Rezultati so pokazali, da je bil pridelek soje največji pri zatiranju plevelov skozi celo rastno sezono in ko je bila soja posejana v vrstah s 25 cm razmikom in z 10 cm razdaljo med rastlinami v vrsti (P2), ne glede na uporabo fosforjeva bio-gnojila. Zapleveljenost celo sezono in odsotnost gnojenja z bio-gnojili je dala ne glede na način setve najmanjši pridelek. Uporaba bio-gnojil ni značilno vplivala na biomaso plevelov. Največja biomasa plevelov je bila, kadar ti niso bili zatirani celo rastno sezono in, ko je bila soja posejana v vrstah s širšim razmikom, torej z manj enakomerno prostorsko razporeditvijo (P1). Pri obravnavanjih W2 in W3, ko je bila soja posejana v vrstah z manjšim razmikom in so bile rastline bolj enakomerno razporejene (P2), so imeli pleveli opazno manjšo biomaso. Takšni razporeditvi rastlin soje (W2 in W3) sta zmanjšali biomaso plevelov za 31.8 in 31.7 %, v primerjavi z raporeditvijo pri obravnavanju P1. Zaključimo lahko, da setev soje v vrstah z ožjim razmikom značilno poveča njen pridelek in zavre rast plevelov. Uporaba fosforjevih bio-gnojil ni imela značilnega vpliva na pridelek soje, kadar je bila ta posejana v vrstah z ožjim razmikom, P2, in če so bili pleveli nadzorovani celo rastno sezono.

Ključne besede: *Glycine max*, fosforjeva bio-gnijila, razporeditev rastlin, pridelek soje, nadzor plevelov

1 Dept. of Crop Production and Breeding, Faculty of Agriculture and Natural Resources, Razi University, Kermanshah, Iran

* Corresponding author: mohammadi114@yahoo.com

1 INTRODUCTION

Soybean (*Glycine max* L.) is an important two-purpose crop which is extensively grown as a source of edible oil and protein for human nutrition in Iran. In soybean, weed infestation is considered a persistent and complex constraint in many regions of the world, as it influences soybean growth and development through competition for nutrients, water and light (Vollmann et al. 2010) as well as the production of allelopathic compounds (Rice 1984; Bhowmik and Doll 1982). Weeds are a serious constraint to easy harvesting in soybean and can reduce yield and economic returns. Thus, weed control is considered a key factor for successful soybean production, and various weed management systems have been developed for that purpose (Buhler and Hartzler, 2004). Weed control in soybean can be labor intensive or involve the intensive use of herbicides in Iran. Intensive herbicide use can increase costs, pose a threat to the environment and may promote the development of herbicide resistancein weeds. The implementation of an integrated weed management (IWM) system is seen by many weed scientists as a means of achieving the goal of reducing the amount of herbicide used while still maintaining crop yield (Swanton and Weise 1991).

According to Johnson et al. (1997) there is a trend towards reducing crop row width as a means of increasing crop competition to suppress weeds. Early results in narrow-row soybean show that this method can provide adequate weed control and soybean yield (Steckel et al. 1990; Prostko and Meade 1993). Narrow rows make more efficient use of available resources and should allow quicker canopy closure and thus quicker shading of the ground thereby improving weed control (Fernandez et al. 2002). In general, crop competitive ability can also be increased by improving planting uniformity. Olsen et al (2005a; 2005b) reported that wheat produced more biomass and had less weed biomass as crop planting uniformity increased. According to Weiner et al. (2001) a more uniform planting distribution should enable crops to compete more successfully with weeds. In Iran, soybean is usually planted in a wide row spacing (50 cm). This row spacing can reduce potential crop yield and economic return due to less efficient use of available resources such as light, water and nutrients by the soybean plants and increase weed infestation.

Moreover, the competitive relationship between crop and weeds is highly dependent on many factors including the characteristics of the crop and the weeds, the environmental variables, the cultural practices (Knezevic et al. 2002) and supply and availability of nutrients (Evans et al. 2003; Di Tomaso 1995). The availability of nutrients can influence the timeliness and extent of early season competition from weeds (Weaver et al. 1992). Phosphorus is an important element which can affect the competitive interactions between a crop and weeds. It is only second to nitrogen as a mineral nutrient required for plant growth (Ogbo 2010). Most of the soils in Iran are phosphorous deficient or marginally deficient and a massive increase in the rate of application of chemical fertilizers has been adopted to ameliorate this deficiency (Cox et al. 1993). However, a large proportion of the phosphorous content of chemical fertilizers is quickly transformed to the insoluble form such as calcium phosphate, thereby making them unavailable to plants. In addition, there are global concerns that the un-balanced use of chemical fertilizers has a role in environmental degradation and climate change (Day and Quinn 1989; Daynard et al. 1971). However, nutrients applied to soils are also available for weeds and these un-wanted plants are better able to utilize added nutrients than crops (Carlson and Hill 1986; Peterson and Nalewja 1992). Therefore, in an attempt to reduce environmental risk and cost with chemical fertilizer use and increase crop nutrient use efficiency, phosphorous biofertilizers (phosphate-solubilizing microorganisms) has been considered as possible substitutes for traditional mineral P fertilizer. These microorganisms have been distinguished by their relative ability to dissolve calcium phosphate and apatite in association with plant roots. This activity was attributed to organic acid and chelating metabolites produced by these microorganisms (Deinum et al. 1996; Dong and Pierdominici 1995). However, phosphate biofertilizer have shown variation in their performance in related to their environmental condition.

This study was carried out to investigate the effects of phosphorus biofertilizer and planting arrangement on soybean under different weed pressure treatments in Kermanshah, west Iran.

2 MATERIALS AND METHODS

The study was carried out in 2009 at the Agricultural Research Farm of Razi University, Kermanshah, west Iran. The soil type was a silty clay with a pH of 7.8 and 0.8 % organic matter. The land was plowed and disked before planting. The soybean cultivar was 'Williams' (a cultivar that is commonly planted in the region). All soybean seeds were inoculated with *Bradyrhizobium japonicum* Kirchner bacterium prior to sowing. The crop was planted on 9 May 2009 at a constant density of 40 plants m^{-2}. Soybean is a summer and irrigated crop in western Iran; therefore, it is not dependent on seasonal rainfall. Irrigations were carried out at 7-9 day intervals throughout the growing season in term of crop need.

The experiment was a factorial with three factors arranged in a randomized complete block design with four replications. The first factor was planting arrangement (50 and 5 cm (P1) or 25 and 10 cm (P2) for inter-row and inter-plant spacings, respectively), the second factor was phosphate biofertilizer (no-inoculation (I0) and inoculation (I1)) and the third factor was weed treatment (full season weed-free condition (W0), weedy condition until soybean 4-trifoliate stage (W1), weedy condition until soybean flowering stage (W2) and full season weedy condition (W3)). Each plot consisted of six soybean rows of 8 m long with predetermined inter-row and inter-plant spacings. Before planting, the seeds were also inoculated with phosphate biofertilizer (Barvar 2) containing the phosphate solubilizing microorganisms *Pantoea agglomerans* Eving and Fife and *Pseudomonas putida* Trevisan. Weed removal was carried out by hand.

At maturity, soybean plants located at 4 m^2 from each plot were harvested by hand and allowed to dry to a constant mass and weighed and biological yield (total aboveground dry mass) was determined. Subsequently, they were threshed and cleaned and seed yield was calculated. Then harvest index (HI) was calculated according to the following equation:

$$HI = (\text{Seed yield} / \text{Biological yield}) \times 100$$

Additionally, 100-seed weight were determined according to the recommendations of the International Seed Testing Association (ISTA) (Draper, 1985). Before harvesting, the number of pods per plant and the number of seeds per pod were measured on 5 randomly selected plants in the centre rows of each plot, except from the rows that were used for yield measurement. Weed biomass was also measured by harvesting weeds at the ground level in three random 0.5×0.5 m quadrats in each plot at the end of the growing season for the W3 treatment and before each weed removal for the W1 and W2 treatments. Then weeds dried at 75° C to constant mass and weighed. Data analyses were carried out using SAS (SAS Institute 2003).

3 RESULTS AND DISCUSSION

Analysis of variance (Table 1) revealed that all of the traits under study including soybean seed yield (SY), the number of pods per plant (PPP), the number of seeds per pod (SPP), 100-seed weight (SW), harvest index (HI) and weed biomass (WB) were significantly affected by weed treatments (at the 0.01 level of probability). There was a significant three-way interaction (weed treatment×planting arrangement×phosphate biofertilizer) for SY, PPP and SPP. The significant two-way interactions including weed treatment×planting arrangement, weed treatment× phosphate biofertilizer and planting arrangement×phosphate biofertilizer were observed for HI. However, SW was significantly affected by the two-way interactions including weed treatment×planting arrangement, weed treatment×phosphate biofertilizer. However, WB was influenced by a two-way interaction (weed treatment×planting arrangement) and phosphate biofertilizer alone or in combination with other factors had no significant effect on this trait.

Table 1: Analysis of variance of the traits under study

Source of Variance	Mean Square					
	Seed yield	Pod/plant	Seed/pod	100-seed weight	Harvest index	Weed biomass
Replication	309.03 ns	7.80 ns	0.04 ns	0.33 ns	1.24 ns	672420.05 ns
Weed Interference (WI)	94876.00 **	6854.90 **	0.19 **	1.80 **	314.09 **	2231939.50 **
Phosphate Biofertilizer (PB)	1407.20 *	172.50 **	0.01 ns	0.94 *	285.30 **	150.60 ns
Planting Arrangement (PA)	5682.70 **	3719.40 **	0.03 ns	1.02 *	3.77 ns	3226900.00 **
WI×PB	2124.90 **	752.40 **	0.09 **	0.91 *	42.80 **	236226.10 ns
WI×PA	113.50 ns	658.60 **	0.06 **	1.09 **	57.30 **	926873.05 *
PB×PA	989.40 ns	516.90 **	0.08 **	0.02 ns	147.80 **	74342.09 ns
WI×PB×PA	3973.90 **	204.12 **	0.06 **	0.57 ns	25.15 ns	53670.50 ns
Error	335.60	17.23	0.01	0.23	9.32	257976.06

ns, * and **: Non significant and significant at the 0.05 and 0.01 level of probability, respectively

The highest SY was obtained when weeds were controlled for all of the growing season (W0) and soybean was planted at the inter-row and inter-plant spacings of 25 and 10 cm, respectively (P2) whether phosphate biofertilizer was used or not (Table 2). For both planting arrangements, full season weedy condition (W3) and at the lack of the biofertilizer (I0) led to the lowest SY (Table 2). It seems that in weed free condition and a more uniform planting arrangement soybean yield is not significantly affected by phosphate biofertilizer due to a lower competition for this essential element. However, in the presence of weeds, phosphate biofertilizer could reduce the harmful effects of these unwanted plants. In general, soybean seed yield decreased when the weed interference period increased. Although, in most cases, the reductions were lower when soybean was planted as the P2 planting arrangement when compared with the P1 planting arrangement (Table 2). Row spacing and spatial uniformity can play important roles to manage weeds in cropping systems. Mohammadi et al. (2012) reported that corn yield was improved and weed biomass was decreased in response to decreasing row spacing. Moreover a more uniform crop spatial (as seen at the P2 planting arrangement) decreases competition within the crop population early in the growing season (Olsen and Weiner 2007) and maximizes the total shade cast by the crop by reducing self shading (Weiner et al. 2001). According to Kristensen et al. (2008) in the presence of weeds the highest yields were obtained with high spatial uniformity.

The highest PPP was occurred in the plots in which weeds were removed throughout the growing season, phosphate biofertilizer was applied and soybean was planted as the P2 planting arrangement (Table 2). This can be attributed to the lack of weed harmful effects on the crop, more crop spatial uniformity and consequently a lower competition among the soybean plants. Moreover, many researchers have reported an improve in growth and P-uptake by crops through the inoculation of phosphate solubilizing microorganisms in pot experiments (Vassilev et al. 2006; Omar 1998) and under field conditions (Valverde et al. 2006; Duponnois et al. 2005; De Freitas et al. 1997). In a study, Mittal et al. (2008) observed two-fold increase in seed number of chickpea due to the use of phosphate solubilizing microorganisms.

Table 2: Soybean plant traits as influenced by weed treatment, planting arrangement and phosphate biofertilizer

Weed treatment	Planting arrangement	Phosphate biofertilizer	Soybean plant traits		
			Seed yield (g m^{-2})	Pods/plant	Seeds/pod
W0	P1	I0	305.6 b	86.6 c	2.1 ef
		I1	319.3 b	66.3 d	2.3 cde
	P2	I0	323.3 ab	101.7 b	2.3 cde
		I1	346.9 a	117.1 a	2.4 abc
W1	P1	I0	189.5 ef	55.3 fg	2.5 ab
		I1	206.9 de	63.5 de	2.4 abc
	P2	I0	239.3 c	68.8 d	2.5 ab
		I1	200.1 de	82.5 c	2.1 ef
W2	P1	I0	161.3 gh	56.2 fg	2.1 ef
		I1	191.9 ef	43.2 i	2.2 def
	P2	I0	220.1 cd	63.0 de	2.4 abc
		I1	173.7 fg	52.4 gh	2.2 def
W3	P1	I0	134.3 ij	49.2 h	2.1 ef
		I1	141.6 hi	38.4 ij	2.1 ef
	P2	I0	114.9 j	36.7 j	2.1 ef
		I1	182.9 efg	58.5 ef	2.2 def
LSD (0.05)			26.1	5.9	0.2

Dissimilar letters at each column indicate the significant difference at the 0.05 level of probability (LSD test).
Abbreviations: W0, W1, W2 and W3: full season weed free condition, weedy condition until soybean 4-trifoliate stage, weedy condition until soybean flowering stage and full season weedy condition, respectively. P1: soybean planted at the inter-row and inter-plant spacings of 50 and 5 cm, respectively; P2: soybean planted at the inter-row and inter-plant spacings of 25 and 10 cm, respectively. I0 and I1: no inoculation and inoculation with phosphate biofertilizer, respectively.

The number of seeds per pod didn't show an obvious response to the treatments under study, although, in most cases, full season weedy condition and weedy condition until soybean flowering stage led to the lowest values of this trait (Table 2). Weed interference until 4-trifoliate stage didn't significantly influence 100-seed weight when compared with full season weed free condition, although, the longer weed interference reduced this yield component, notably (Fig. 1). However, for all of the weed treatments, the use of phosphate biofertilizer didn't significantly affect soybean 100-seed weight (Fig. 1). Moreover, for all weed treatments, 100-seed weight was higher when soybean was planted as the P2 planting arrangement (Fig. 2). Although, the positive effect of this planting arrangement on soybean seed mass was more obvious in the plots in which weeds were controlled throughout the growing season (Fig. 2).

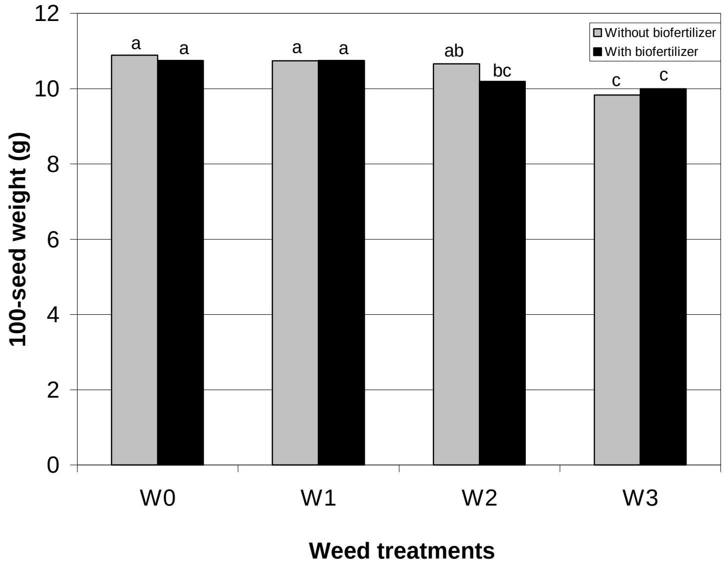

Figure 1: The effect of phosphate biofertilizer on soybean 100-seed weight under different weed treatments. Abbreviations: W0, W1, W2 and W3: full season weed free condition, weedy condition until soybean 4-trifoliate stage, weedy condition until soybean flowering stage and full season weedy condition, respectively.

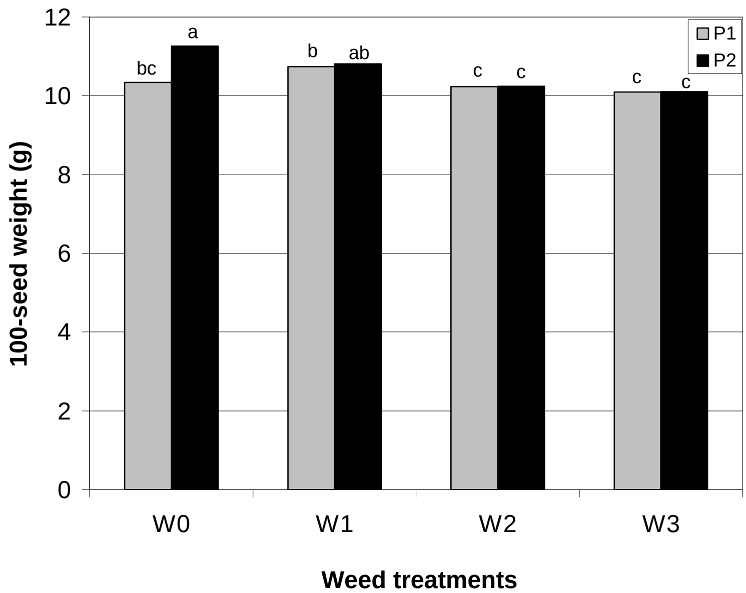

Figure 2: Soybean 100-seed weight as influenced by different planting arrangements and weed treatments. Abbreviations: W0, W1, W2 and W3: full season weed free condition, weedy condition until soybean 4-trifoliate stage, weedy condition until soybean flowering stage and full season weedy condition, respectively. P1: soybean planted at the inter-row and inter-plant spacings of 50 and 5 cm, respectively; P2: soybean planted at the inter-row and inter-plant spacings of 25 and 10 cm, respectively.

Harvest index was significantly influenced by phosphate biofertilizer×planting arrangement interaction (Table 1). The highest HI was observed in the more uniform spatial arrangement (P2) and when phosphate biofertilizer was applied (Fig. 3). Moreover, weed free condition for the entire growing season led to the highest HI when soybean was planted as the P2 planting arrangement (Fig. 4). Harvest index is the fraction of the total crop biomass allocated to the economic yield (Williams et al. 1989; Sto¨ckle et al. 1994) and a higher HI indicates a more crop efficiency to allocate the produced biomass to the seeds. It seems that, the lower inter- and intra-specific competitions and higher phosphorus available for the crop can significantly increase the biomass allocated to soybean generative organs and consequently improve HI.

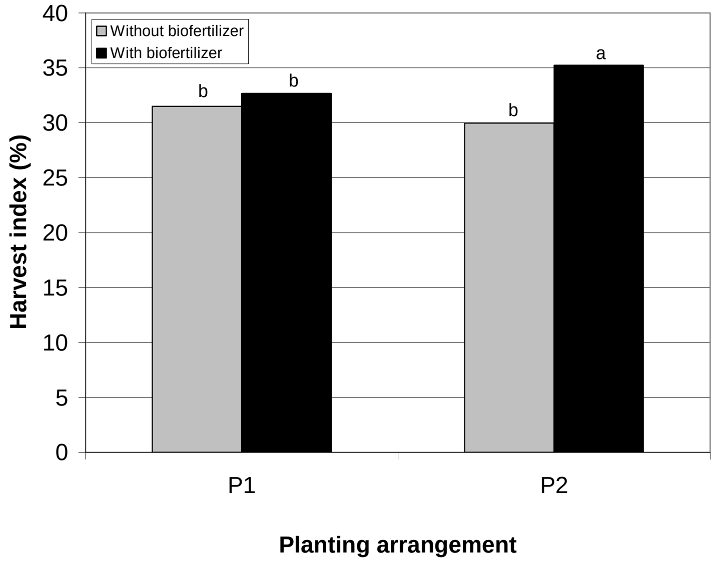

Figure 3: The effect of phosphate biofertilizer on soybean harvest index under different planting arrangement. Abbreviations: P1: soybean planted at the inter-row and inter-plant spacings of 50 and 5 cm, respectively; P2: soybean planted at the inter-row and inter-plant spacings of 25 and 10 cm, respectively.

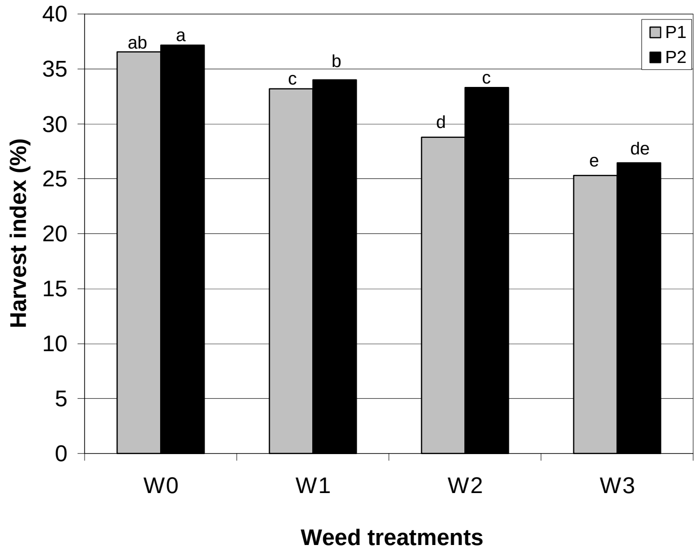

Figure 4: Soybean harvest index as influenced by different planting arrangements and weed treatments. Abbreviations: W0, W1, W2 and W3: full season weed free condition, weedy condition until soybean 4-trifoliate stage, weedy condition until soybean flowering stage and full season weedy condition, respectively. P1: soybean planted at the inter-row and inter-plant spacings of 50 and 5 cm, respectively; P2: soybean planted at the inter-row and inter-plant spacings of 25 and 10 cm, respectively.

Weed biomass was also significantly affected by weed treatment×planting arrangement interaction (Table 1). The highest weed biomass was produced when weeds were not controlled throughout the growing season and soybean was planted in wider row spacing and a less uniform spatial arrangement (P1) (Fig. 5). For W2 and W3 treatments, soybean planted in a narrower row spacing and a more uniform spatial arrangement (P2) produced a notable lower weed biomass, so that, this planting arrangement reduced weed biomass by 31.8 and 31.7 % in W2 and W3, respectively as compared to the P1 planting arrangement. However, in W1 treatment there was no significant difference between the two planting arrangements in term of weed biomass (Fig. 5) indicating the important weed suppressing effect of a more uniform planting arrangement in the higher weed pressure conditions. In general, crop canopy expansion and soil cover vary with planting arrangement (Ottman and Welch 1989; Tetio-Kagho and Gardner 1988). According to Fernandez et al. (2002) radiation interception and use efficiencies as well as nitrogen use efficiency of crop were positively related to the increased planting uniformity and for maximum weed suppression, crop should be planted in a square or triangular lattice arrangement. In another study, Mohammadi et al. (2012) found that both crop yield and weed control can be improved by increasing the planting spatial uniformity in a corn cropping system.

There was a negative and significant correlation between soybean yield and weed biomass produced (r = -0.76). It can be concluded that increasing soybean yield in the P2 plots is mainly due to a higher weed suppressive effect of this planting arrangement. However, a lower intra-specific competition can also play an important role. Kristensen et al. (2008) reported that in the presence of weeds the highest yields were obtained with high crop density and high spatial uniformity.

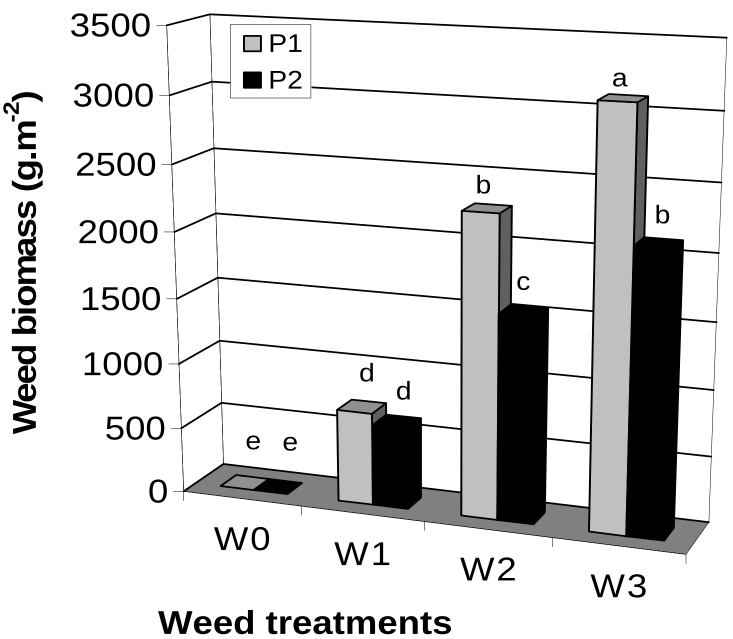

Figure 5: Weed biomass as influenced by different planting arrangements and weed treatments.
Abbreviations: W0, W1, W2 and W3: full season weed free condition, weedy condition until soybean 4-trifoliate stage, weedy condition until soybean flowering stage and full season weedy condition, respectively. P1: soybean planted at the inter-row and inter-plant spacings of 50 and 5 cm, respectively; P2: soybean planted at the inter-row and inter-plant spacings of 25 and 10 cm, respectively.

4 CONCLUSION

This study revealed that soybean planting in a more uniform spatial arrangement via a narrower row spacing can significantly improve soybean yield and reduce weed growth especially in a higher weed pressure condition. Phosphate biofertilizer had no positive effect on soybean yield when soybean was planted in a more uniform spatial arrangement (P2) and weeds were controlled for the entire growing season. However, in the presence of weeds and a decreased planting uniformity (P1), the biofertilizer could significantly improve soybean yield indicating a P-limitation in this condition probably due to the higher intra- and inter-specific competitions for this essential element.

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