RESEARCH ARTICLE

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Evaluation of radiation use efficiency of common bean (*Phaseolus vulgaris* L.) cultivars as affected by plant density under Mashhad climatic conditions

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ABSTRACT
In order to determine the effect of different plant densities in bean cultivars, an experiment was conducted as factorial layout based on a randomized complete block design with three replications at Agricultural Research Station, Ferdowsi University of Mashhad, during growing season the 2014-2015. Factors included four bean cultivars (such as Akhtar, D-81083Line, Naz and Goli), and three plant densities (including 13.3, 20 and 40 plants.m-2). Study has addressed some indicators including leaf area index (LAI), amount of absorbed radiation, dry matter accumulation and radiation use efficiency (RUE) in bean cultivars at different plant densities. The trend of increasing dry matter accumulation in all cultivars entered to the linear growth phase on the 20th day after planting and reached to its maximum on the 70th day after planting. The highest dry matter was obtained in Goli (300.4 g.m-2) and Naz (285.1 g.m-2) cultivars which was 32 and 30% higher compared to Akhtar and 30 and 28% higher compared to D-81083Line cultivar, respectively. The highest radiation use efficiency (2.2 g.MJ-1) was obtained in treatment at density of 40 plants.m-2 and was in Goli (2.01 g.MJ-1) and Naz (1.98 g.MJ-1) cultivars. With increasing plant density, maximum leaf area index in bean cultivars increased gradually to its highest level (40 plants.m-2) and due to plants ghosting, continued to decrease. This result can be used for modeling of leaf area. With increasing plant density due to increasing of leaf area index, the amount of absorbed radiation increased and therefore the time to reach maximum dry matter accumulation decreased and dry matter accumulation increased.

Key words: Bean *(Phaseolus vulgaris L.*), plant density, radiation use efficiency

Introduction

The common bean (Phaseolus vulgaris L.) is one of the most important food legumes, consumed worldwide as pods of green beans or seeds of dry beans. The common beans are rich and inexpensive sources of proteins, carbohydrates, dietary fibers, minerals and vitamins to millions of peoples in developed and developing countries (Majnoun Hosseini, 2008). According to the recent FAO statistics, the common bean has the highest production after pea in Iran (FAO, 2013). There are different methods available to estimate crops yield and one of these method is calculation of dry matter based on photosynthetic radiation use efficiency and restraining daylight in dry matter production (Rosati et al., 2004). Radiation is one of the most important climate factors that directly and indirectly affect all plant life functions. Optimum density has occurred when the plant reaches to its maximum leaf area index at the beginning of reproductive stage (Ahmad et al., 2008). Optimum plant density can influence the amount of radiation received by leaves and may delay aging of leaves (Ahmad et al., 2008). The number of leave per plant is a genetic factor and fixed, so with increasing density of leaves per unit area, leaf area index increases as well (Gonzalo et al., 2006). With increasing plant density, the amount of light absorbed in the upper layers of canopy increases (Khan et al., 2010). In high density, wheat tillers reduced light penetration into the canopy (Green et al., 2003). According to Ghadaksaz et al., (2011) investigation on plant density, it has been demonstrated that in different density of bean (45, 55 and 65 plants.m-2), the plant will be reached to the highest, leaf area index in higher density compared to the lower density. Regarding the importance of legume family for its high protein content and high economic yield (Blaise et al., 2005) this research was conducted to study the effect of plant density in common bean varieties in terms of light absorption, light extinction coefficient and radiation use efficiency (RUE) under Mashhad climatic conditions.

Materials and Methods

This study was conducted at Agricultural Research Station, Ferdowsi University of Mashhad, (Iran), located 10 km south east of Mashhad (Longitude: E59° 15' and 60° 36', Latitude:N 35° 43' and 37° 8'and 985 m above sea level) during 2014 and 2015. Prior to field experiment, soil samples were collected randomly from different fallow field, and analyzed. For land preparation, the site was cleared of large debris and disked well and drainage canals prepared. The experimental design was factorial layout based on a randomized complete block design with 24 treatments and four replications. In this experiment factors were four bean varieties with different growth style including, Akhtar (determinate and upright), D-81083Line (determinate and upright) Naz (indeterminate and prostrate) and Goli (indeterminate and prostrate) with three plant density (13.13, 20 and 40 plants.m^{-2}). At planting time, density was considered high and after well establishment (4-6 leaf) optimum density was done. In each plot four rows with 50 cm spacing were prepared. Plots were 2×5 m. Seed planting was done with high density (50 plants.m-2) in May. At 4-6 leaf, Crop management followed the standard cultural practices. To determine leaf area index (LAI) and dry matter (DM), destructive samplings were done 45 days after planting time. This sampling was done each twenty days for six times and recorded for four plants. Leaf area was measured by Delta-T system (Bio-Science). For measurement of leaf dry weight, leaves were removed from the stems and placed in paper bags and dried in an oven at 75º C for 48 hours and weighted (0.01 g accuracy).

Estimates of leaf area index (LAI) were based on followed equation (Yin et al., 2003):

$$LAI = \frac{a+b\times4\times\left(exp\left(-\frac{x-c}{d}\right)\right)}{\left(1+exp\left(-\frac{x-c}{d}\right)\right)^2} \qquad (1)$$

a: With of origin, b: Maximum leaf area index, c: Time to reach maximum leaf area index, x: The number of days after planting

Based on the number of sunny hours that was obtained from weather station of Mashhad, amount of radiation reached to top of the canopy were calculated through Goudriaan & Van Laar (1994) method. Light extinction coefficient (K) can be measured through below equation (Ghosh et al., 2004).

$$K = min(1.43 \times LAI^{-0.5}) \qquad (2)$$

The amount of light absorbed daily was obtained according to following equitation (Nassiri Mahallati, 2000):

$$Ia = IO(1-p) \times \left(1 - exp(-k \times LAI)\right) \qquad (3)$$

Ia: Light absorbed by the plant community (MJ.m^2), I0: Light reached top of the canopy (MJ.m^2), P: Reflection coefficient for bean (0.08) (Alizade et al., 2013), k: Light extinction coefficient for bean (0.6) (Alizade et al., 2013).

LAI: Leaf area index

Finally, the radiation use efficiency was obtained through calculation of linear regression slop between dry matters and accumulative radiation (Nassiri Mahallati, 2000).The collected data were analysed using SAS 9.1 software. Mean comparison was done by multiple Duncan's test, Significant F-values were tested at the p≤0.05 significance level. All charts and graphs were plotted by Slide write software.

Results

Leaf area index (LAI)

Effects of different plant density (A), and cultivars (B) on

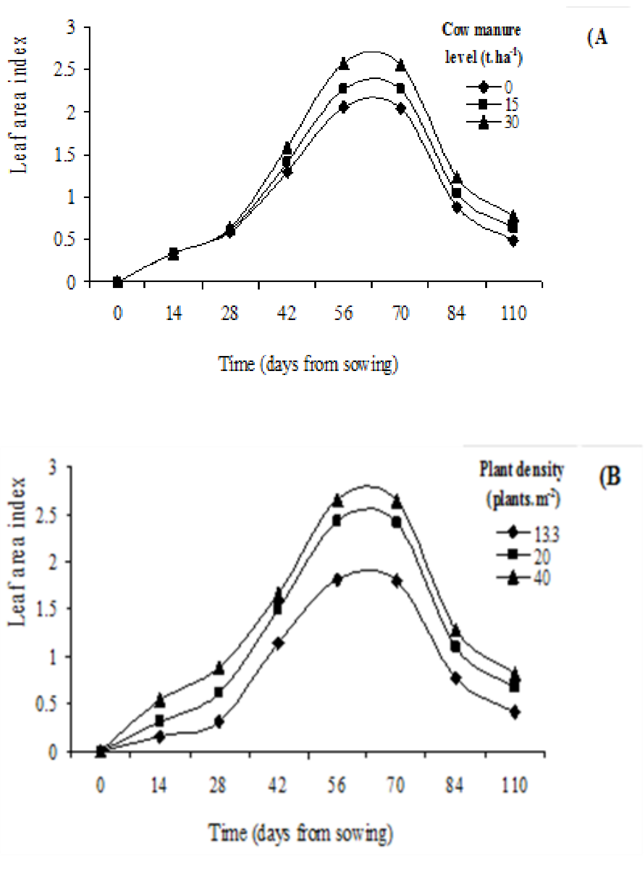

Figure 1. *Effect of different plant density (A) and cultivars (B) on leaf area index in bean.*

leaf area index of bean are shown in (Figure 1).

In general, the development of leaf area and dry matter accumulation in most legumes is usually slow for a long period after planting. Therefore, the major part of radiation in legumes fields waste at the beginning of season due to the poor vegetation cover and low density and may be associated with lower legumes yield compared to other plants (Parsa & Bagheri, 2008). The trend of leaf area index during growing season was the same in different plant density, as it was slow and gradual at the beginning of growth season and increased constantly with more leave production in all treatments at 28 days after planting and reached to maximum leaf area index (56 days after planting time) after full-flowering at beginning of physiological maturity (Figure 1). The highest leaf area index (2.65) was observed at plant density of 40 plants.m^{-2} and the lowest (1.82) was obtained at 13.13 plants.m^{-2}. It seems that density of 40 bean plants.m-2 because of more desirable vegetation cover, enough light interception into the canopy (Moaveni et al., 2011), less competition for nutrients, and availability of water can increase leaf area index. There has been an increase in the value of leaf area index in all bean cultivars at the beginning of growth season and continued up to 70 days after planting and after that decreased gradually (Figure 1). Goli cultivar with highest leaf area index (2.61) showed more photosynthesis rate that associated with higher dry matter and grain yield. Growth indices are under competition indirectly, as competition can affect leaf area and dry matter (Asghari et al., 2006).

The trend of dry matter accumulation (DM)

Trends of dry matter accumulation indicated that the highest dry matter under different plant density were obtained in plants with greater leaf area index which caused higher potential of dry matter accumulation (Figure 2, 3 and 4). At the beginning of growth season, amount and rate of dry matter accumulation was partially low, while with increasing leaf area index (Figure 1), the photosynthesis in plant community increased and the slope of dry matter accumulation curve went up strongly. After constant rate dry matter accumulation due to leaf senescence and aging, remobilization of stored carbohydrates, increasing plant respiration and non-photosynthetic tissues, the slope of curve decreased and then remained stable (Hegazy et al., 2005). Dry matter of bean increased with increasing plant density. With decreasing plant density from 40 to 13.13 plants.m^{-2}, total dry matter up to 24% decreased compared to control (Figure 3). The highest dry matter accumulation (293.43 g.m^{2}) was obtained in 40 plants.m^{-2} (Figure 3). It seems that increasing plant density due to higher number of plants per unit area caused maximum light interception followed by increasing photosynthesis rate. Rabie & Jelani (2015) observed that with increasing row spacing and plants spacing in the row resulted decreasing plant density, seed and biological yield of common bean significantly decreased.

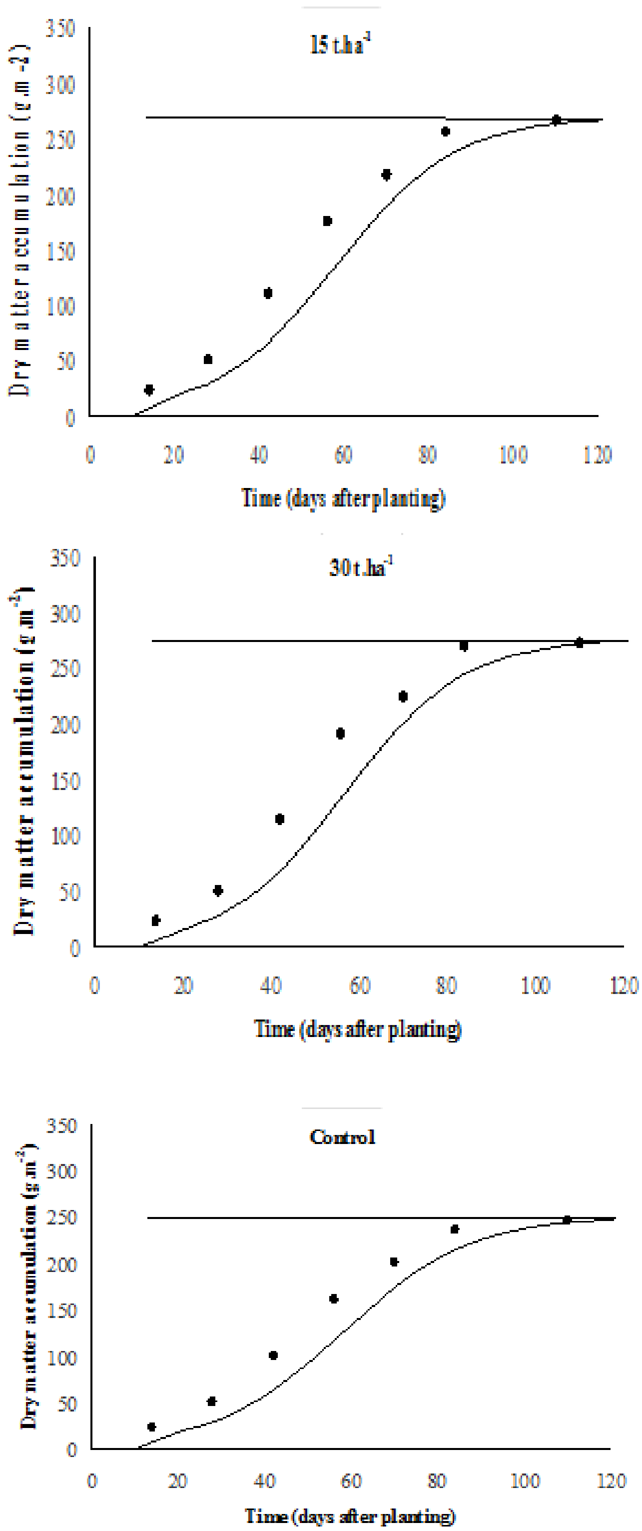

Figure 2. *Effect of cow manure levels on dry matter accumulation in bean.*

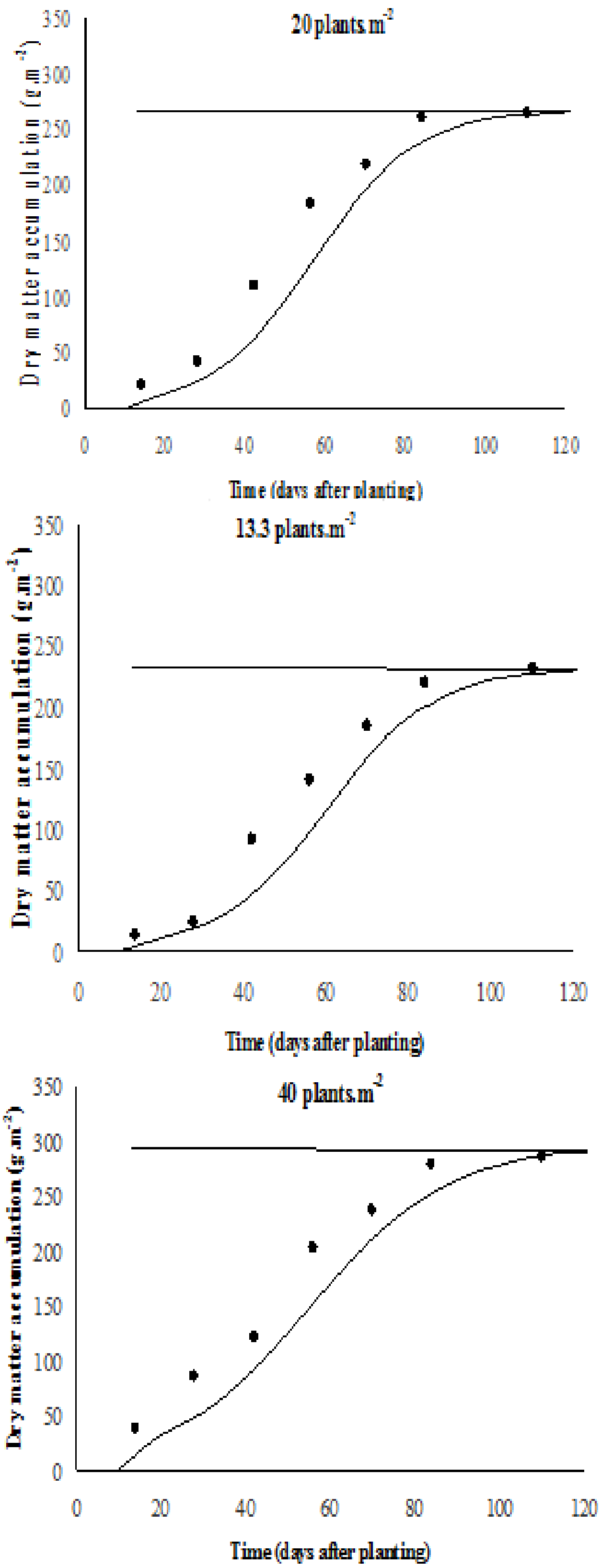

Figure 3. *Effect of plant densities on dry matter accumulation in bean.*

The total dry matter accumulation in Goli and Naz cultivars (Indeterminate Prostrate) (with 300.4 and 285.1 $g.m^{-2}$, respectively) was 32% and 30% higher compared to Akhtar cultivar and 30% and 28% higher compared to D-81083Line (determinate Upright), respectively. (Moeini et al., 2009) in a study on plant spacing in bean demonstrated that prostrate cultivars have higher seed yield compared to upright and semi-upright cultivars.

Discussion

Radiation absorption and radiation use efficiency, with increasing leaf area index (Figure 2) the light absorption by bean canopy increased gradually (Figure 5) and reached to maximum radiation absorption, after a while because of reducing leaf area, light absorption decreased constantly. The time to reach maximum leaf area index in bean plants was compatible with maximum radiation absorbed by canopy under Mashhad climatic conditions which is very important in terms of crop management and plant density (Scott & Jaggard, 2000). Differences between cultivars in radiation use efficiency (RUE) arise from either differences in partitioning between root and shoot or differences in light interception (Board, 2000). The amount of radiation absorption affected by plant density, as the highest light absorption (86%) was recorded in density of 40 $plants.m^{-2}$ and the lowest (49%) was obtained at 13.3 $plants.m^{-2}$ (Figure 5). The trend of RUE changes in bean under different plant densities under Mashhad weather conditions has been shown in (Figure 6). Plant density had a significant effect on RUE of bean ($p \leq 0.01$). The differences between RUE in different plant densities contributed to amount of cumulative radiation in each treatment. The RUE was calculated 1.75, 1.95 and 2.20 $g.MJ^{-1}$ for 13.13, 20 and 40 $plants.m^{-2}$, respectively (Figure 6). It seems that increasing plant density because of increasing plants number and leaf area index can decrease non intercepted light and increase radiation use efficiency, as the highest RUE was obtained at density of 40 $plants.m^{-2}$ (Figure 7). There are significant differences between cultivars in terms of RUE. The radiation use efficiency was computed with 2.01 and 1.98 $g.MJ^{-1}$ in Goli and Naz cultivars, respectively, while the RUE was obtained 1.67 and 1.50 $g.MJ^{-1}$ in Akhtar and D-81083Line cultivars, respectively. This result showed that Goli cultivar was more efficient (17 and 14%) compared to Akhtar and D-81083Line, respectively in conversion of solar energy to dry matter. Also, Naz cultivar was more efficient (16 and 24%) compared to Akhtar and D-81083Line, respectively that this difference related to structural and genetic characteristics (Cheema et al., 2010).

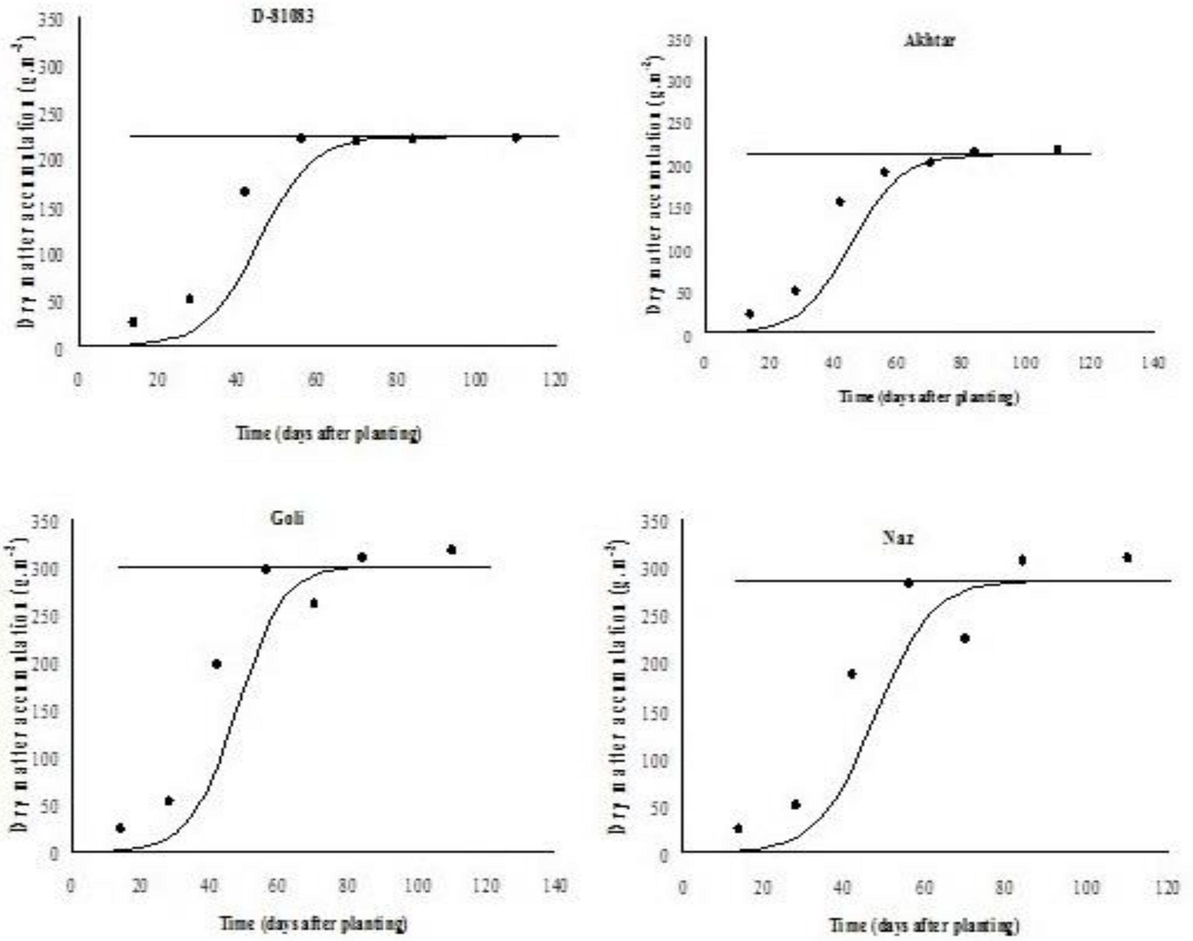

Figure 4. *Effect of cultivars on dry matter accumulation of bean.*

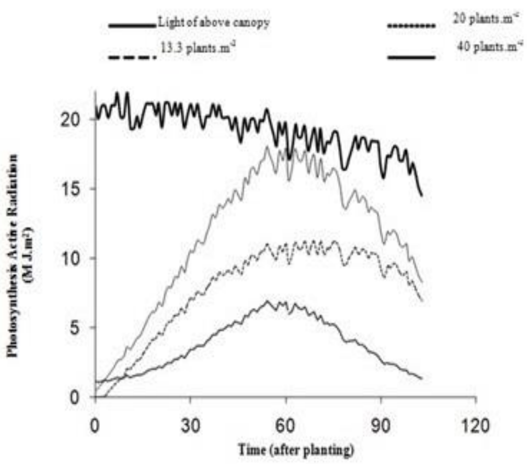

Figure 5. *Effect of different plant densities on light interception on top of the canopy and light absorption in the canopy of bean during days after planting.*

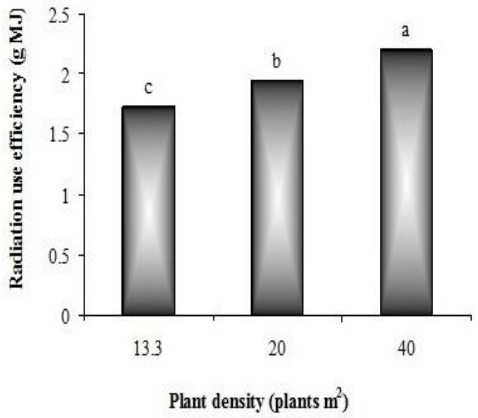

Figure 6. *Effect of different plant densities on radiation use efficiency (RUE) under Mashhad climatic conditions*

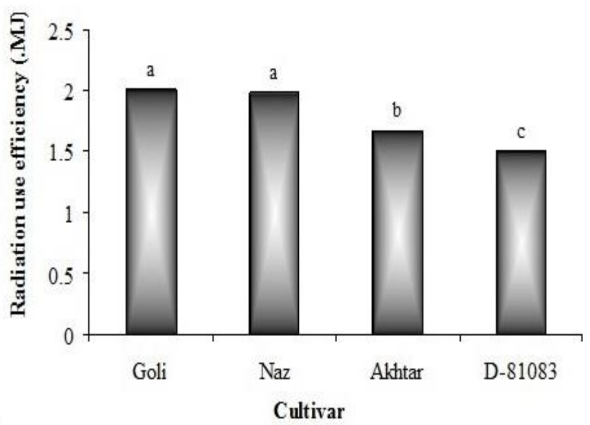

Figure 7. *The effect of different bean cultivars on radiation use efficiency (RUE) under Mashhad climatic conditions*

Conclusion

With increasing plant density, maximum leaf area index in bean cultivars increased gradually to its highest level (40 plants.m^{-2}) and due to plants ghosting, continued to decrease. This result can be used for modelling of leaf area. With increasing plant density due to increasing of leaf area index, the amount of absorbed radiation increased and therefore the time to reach to maximum dry matter accumulation decreased and dry matter accumulation increased. Different plant densities had significant effects on radiation use efficiency (RUE), as in this study RUE range was obtained from 1.5 to 2.2 g.MJ^{-1} under Mashhad weather conditions. As a result, with appropriate management of agricultural inputs such as plant density and understanding the characteristics of different plant varieties like bean may be helpful to achieve maximum yield.

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