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Evaluation radiation use efficiency and growth indicators on two mung bean (*Vigna radiata* L.) genotypes under the influence of biological fertilizers.

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ABSTRACT

Leaf area index (LAI) and radiation use efficiency (RUE) are important eco-physiological characteristics for the realization of crop growth, development, and radiation absorption. A factorial field experiment was carried out base on a randomized complete block design with three replications. Two mung bean genotypes (Dezfouli and Indian) were planted under six fertilization treatments during 2017 and 2018. Six fertilization treatments include: (1) free-living nitrogen fixating bacteria (NFB), (2) phosphorus solubilizing bacteria (PSB), (3) potassium solubilizing bacteria (KSB), (4) free-living nitrogen fixating bacteria + phosphorus solubilizing bacteria + potassium solubilizing bacteria (NFB + PSB + KSB), (5) nitrogen fertilizer (source of urea 46%), and (6) Control (without biological and chemical fertilizers). The maximum LAI was recorded in NFB + PSB + KSB treatment in Dezfouli genotype that compared with controls, increased by 37% and 42%, respectively, in 2017 and 2018. The maximum absorbed radiation at NFB + PSB + KSB treatment increased by 20% and 12% when compared with the control in 2017 and 2018. Also, maximum radiation was proportional to the time of maximum LAI. During 2017 and 2018, the highest RUE (1.21 and 1.03 g MJ^{-1} m^{-2}, respectively) obtained from Indian genotype in the NFB + PSB + KSB application. The greatest effects of plant growth-promoting rhizobacteria (PGPR) was observed in the NFB + PSB + KSB treatment compared to other treatments. The PGPR could promote mung bean biomass via increasing of LAI and RUE.

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KEYWORDS
free-living nitrogen fixating; leaf area index; phosphorus solubilizing bacteria; potassium solubilizing bacteria

Introduction

Mung bean (*Vigna radiata* L.) is generally known as green gram (Ram and Meena, 2015). Pulses are expected to be an essential component of improving and diversifying farming systems and diets worldwide (Ebert et al., 2017). Legumes have relatively high protein contents and contribute crucial vitamins, micronutrients, and protein to the food (Choudhary et al., 2017).

Quantification of crop growth and its drivers has long been a subject of investigation because of their critical importance for many applications, including crop growth, biomass, and response to environmental factors (Kukal and Irmak, 2020). A simple framework extensively used to evaluate biomass about the available photosynthetically active radiation (PAR) (Bonelli and Andrade,

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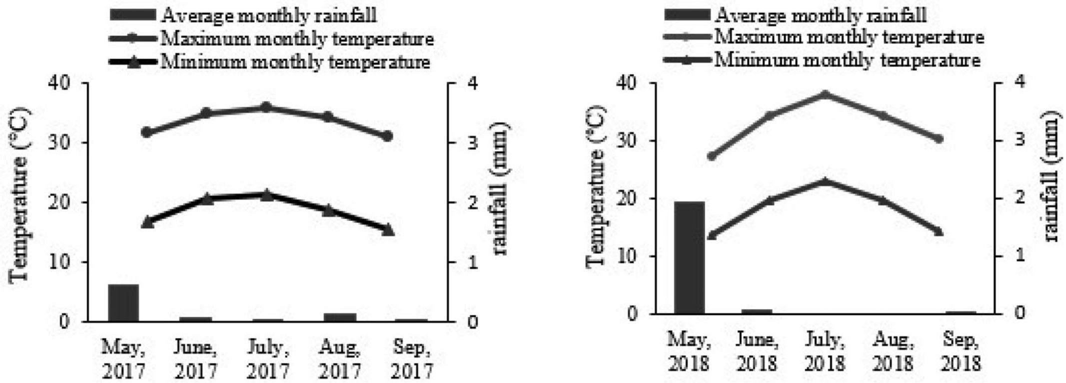

Figure 1. Monthly rainfall and average temperature during the growing season 2017 and 2018 of mung bean (at the experimental station, Faculty of Agriculture, Ferdowsi University of Mashhad, Iran).

2020). This framework proposes that biomass depends upon the (i) amount of incident photosynthetically active radiation (IPAR) during the crop season (i.e., from emergence to physiological maturity), (ii) amount of IPAR the crop absorbed (PARa) (iii) amount of PARa the crop converted into biomass (Rattalino Edreira et al., 2020). The ratio between biomass produced and light energy fixed by plants is called radiation use efficiency (RUE) (g MJ^{-1}) (Zhang et al., 2008). Accurate estimates of RUE and other interactions, are imperative to indicate growth, productivity, and other physiological processes in any vegetative level (Kukal and Irmak, 2020). RUE influenced by radiation regime (diffuse or direct), temperature, photosynthetic pathway, and leaf nitrogen and chlorophyll contents and environmental and management practices (Akmal and Janssens, 2004; Rosati et al., 2004).

A group of bacteria now referred plant growth-promoting rhizobacteria (PGPR), which release phytohormones, such as *Azospirillum, Azotobacter*, *Thiobacillus*, *Pseudomonas, Rhizobium* (Ruzzi and Aroca, 2015), which can affect plant growth directly or indirectly (Çakmakçi et al., 2006). A wide array of crops' radiation absorption and RUE studied under biofertilizer. Khorramdel et al., (2016) reported that the application of biofertilizers increased RUE by 69% when compared with control in Black Cumin (*Nigella sativa* L.). Also, application with biofertilizers enhances the availability of nutrients, particularly nitrogen and phosphorus. RUE in sulfur and nitroxin was higher compared to control (1.31, 1.24, and 1.09, respectively), which resulted in the highest biological and seed yield in sesame (*Sesamum indicum* L.) (Jahan et al., 2013). The application of PGPR in the agroecosystems is one of the possibilities that improve crop yield via increase resources use efficiency. This study aimed to evaluate ecophysiological traits and growth indicators of mung bean under the PGPR application conditions.

Materials and methods

Site description and experimental design

The current study conducted during two growing seasons at Faculty of Agriculture, Ferdowsi University of Mashhad, Iran (latitude: 36°15′N, longitude: 59°28′E, altitude: 985 m and mean annual rainfall: 286 mm), located in the central part of Khorasan Razavi province in Iran, sowing date of the first year, 28 May 2017 and the second year, 4 May 2018. Monthly rainfall and average temperature data during these months presented in Figure 1.

The experiment was carried out based on a completely randomized block design arranged in factorial design with three replicates and two mung bean genotypes (Dezfouli and Indian). Treatments were: (1) free-living nitrogen fixating bacteria (NFB), (2) phosphorus solubilizing

Table 1. Physical and chemical properties of the soils used in the site experiments in 2017 and 2018 (0 −30 cm).

Year	Texture	Electrical Phosphorus (mg kg^{-1})	Nitrogen (%)	Organic carbon (%)	Mineral carbon (%)	conductivity (dS m^{-1})	Soil acidity	Potassium (mg kg^{-1})
2017	Loam	2.88	7.41	119	20	0.063	0.61	1.05
2018	Loam	1.98	7.91	216	16.3	0.068	0.65	1.25

bacteria (PSB), (3) potassium solubilizing bacteria (KSB), (4) free-living nitrogen fixating bacteria + phosphorus solubilizing bacteria + potassium solubilizing bacteria (NFB + PSB + KSB), (5) nitrogen fertilizer (NF, source of urea 46%), and (6) control (without biological and chemical fertilizers). NFB was a set of strains of *Azospirillum* sp., *Azotobacter* sp., *Bacillus* sp. PSB was a set of strains of *Bacillus* sp. and *Pseudomonas* sp. and KSB strains of *Thiobacillus* sp., as liquid with 10^7 CFU per mL, that prepared by Dayan Company in Iran. Before the start of the experiment, soil samples from the depth of 0–30 cm collected. The results are shown in Table 1.

Mung bean seeds were sown in $3 \times 4\,m^2$ plots so as given 50 cm inter-row and 10 cm intra-row at 0.5 cm depth of both years. Before planting all treatments, except control and nitrogen fertilizer, inoculated by biofertilizer. Bacterial treatments applied in three stages (at the time of sowing, second irrigation, and before flowering stage). For nitrogen fertilizer treatment, nitrogen fertilizer application was 40 kg ha^{-1}, which was applied in two stages (during planting and before flowering). As soon as the seeds are sown, the plots irrigated, and irrigation continued every seven days until harvesting time. The hand weeding was conducted only twice before canopy closure.

Data collection and analysis

Leaf area and accumulative dry matter (DM) measurements were performed from 20 days after emergence (DAE) every 15 days to the end of the growing season. Leaf area index (LAI) measured by leaf area meter (Delta-T Model, England, UK). In each sampling, five plants from each plot randomly chosen, and leaf area and dry matter measured. The samples were oven-dried at 70 °C for 72 hr, then weighed to calculate LAI the following Eq. 1 was used (Loomis and Williams, 1963):

(1)

where a is the intercept, b is maximum LAI, c is x value for maximum LAI (estimated from data), d is the inflexion point of LAI, and x is the time (DAE).

To calculate daily DM, the following Eq. 2 was used (Shoor et al., 2012):

$$\mathrm{DM} = \frac{a}{(1 + b \times e^{(-c \times x)}} \tag{2}$$

where a is the maximum DM that estimated from measured data (g m^{-2}), b is x value for log in the linear stage of DM trend, c indicates relative growth ratio (g g day^{-1}), and x is the time (DAE).

Then, by deriving the first equation, the crop growth rate (CGR) (g m^{-2} d^{-1}) was calculated (Eq. 3).

$$\mathrm{CGR} = \frac{a \times b \times c \times e^{(-ct)}}{(1 + b \times e^{(-c \times x)})^2} \tag{3}$$

The RUE calculated based on g MJ^{-1}, through the slope of the linear regression between TDM accumulation (g m^{-2}) and cumulative, absorbed the total daily solar radiation. The

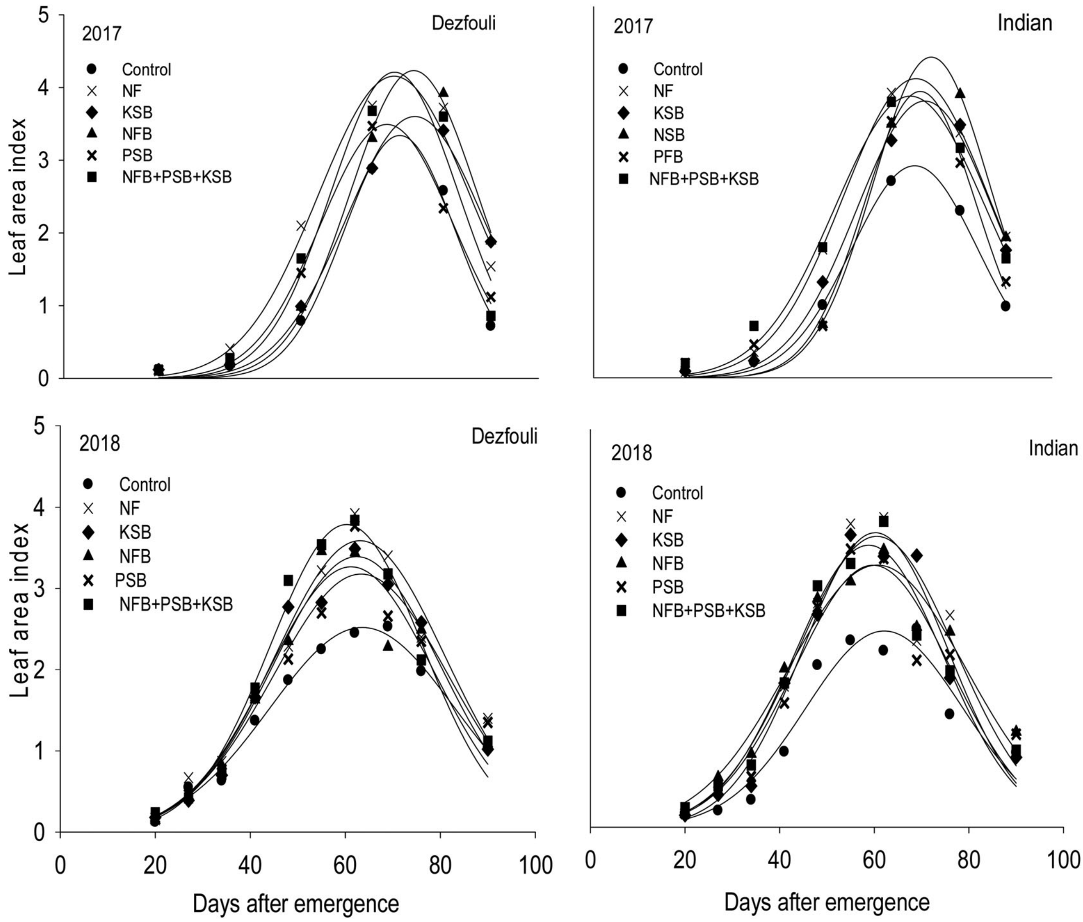

Figure 2. Effect of bio-fertilizer on leaf area index of Dezfouli and Indian mung bean during growth season. NF: Nitrogen fertilizer with a source of urea 46%, KSB: Potassium solubilizing bacteria, NFB: Free-living nitrogen-fixing bacteria, PSB: Phosphate solubilizing bacteria.

radiation absorption level calculated using the Eq. 4, (Tsubo et al., 2005):

$$I_{abs} = I_0 \times 0.5 \times (1 - P) \times (1 - e^{(-K \times LIA)}) \quad (4)$$

where I_{abs} is absorbed radiation by mung bean canopy (MJ m^{-2}), I_0 is total daily radiation (MJ m^{-2}) which was simulated by the method cited by Goudriaan and Van Laar (2012) for growing seasons of 2017 and 2018, P and K are reflection and radiation extinction coefficients considered 0.05 and 0.6, respectively (Ebadi et al., 2014).

Statistical analysis

Data analyzed by JMP 4.01 software. Data estimation and graphs draw done using Slide-write 7.02, Sigma plot 13.01, and Excel 2016, respectively.

Results and discussion

LAI responses

LAI As shown in Figure 2. In all treatments, LAI increased faster 40 DAE and continued until the 70 DAE, then started decreasing due to drying of older leaves up to senescence (Figure 2). A similar finding was reported by Banerjee et al. (2012). Application biofertilizer is a crucial factor, especially 40 DAE, for efficiently converting radiation and plant nutrients into biomass. The maximum LAI was recorded in NFB + PSB + KSB treatment in Dezfouli (37%) and Indian (38%) genotypes, compared to the control, respectively, during 2017. The maximum LAI recorded in NFB + PSB + KSB treatment of Dezfouli (42%) and Indian (39%) genotypes, when compared with the control in 2018 (Figure 2 (.

The difference in LAI between biofertilizers and control (Figure 2) could be related to hormonal ratios leading to the allocation of more dry matter to the leaves (Vessey, 2003). In biological fertilizer treatments, nitrogen is always available for the plant; the leaves age and leaf area decrease later (Wu et al., 2005). Weiss et al. (2004) reported that LAI has a significant impact on photosynthesis and PAR interception; also, intercepted PAR is a function of LAI and crop architecture. Maintaining photosynthetic levels of corn (*Zea mays* L.) at the end of the growing season has a direct effect on yield (Shekoofa and Emam, 2007). There is much evidence indicating that PGPR through phytohormones and organic acids synthesis increases nutrient availability, N fixation, and improving water relations (Jahan et al., 2013). These findings are in line with some earlier findings in case of soybean (*Glycine max*) (Aduloju et al., 2009) and sunflower (*Helianthus annuus* L.) (Gorttappeh et al., 2000).

Dry matter accumulation

Dry matter (Figure 3) depends on the amount of photosynthetically active radiation absorbed (PARa) in the crop and its conversion into biomass (Rattalino Edreira et al., 2020). The empirical measured RUE can multiply with intercepted (or absorbed) PAR to calculate daily gross dry matter production (Kukal and Irmak, 2020(.

DM improved by the application of NFB + PSB + KSB compared to control treatment about 30% in 2017. In the second year (2018), DM was 31% higher than control in Indian genotype at NFB + PSB + KSB treatment (Figure 3). Dry matter in the Dezfuli genotype had 6% in 2017 and 4% in 2018 more than Indian genotype (Figure 3). In the flowering stage, the highest dry matter obtained from (NFB + PSB + KSB) treatment (Figure 3). Biofertilizers add nutrients through the natural processes of nitrogen fixation, solubilizing phosphorus and potassium absorption (Nihayati et al., 2019). The maximum DM also recorded in soybean and mung bean by Mondani et al. (2019) and Bashir et al. (2016) with the application biofertilizer. Combined application of Rhizobium + PSB produced maximum values of DM at all the growth stages during the year (Khalil et al., 2020). Dry matter accumulation in plants highly correlated with their ability to absorb more fraction of radiation (Rosati et al., 2004). In this research, changes in pattern DM (Figure 3) were agreement whit radiation absorption (Figure 6). In both years, the highest dry matter obtained from the application biofertilizer in the highest PAR (Figure 6).

Considering this and light extinction coefficient of treatments, it could suggested that biofertilizers with lower light extinction coefficient compared to control likely affected sesame leaves spatial distribution.

CGR

The CGR is a simple and important index of agricultural productivity on rate of dry matter production (Mondal et al., 2017). CGR was slow in the early stages of growth because the plant cover

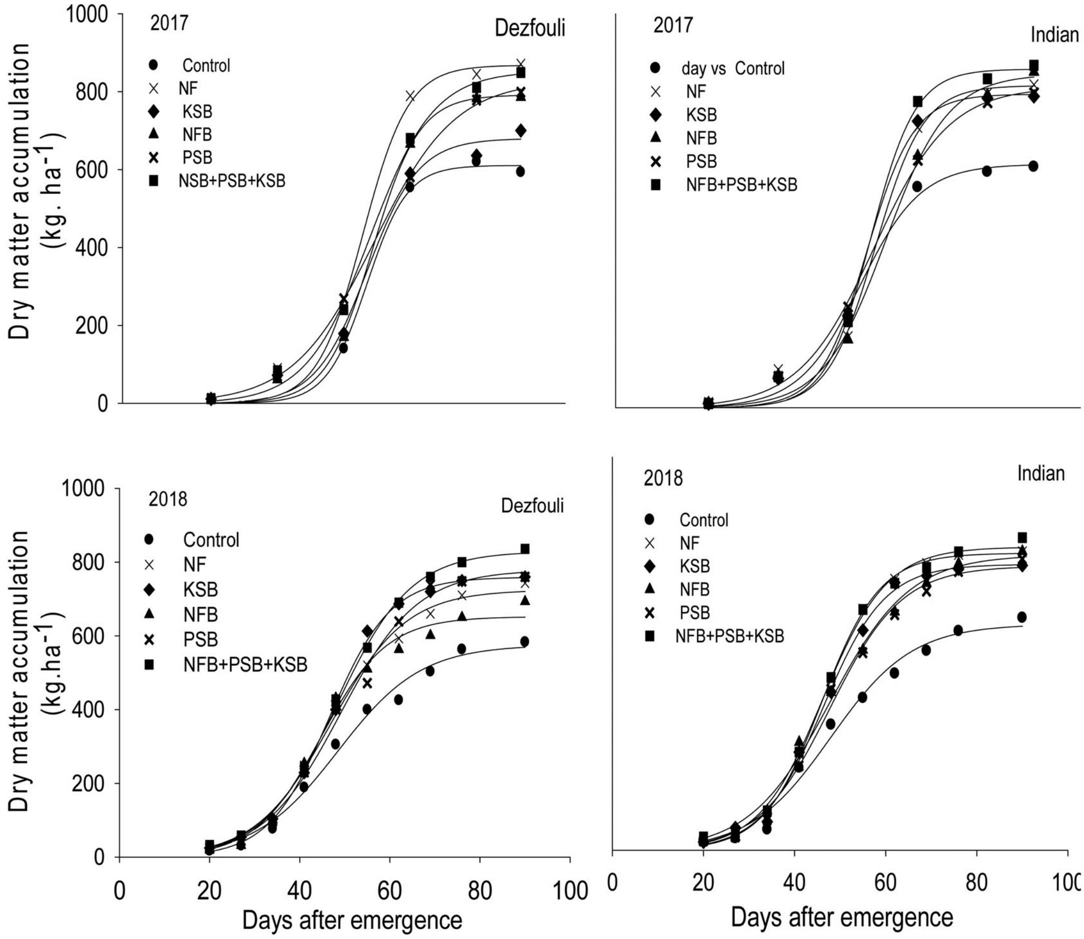

Figure 3. Effect of bio-fertilizer on dry matter accumulation of Dezfouli and Indian mung bean during growth season. NF: Nitrogen fertilizer with a source of urea 46%, KSB: Potassium solubilizing bacteria, NFB: Free-living nitrogen-fixing bacteria, PSB: Phosphate solubilizing bacteria.

was incomplete, and the plants absorb just a part of the solar radiation. 35 DAE with increasing leaf area, root growth, and solar radiation absorb improved, thereby dry matter production and CGR increased (Figure 4). When LAI is large to intercept 95% of radiation then plant gets optimum CGR and also greater light interception stimulates CGR which in turn increases dry matter and LAI (Mondal et al., 2017). Greater LAI causes higher light interception which further enhances CGR and thus results in higher biomass (Datta et al., 2012).

During the growing season (65 DAE), the CGR reached its maximum. In this experiment, the increasing and decreasing trend of CGR was not affected by all fertilizer treatments; however, maximum and minimum CGR did not occur in all treatments at the same time. According to Figure 4, the highest rate of CGR in Dezfuli and Indian genotype obtained the application at NFB + PSB + KSB, which was 31% and 46% higher than control during 2017 and 36% and 42% in 2018, respectively. Increasing of radiation absorption by crops which followed by the increased growth rate, is accord with canopy closure and linear growth stage of LAI (Goudriaan and Van Laar, 2012; Soltani et al., 2006). In the study, this stage began 30 DAE and continued up to 60 DAE and was entirely in agreement with trend of a fraction of absorbed radiation (Figure 6) and consequently was following dry matter accumulation (Figure 3).

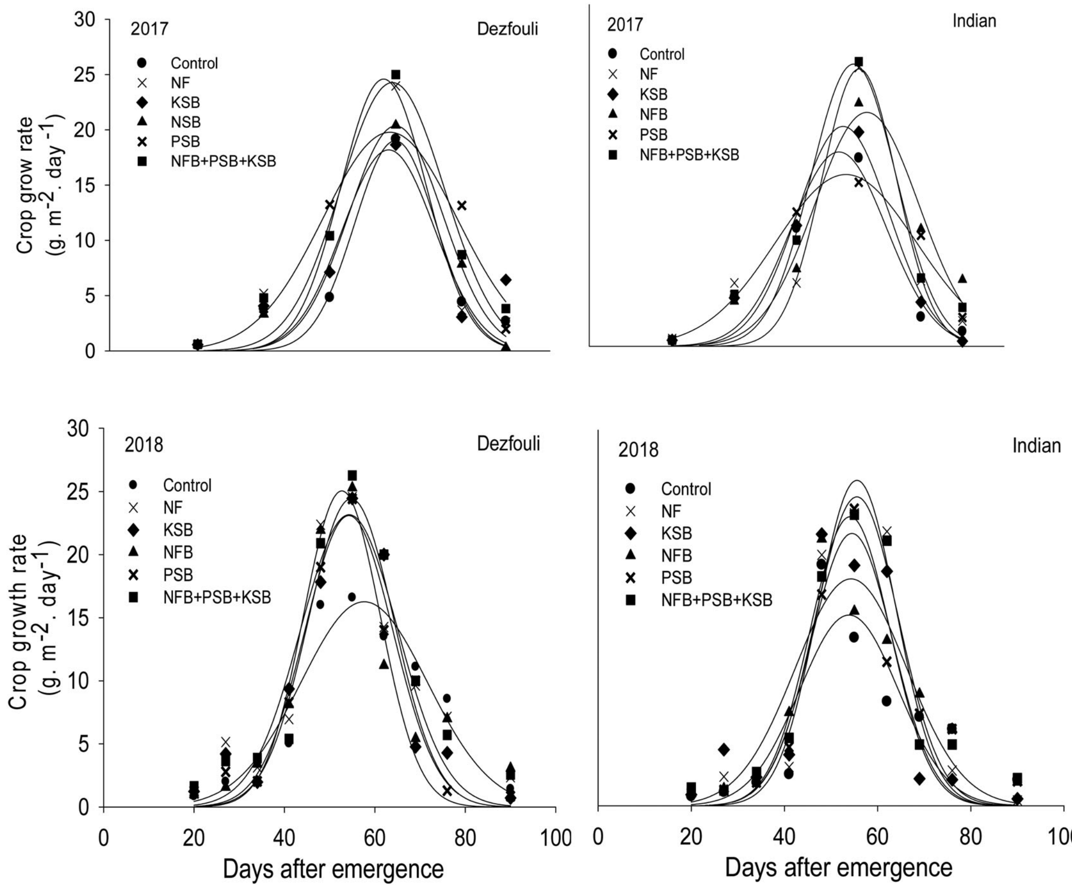

Figure 4. Effect of bio-fertilizer on crop growth rate (CGR) of Dezfouli and Indian mung bean during growth season. NF: Nitrogen fertilizer with a source of urea 46%, KSB: Potassium solubilizing bacteria, NFB: Free-living nitrogen-fixing bacteria, PSB: Phosphate solubilizing bacteria.

Radiation absorption

Total radiation and radiation absorption presented in Figures 5 and 6. As a result, the maximum absorbed radiation by canopy happened about 60 DAE. The fraction of absorbed radiation (Figure 6) was in agreement with the LAI (Figure 2).

The maximum radiation absorbed was proportional to the maximum LAI of mung bean, followed by a decrease in LAI until the end of the growth period. The maximum radiation absorption was affected by experimental treatments, and the final stages of the radiation absorbed were diverse. The fraction of radiation absorbed, indicating NFB + PSB + KSB treatment, increased 20% and 12% when compared with control during the 2017 and 2018 (Figure 5). The radiation absorption generally achieves to 85–95% of daily solar radiation when the LAI is about 3–3.85 in the canopy (Figures 2 and 6). Ghosh (2000) reported that radiation absorption efficiency depended on leaf area and leaf distribution in the canopy. When LAI is >3, almost 90% of PARa is intercepted by the canopy (Sarlikioti et al., 2011). These results agreed with the conformity of Jahan et al. (2013) and Yildirim et al. (2017). Lindquist et al. (2005) reported that a reduction in LAI resulted in reduced PARa and contributed to consistently lower biomass. Also, Stimulating effects of biofertilizer application also increased greater amount of radiation absorption by the crop plants which have contributed toward the dry matter of plants biofertilizer treatments (Aduloju et al., 2009).

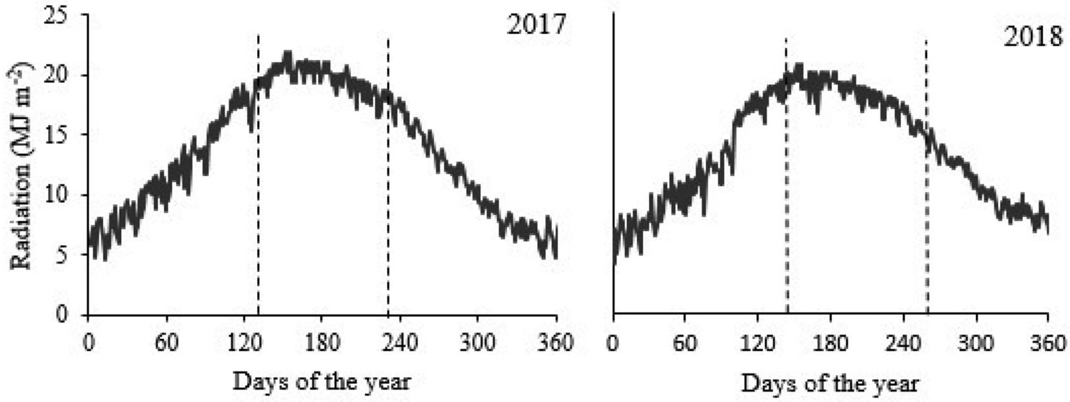

Figure 5. Total solar radiation reaching the earth's surface during the year (the range between the two points indicate the mung bean growth period).

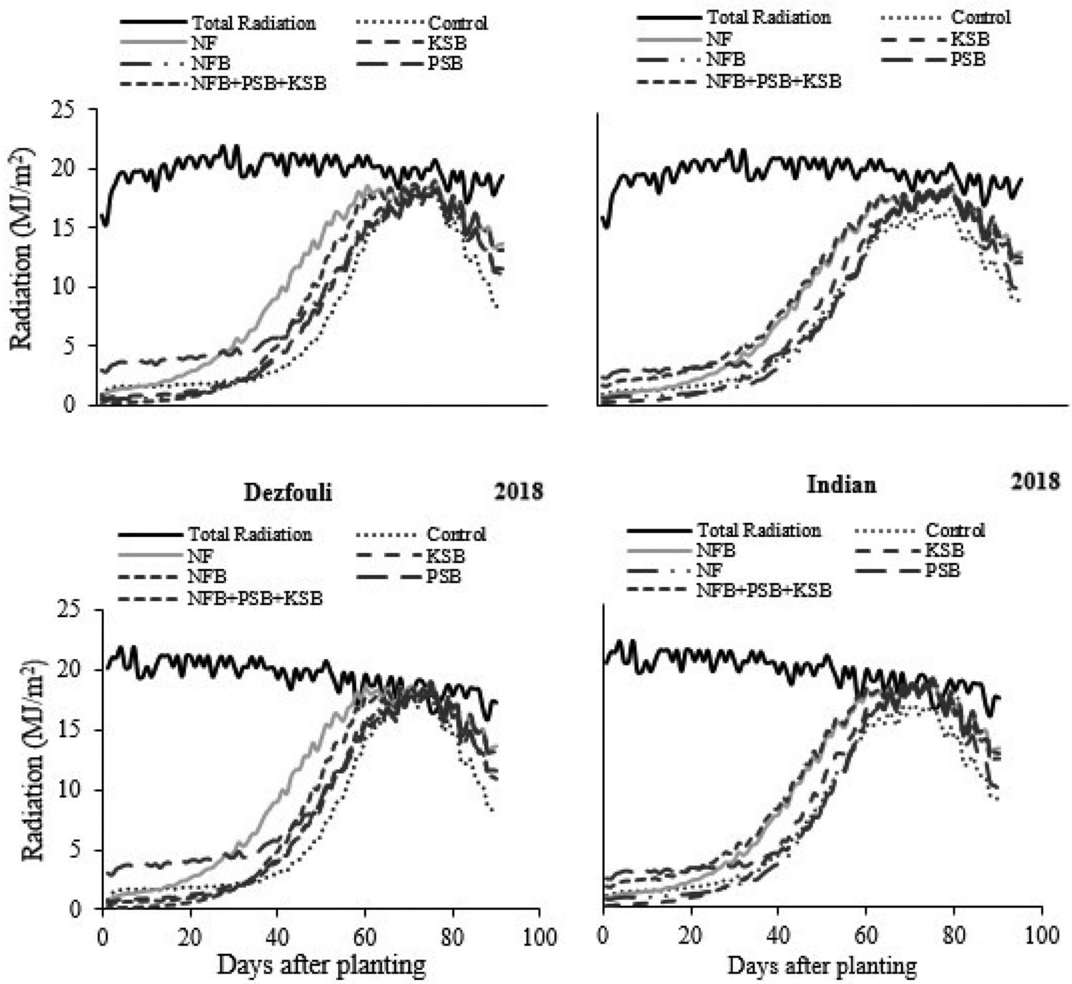

Figure 6. The trend of absorbed Radiation (PARa) of Dezfouli and Indian mungbean in 217 and 2018. NF: Nitrogen fertilizer with a source of urea 46%, KSB: Potassium solubilizing bacteria, NFB: Free-living nitrogen-fixing bacteria, PSB: Phosphate solubilizing bacteria.

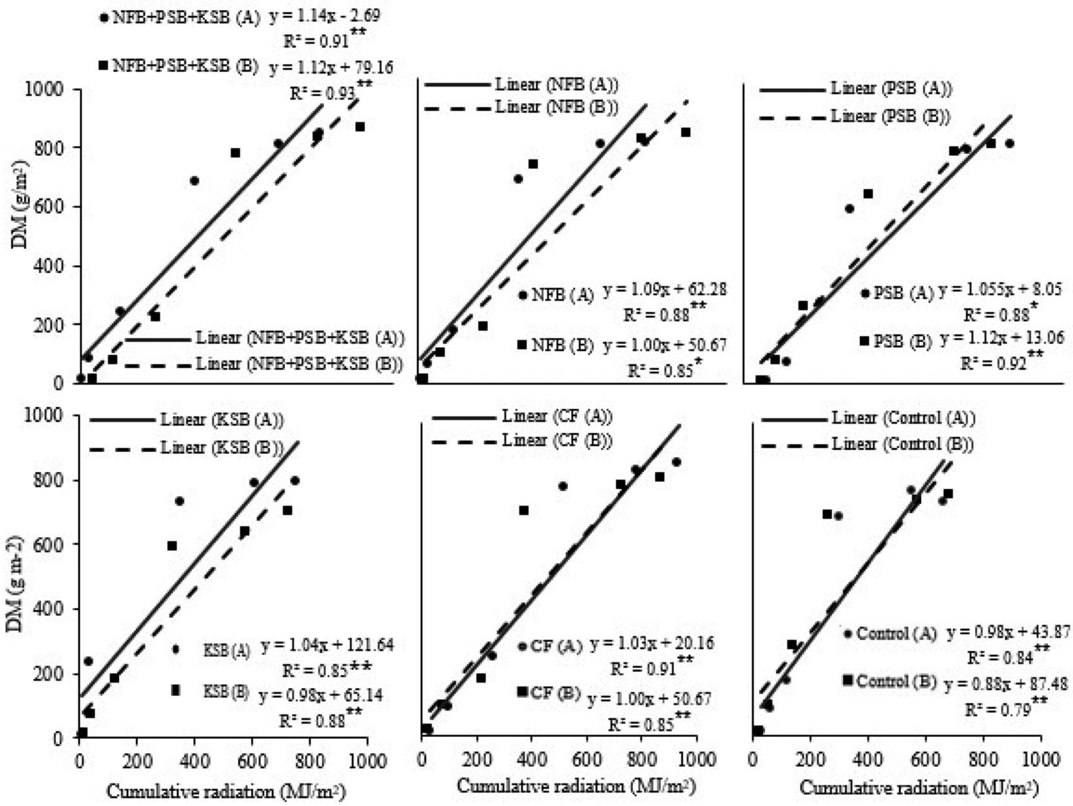

Figure 7. Dry matter as a function of accumulated radiation interception (PARacc) in Dezfuli (A) and Indian (B) mung bean under the influence of different treatments in 2017 (the regression slope is equal to radiation use efficiency). NF: Nitrogen fertilizer with a source of urea 46%, KSB: Potassium solubilizing bacteria, NFB: Free-living nitrogen-fixing bacteria, PSB: Phosphate solubilizing bacteria.

Increasing radiation absorption by crops followed by increased growth rate coincides with canopy closure and linear growth stage of leaf area (Soltani et al., 2006). In the present study, this stage began 40 DAE and continued up to 70 DAE. It was entirely in agreement with the trend of a fraction of absorbed radiation (Figure 6) and consequently was following dry matter accumulation (Figure 3).

RUE

The RUE estimated based on seasonal for each genotype from measurements of aboveground biomass and cumulative PARa (Figures 7 and 8). The RUE ranged across 1.14–0.67 g MJ^{-1} in different treatments. The greatest RUE observed in the NFB + PSB + KSB treatment when compared with other treatments (Figures 7 and 8).

RUE was strongly affected by biofertilizer application. The maximum RUE was obtained by Dezfouli and Indian genotypes in NFB + PSB + KSB treatment 1.14 ($R^2 = 0.93^{**}$) and 1.12 ($R^2 = 0.91^{**}$), g MJ^{-1} by 16% and 21% increase when compared with the control, followed by NFB treatment 1.09 ($R^2 = 0.88^{**}$) in Dezfouli genotype in 2017. In 2018, the maximum RUE was recorded by Dezfouli and Indian genotypes with NFB + PSB + KSB treatment 1.01 ($R^2 = 0.94^{**}$) and 1.03 ($R^2 = 0.92$**), g MJ^{-1} by 48% and 30% increase when compared with the control. The RUE was enhanced when the PGPR applied (Figures 7 and 8). It seems that the advantages of rhizobacteria contained in PGPR (Mondani et al., 2019), such as releasing phosphorus and

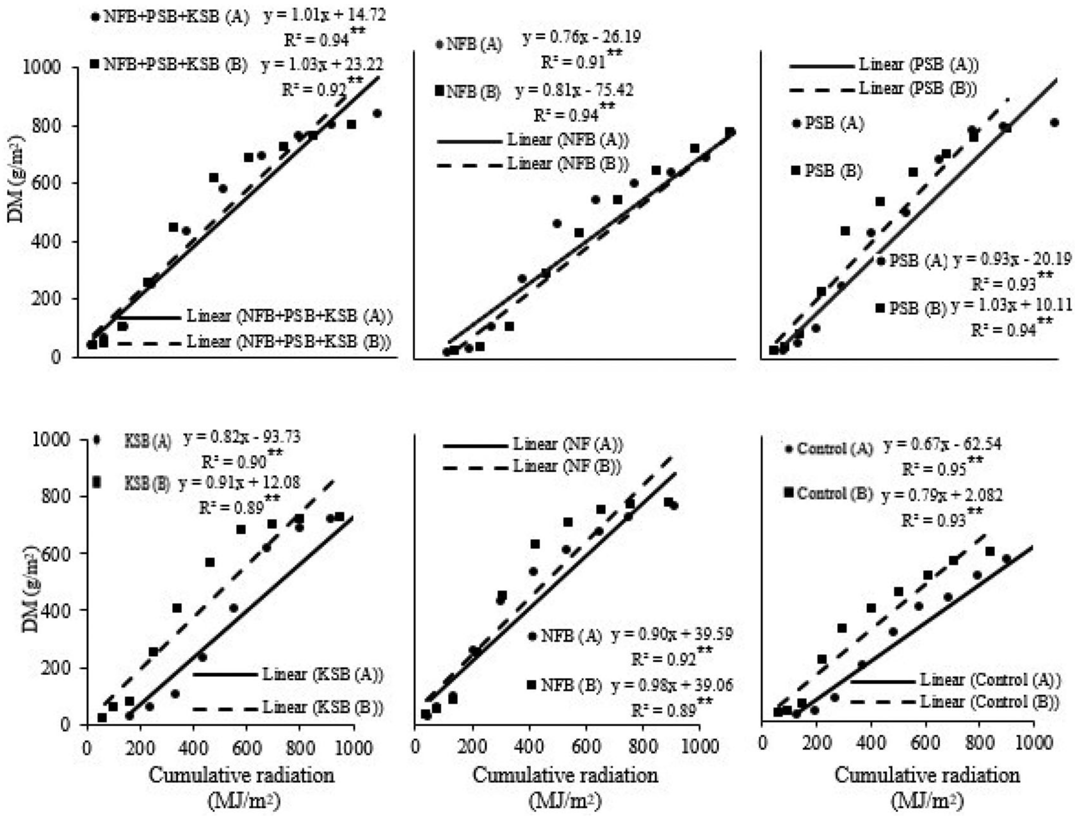

Figure 8. Dry matter as a function of accumulated radiation interception (PARacc) in Dezfuli (A) and Indian (B) mung bean under the influence of different treatments in 2017 (the regression slope is equal to radiation use efficiency). NF: Nitrogen fertilizer with a source of urea 46%, KSB: Potassium solubilizing bacteria, NFB: Free-living nitrogen-fixing bacteria, PSB: Phosphate solubilizing bacteria.

potassium from unavailable sources, enhanced Sesame RUE (Jahan et al., 2013). The results showed that biofertilizers enhanced the utilization of radiation absorbed by mung bean canopy. A number of authors have found close correlation among crop growth and yield with the radiation absorption and the RUE (Li et al., 2009; Miranzadeh et al., 2011; Ali et al., 2012). Accordingly, in this research, canopies with maximum LAI reached the maximum RUE values in response to biofertilizer. Thus, maximal RUE values were intensified and directly related to canopy LAI.

Conclusions

Our results indicate that application of biofertilizer is a crucial factor, especially 40 DAE, for efficiently converting radiation and plant nutrients into biomass. The result showed that the PGPR improved the LAI, DM, PARa, and RUE in mung bean. The greatest effects of the PGPR on measured traits also were observed in NFB + PSB + KSB treatment. The trend of the LAI and PARa changes was following the trend of the DM accumulation, and maximal RUE values were intensity and directly related to canopy LAI. The RUE indicated the amount of dry matter that could be produced by mung bean through photosynthesis per unit of absorbed radiation. Thus, in this linear relationship, an increase in the TDW is a meaningful linear relationship, and the TDW is essential.

In conclusion, application bio fertilization as a substitute for inorganic fertilizers in order to grow plants should not be considered a simple, objective, and short-term benefit, but as an ecological approach to improving environmental conditions and human health.

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