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GROWTH AND YIELD OF SOYBEAN (*Glycine max* L.) VARIETIES AS INFLUENCED BY DIFFERENT DOSES OF *Bradyrhizobium japonicum* INOCULATE IN DRY LAND OF THE ARABIA SEA COAST AREA (Balochistan Province, Pakistan)

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Abstract

Soybeans (*Glycine max* L.) are an important source of oil and protein for a large part of the population of Asia and America. It is known that in soybean the formation of arbscular mycorrhiza and root nodules leads to an increase in fresh weight, dry weight and seed weight compared to the control. However, in Pakistan, and especially in the Balochistan province, the effect of treating soybean seeds with inocula is extremely poorly studied. We perforemed our study to check the adaptability of soybean varieties under rhizobia inoculation in the coastal region. The obtained data are novel for the dry tropical area of Balochistan near the Arabian Sea (20 km) Research was conducted at Agronomic research farm of Lasbela University of Agriculture, Water and Marine Sciences, Balochistan during winter season 2018. Randomized Complete Block design (RCBD) with factorial arrangement having net plot size 4.5 m×3 m (13.5 m^2) was used with three replications. Treatments comprise two soybean varieties NARC I and NARC II and three doses of *Bradyrhizobium japonicum* inoculum, i.e. 200 g·$acre^{-1}$, 400 g·$acre^{-1}$ and 600 g·$acre^{-1}$. The results showed that maximum plant height (35.4 cm), number of pods (24.7 $plant^{-1}$), pod length (4.5 cm), the number of nodules (64.5 $plant^{-1}$), root length (13.2 cm), seed index (31.8 g), oil content (34.5 %), protein (37.7 %), seed yield (1160.0 kg·ha^{-1}) and biological yield (2019.7 kg·ha^{-1}) was recorded in NARC II variety. The interaction NARC I×600 g·$acre^{-1}$ inoculum indicated maximum plant height (41.3 cm), number of pods (31.3 $plant^{-1}$), pod length (4.8 cm), number of nodules (83.6 $plant^{-1}$), root length (15.3 cm), seed index (40.2 g), oil (38.0 %) and protein (43.0 %) content, seed yield (1333.8 kg·ha^{-1}), biological yield (2325.0 kg·ha^{-1}), and harvest index (1.3 %). Minimum plant height (22.6 cm), number of pods (15.0 $plant^{-1}$), pod length (3.1 cm), number of nodules (42.3 $plant^{-1}$), root length (7.5 cm), seed index (18.5 g), oil content (29.8 %), protein (30.5 %), seed yield (876.3 kg·ha^{-1}), biological yield (1448.3 kg·ha^{-1}) and harvest index (1.1 %) were found for NARC I×200 g·$acre^{-1}$. Based on the results it was concluded that different doses of inoculum significantly affect the soybean varieties. Soybean variety NARC II produced maximum seed yield under 600 g·$acre^{-1}$ inoculum doses. Maximum nodule formation was also found at an inoculum rate of 600 g·$acre^{-1}$.

Keywords: *Glycine max* L., soybean, *Bradyrhizobium japonicum*, inoculum, plant growth, yield components, Arabian Sea coast

Soybean (*Glycine max* L.) is the most important oilseed crop in the world, belonging to the bean family *Fabaceae* and sub family *Faboidae.* It is processed in to various products, such as porridge powder, edible oil, soy meat, soymilk and soy coffee. Soybean is an important oil and protein source for large population residing in Asia and the American continents [1].

Morphologically soybean belongs to *Fabaceae* family; taproot system of soybean extends upto 1.5 m length with lateral branches with 0-30 cm horizontally spread. Growth pattern in soybean is determinate and indeterminate. Determinate soybean type plants first complete their vegetative growth and then enter in reproductive phase. Indeterminate type can express vegetative and reproductive growth simultaneously. Flowering of soybean is about 15-20 days, depending on the length of the day, the temperature, and the growth habit, indeterminate begins flowering in earlier than determinate. Soybean was originated in China where its records go back to 2838 B.C. It was introduced in Pakistan in the early 1960's from the USA for experimental purposes. In Pakistan soybean with blackseeds (Mothi) has been cultivated in the northern hilly areas [2].

Soybeans are grown mainly in the United States, Brazil, Argentina, and China. Soybeans have become unripe as far as agricultural and commercial use is concerned [3]. At the beginning of 21st century, extensive areas in South America were converted to agricultural fields to produce soybean crop. Soybeans has been an ancient crop since the beginning of agriculture [4]. Due to its high content of macronutrients and micronutrients, soybeans are recognized as a nutritious food for human consumption, livestock, industry and medicinal purposes [5]. Soybeans are considered a healthy food because they are high in essential amino acids that make protein [6].

In 2016, soybean was planted on 120.48 million hectares in the world, which produced 351.48 million tons seed. The largest producer of soybean is the USA (117.20 million metric tons). USDA expected its worldwide production for 2017-18 to reach 347.7 million metric ton. In Pakistan during 2016 its oil production was 240 tons which has increased up to 260 tons in 2017 [7]. Soybean is a very important recognized oil seed and protein crop in the world. It is a good source of protein, unsaturated fatty acids, minerals like Ca and P including vitamins A, B and D that meet different nutritional needs [8]. The soybean crop fixes free N from atmosphere with the help of *Bradyrhizobium japonicum* in the roots of soybean. The aim of crop rotation is to enhance the soil fertility and productivity [9].

Inoculation is practiced by applying *B. japonicum* culture directly to the seeds. Inoculation is considered necessary when there is insufficient Bradyrhizobium japonicum in the soil [10]. Soybeans are probably one of the world's oldest food crops and number one in the world's oil seeds [11]. The effect of *B. japonicum* inoculation on soybean nodule formation and nitrogen fixation has been reported by many researchers [12]. This positive effect of inoculums by *B. japonicum* was accompanied with increase in seed yield of soybean [13]. Soybean seed co-inoculation with vesicular-arbuscular mycorrhizae (VAM, *Glomus macrocarpum*) and *B. japonicum* increased VAM infection and nodule formation compared to control. There was also an increase in fresh weight, dry weight, and seed weight compared to control [14].

In Pakistan, soybean is grown all over the country especially in hilly areas. It is the tropical leguminous crop which can fix the nitrogen from atmosphere to the soil [15]. Among leguminous crops, soybean is considered as most important crop because of very high nutritive contents. Temperate, tropical and subtropical and climates areas are best for its growth and East Asia is considered as the origin land of this crop [16]. Soybean has been documented as main crop of China back in 11th century and was later introduced in America and was tested by different researchers regarding its nutritive value and optimum growth conditions [17]. It was also introduced and cultivated successfully in the food deprived African continent in 1903 and then has been cultivated as the major food crop [18].

Legume crops convert the atmospheric nitrogen to ammonia nitrogen which is used by the plants. To enhance the nitrogen fixing process, rhizobium inoculation is introducing commercially in soil [19]. Nitrogen fixation process occurs in root nodules. The relationship between rhizobia and legume is symbiotic in which both are benefited. During this process, the inoculated bacteria invade the hairs of plant root and their multiplication site in the tissue of outer root; and form nodules which perform atmospheric nitrogen fixation [20]. Another important factor to have maximum legume crop yield is to maintain the soil fertility which will ensure the nodule formation and nitrogen fixation. Symbiotic nitrogen fixation is adopted by the legumes to fix the atmospheric nitrogen [21]. Importantly, phosphorous and potassium have great impact on nodulation and subsequently nitrogen fixation. Molybdenum is another important micronutrient which plays its role in nitrogen fixation [22].

R.M. Morshed et al. [23] conducted experiment at Faculty of Biology at Gulnagar University, Dhaka during the 2004-2005 in rabi season using G2 (Bangladeshi soybean) variety. Used N rates were (N_1 10.58), (N_2 15.87), (N_3, 21.16), (N_4, 26.45), (N_5 31.74), (N_6, 37.03) kg·ha^{-1}. The seeds were inoculated with *Bradyrhizobium* before sowing. Soybean production increased rapidly and significantly, with the N rate up to 26.45 kg·ha^{-1} whereas the highest seed yield of 685 kg·acre^{-1} was achieved. O. Herliana et al. [24] carried out experiment in May to October 2018, for biofertilizer and N doses at the Faculty of Agriculture, Gendarmes Dilman University. This study consists of a completely random design (FCRD) with two factors. The main constituents were *Rhizobium* (R), the *Rhizobium radiobacte*r, *Rhizobium pusenses*, *Rhizobium nepotum*. The second factoe was a dosage of N fertilizer (N) such as 0, 25%, 50%, 75% and 100% (recommended dose is 120 kg), Variations were found in plant tip, leaf type, leaf proximity, stem diameter, dry weight of roots, seed weight, weight of 100 seeds, different pods, pod weight, and plant. The results confirmed that the use of Rю neoptum isolate gave the best results in terms of leaf area, pod weight, pod type, and 25% N fertilizer dose produced stems of variable morphology. There was no interaction between the isolate species and the N fertilizer dose.

A.Z. Khan et al. [25] observed that the planting date and plant density had a substantial impact on the protein and oil content of soybean cultivars. Protein content was higher in late-planted crops than in early-planted crops, however there was an inverse association in terms oil content. L.M. Jaureguy et al. [26] pointed out that early and late planting dates had different effects on eight soybean breeding lines grown for two years in two different locations in Arkansas, USA with different seed compositions (high protein, high oil, high oleic acid, high inorganic phosphorus, low linolenic acid, low saturated fatty acids, and low stachyose).

E.A. Obidiebube et al. [27] tested the adaptation of ten soybean varieties in field experiments performed in two rainforest areas (Asaba and Okpe-Isoko). The subjected varieties included TGX1904-6F, TGX1910-11F, TGX1910-15F, TGX1910-10F, TGX1905-2F, TGX1910-1F, TGX1910-8F, TGX1910-6F, and TGX1905-5F. The results revealed significant differences between the varieties for some of the parameters evaluated ($p \le 0.05$). TGX1910-8F, TGX1905-2F, and TGX1904-6F had the most flowers (68.3), pods (26.3), and days to maturity (106.6), respectively. In terms of dry weight of seeds per hectare (2.9 t·ha^{-1}), the TGX1910-8F strain beat out the TGX1910-15F strain (2.89 t·ha^{-1}). TGX 1910-8F, TGX1905-2F, and TGX1904-6F provided the maximum mean values for average dry weight as compared to other types. Therefore, higher yielding TGX1910-8F and TGX1910-15F are recommended to cultivate under this agro-ecological region.

M. Rehman et al. [28] conducted a field analysis in the agro-ecological conditions of Faisalabad, Punjab to maximize the planting time for various soybean cultivars.The experiment used an RCBD arrangement with three replications, with the date of sowing in the main plot and variety as a sub-plot. According to the findings, upon sowing on January 28, Faisal soybeans generated more pods and seeds per plant. In Faisal soybeans, the highest seed yields of 1647.10 $kg \cdot ha^{-1}$ and 1440.23 $kg \cdot ha^{-1}$ were recorded for sowing date of January28 and January 21, respectively. As a result, January 28 was the perfect time to plant spring soybeans for a high yield. Faisal soybean outperformed the other two cultivars under Faisalabad conditions.

G.E. Nwofia et al. [29] evaluated four soybean genotypes in terms of seed yield, growth and other reproductive factors in 2012 and 2013. TGx 1448-2E, TGx 1485-1D, TGx 1987-1F, and TGx 1835-10E were the four genotypes, with six sowing dates: early June, late June, early July, late July, early August, and late August. Plots varied in the sowing dates, whereas the sub-plots of each plot differ in soybean genotypes. That is, each plot was a set of genotypes of a certain sowing date. Their findings revealed that soybean sown in July produce higher yields of 1320.07 and 860.20 $kg \cdot ha^{-1}$in 2012 and 2013, respectively. Soybean with the TGx1485-1D genotype proved best performance with yields of 980.74 $kg \cdot ha^{-1}$ in 2012 and 520.58 $kg \cdot ha^{-1}$ in 2013.

A. Nsengiyumva et al. [30] performed experiment at Nyarubaka sector of Kamonyi District Rwanda to investigate the reaction of two soybean varieties (Peka6 and SB24) with rhizobium inoculation without phosphorus limitation. Peka6 was more sensitive to the rhizobium inoculants than SB24. T. Shah et al. [31] performed field experiments to check the sowing time for various cultivars of soybean at Charsadda, Khyber Pakhtunkhwa, Pakistan. Experiment was consisted of 4 planting windows with two varieties. Result showed that varietyWilliams-82 and planted on March 21 produced large number of pods and seeds per plant.

Y. Kawasaki et al. [32] revealed the late sowing influence on seed yields of soybean during consecutive two years (2016-2017) in Japan. It was reported that the delayed sowing of soybean seed caused significant increase in HI (harvest index) from 0.464-0.571 in the year 2016 and from 0.524-0.585 in the year 2017, but sowing density had insignificant effect ($p > 0.05$). R.C. Umburanas et al. [33] conducted field trial for two growing seasons to investigate how sowing dates and seeding rates influence soybean yield and its attributes. It was discovered that late sowing decreased yield because of lower shoot biomass. Higher seeding rates, on the other hand, reduced the amount of shoot biomass, leaf area, pods, and seeds per plant.

G. Toum et al. [34] determined yield and crop quality, height to first pod, number ofpods per plant-1, 100-seed weight, harvest index, straw production, seed yield, grain protein, and oil content. The height to first pod, 100-seed weight, harvest index, grain yield, and grain protein were all found to fluctuate considerably between planting dates. Compared to planting later in the season, planting on July1 resulted in a 72 % increase in grain yield (July 15). In comparison to later planting times, early planting (June 15) and mid-planting (July 1) dates resulted in a 5% increase in grain protein (July 15).

The soybean plant growth and grain production as well as grain quality may be influenced by the date of planting [35] and the final product is often reduced when the seeds are planted after May 1 [36]. It did so in the North Central US and in the upper Midwest states [37, 38] Following an analysis undertaken [39], crops were most likely planted in mid-April or early May in the South, which reduced the grains yield. When soybeans were sown in the Northeast United States in mid-June, they did not generate many pods, and they produced fewer, less-yield crops [40].

Planting too early is often affected by cool temperature; due to wet and cool soil condition seed emergence of soybean may delay, in consequent reduced canopy development as well as declined grain yield [41] The grain yields of soybean are usually greater if planted earlier because early planting linger the vegetative period as well as reproductive stage [42]. Another methodolofy is to use rows less than 30 inches apart, which maximizes yield through optimal use of land and resources (in Pakistan, farmers tend to plant in wide rows, which is considered an inefficient practice) [38].

In Pakistan, especially in Balochistan almost no data is available regarding inoculum treatment of soybean seed. This study was conducted to evaluate the suitability of the rhizobia for different soybean varieties and the rhizobia significance in given land texture and environment. Our study presents the first data on the effectiveness of rhizobia when inoculating soybean varieties in the arid zone of the Arabian Sea coast.

The present study was conducted to check the effect of different doses of rhizobia inoculum on the growth and yield of soybean under agro climatic conditions of Lasbela.

Materials and mwthods. The field experiment was conducted to determine the effect of different inoculum doses on the growth and yield of soybean at Lasbela University of Agriculture, Water and Marine Sciences (LUAWMS) Uthal, Lasbela during the February 2018. The LUAWMS is located in Lasbela district 25.8700°N latitude and 66.7129°E longitude. which is situated in Balochistan province, Pakistan. Lasbela district is characterized by loam soil and a dry tropical climate. The area is characterized with an average annual rainfall of 178 mm.

Before and after sowing, five soil samples were collected randomly for each treatment from experimental field. The samples were collected from a depth of 30 cm with help of auger. The entire sample were analysed for its physio-chemical properties. The soil samples were analyzed at Soil Laboratory the Agriculture Research Institute (ARI) Quetta. Soil was oven dried at 105 °C for 24 h. The soil of study area has sandy loam texture having about 91-94% sand particles. The soil pH ranged between 7-7.5, while soil electrical conductivity (EC) was 10.24 dSm^{-1}. Nitrogen and organic matter in the soil was apprx. 0.020 and 0.40 %. The availability of phosphorus and potassium in the soil was apprx. 2.08 and 124 $mg \cdot kg^{-1}$ respectively.

The field experiment was conducted to determine the effect of different inoculum doses on the growth and yield of soybean at Lasbela University of Agriculture, Water and Marine Sciences (LUAWMS) Uthal during 2018. For this purpose, two soybean varieties, i.e. NARC-I and NARC-II and three inoculum doses, i.e. 200 $g \cdot acre^{-1}$, 400 $g \cdot acre^{-1}$ and 600 $g \cdot acre^{-1}$ were examined in randomized complete block design (RCBD) with factorial arrangement having three replications. Recommended seed rate of 40 kg per acre (100 $kg \cdot ha^{-1}$) was used [43]. A total of 18 plots were used in the experiment. The size of the plot was 4.5×3 m (13.5 m^2). Plant populations were maintained by thinning at 4-6 leaf stage. All common cultural practices were used during the growing season.

The inoculant *Bradyrhizobium japonicum* was arranged from National Agricultural Research Center (NARC) Islamabad. Inoculation was done by adopting standard procedures just before drilling and a control without inoculation was also mentioned. For inoculation, 1 kg of sugar was dissolved in 1 litre of water to moisten 40 kg of seed. Moistening of seeds allows the inoculants to stick. Dissolved Gur or sugar serves as initial nutriemts for the bacteria. 600 g of inoculants was spread over the dry seed and mixed in uniformly with the hands covered with gloves. Inoculation was done just before planting, in shady area.

Crop was sown during 2018 spring season with the help of Dibbler. Before sowing, inoculation was prepared using standard procedure and seed were inoculated with different doses of inoculation. After precise land levelling experimental area was ploughed with rotavator, firstly with rotavator followed by planking and then irrigated. The best tillage implement is to provide a tilth for soybean is rotavator. At field capacity, land will be prepared for final seed bed by ploughing with cultivator. Recommended rate of fertilizer (25-60-50 $kg \cdot ha^{-1}$ NPK) was applied. Nitrogenous fertilizer (Urea) was used in split doses at crucial vegetative and reproductive stages. All the Phosphate (P) and Potash (K) fertilizers as Di-Ammonium Phosphate (DAP) and sulphate of potash (SOP), respectively, had been applied at planting.

Soybean crop is harvested by hand with a sickle. The plant is harvested when 90 95% pods turn yellow. Then dried it for 5-6 at days and then threshed. Soybean seed should be considered as physiologically matured when its seed coat is completely yellow, irrespective of the pods color.

Data were collected on various growt and yield components were germination (%), plant height at maturity (cm), number of pods per plant, pod length (cm), seed yield ($kg \cdot ha^{-1}$), biological yield ($kg \cdot ha^{-1}$), harvest index (%), number of nodules per plant, root length (cm), protein (%), oil (%).

Data were processed statistically by Fisher's analysis of variance (ANOVA) methods, and least significant difference (LSD) test at 5% probability level was used to test difference among treatment means [44].

Results. Climatic data of cropped period (Fig., A-D) was collected from meteorological observatory of LUAWMS during 2018.

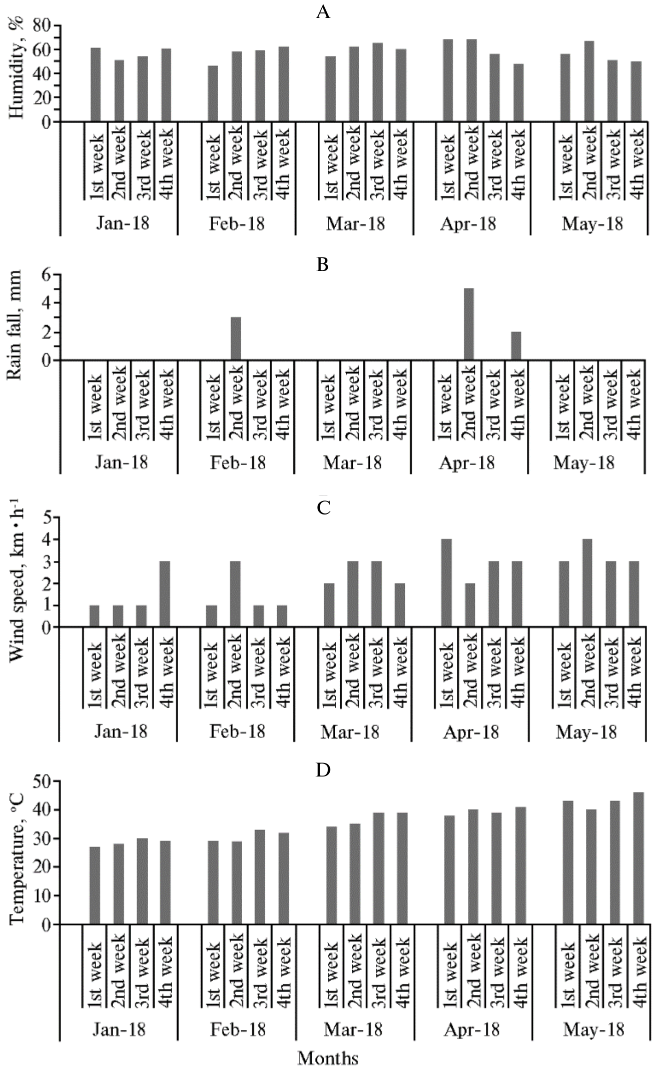
S e e d g e r m i n a t i o n (%). The germination of seed play vital role to achieve the required soybean seed production. Seed germination of soybean cultivars under various inoculum doses was observed non-significant and the results presented in Table 1.The result showed that the germination percentage shows non-significant ($p > 0.05$) varieties for both factors. Interaction between V×I (Varieties × Inoculum doses) showed non-significant result ($p > 0.05$).

The soybean cultivar NARC I produced highest seed germination (67.2%) as compared to NARC II (61.3%). Whereas maximum seed germination (68.8%) were recorded when soybean crop treated with inoculum dose per acre I_1 (200 g), followed by 66.0% for I_3 (600 g) and 58.0% for I_2 (400 g). That is, the minimum seed germination (58.0%) was noted with inoculums dose I_2. The interactive effects indicated that interaction of $I_1 \times V_1$ produced maximum seed germination (74.3%), and minimum seed germination (51.0%) was recorded with interaction of $I_2 \times V_2$.

P l a n t h e i g h t (cm). Plant height is an important part of straw yield and seed yield because it plays important role in photosynthesis and translocation of products from bottom to top of the plant. The morphology of plants is generally considered as genetic character that inherits from the parental material of varieties; however, size of the plant might be influenced by several inputs and crop management related factors.

Significant plant height was recorded in soybean cultivars under various inoculum doses and their results given in Table 1. The soybean cultivar NARC II produced highest plant height (35.8 cm) as compared to NARC I (25.4 cm). Maximum plant height (34.6 cm) was recorded for soybean crop treated at the inoculum dose I_3 (600 g), followed by (30.5 cm) noted with inoculum dose I_2 (400 g). The minimum plant height (26.8 cm) was observed with inoculum dose per acre I_1 (200 g). The statistically analysis of data indicated that there was significant ($p < 0.05$) difference in plant height between soybean cultivars, inoculum doses and their interactions. The interactive effects indicated that interaction of $I_3 \times V_2$ produced maximum plant height (41.3 cm) and minimum plant height (22.6

cm) was recorded with interaction of $I_1 \times V_1$ (see Table 1).



Weekly recorded relative humidity (A), **precipitation** (B), **relative wind speed** (C) **and air temperature** (D) **from January to May 2018 at the site of the experiment on soybean (*Glycine ma*x L.) inoculation with *Bradyrhizobium japonicum*** (Lasbela University of Agriculture, Water and Marine Sciences, Uthal, Lasbela, Balochistan province, 25.8700°N, 66.7129°E; data from the LUAWMS weather station)**.**

1. Seed germination and plant growth in soybean (*Glycine max* L.) depending on the variety and dose of *Bradyrhizobium japonicum* inoculum (Lasbela University of Agriculture, Water and Marine Sciences, Uthal, Lasbela, Balochistan province, 25.8700°N, 66.7129°E, 2018)

Treatment	Seed germination, %	Plant height, см	Pod number per plant
	M	*M*	*M*
A — variety (V):			
V_1 = NARC I	67.2	25.4 b	14.7 b
V_2 = NARC II	61.3	35.8 a	24.7 a
SE	6.8192	0.6939	0.9571
LSD_{05}	15.194^{NS}	1.5461**	2.1326**
B — dose of inoculate (I):			
I_1 = 200 g/acre	68.8	26.8 c	13.8 c
I_2 = 400 g/acre	58.0	30.5 b	21.0 b
I_3 = 600 g/acre	66.0	34.6 a	24.5 a
SE	8.3518	0.8498	1.1722
LSD_{05}	18.609^{NS}	1.8936**	2.6118**

C — variety×dose of the inoculate (V×I):			
$V_1 \times I_1$	74.3	22.6 e	16.0 c
$V_1 \times I_2$	65.0	25.6 d	27.0 b
$V_1 \times I_3$	62.3	28.0 d	31.3 a
$V_2 \times I_1$	63.3	31.0 c	11.6 d
$V_2 \times I_2$	51.0	35.3 b	15.0 cd
$V_2 \times I_3$	69.6	41.3 a	17.6 c
SE	11.811	1.2019	1.6578
LSD_{05}	26.317^{NS}	2.6779**	3.6937**

N o t e. Ccolumn means that are not marked with the same letters are statistically significantly different at p = 0.05; ** — high level of significance, ^{NS} — no statistical significance.

Number of pods per plant. The soybean yield is mainly associated with number of pods per plant that also reflects the effectiveness of treatments. No of pods per plant^{-} in soybean cultivars was found to be highly significant and the finding are presented (se Table 1). The soybean cultivar NARC II produced the highest number pods per plant (24.7) as compared to NARC I (14.7).

Maximum number of pods per plant (24.5) were found in soybean crop treated inoculum dose I_3 (600 g), followed by inoculum dose I_2 (400 g) with 21.0 pods per plant. The less number of pods per plant (13.8) was noted with inoculum dose per acre I_1 (200 g). The statistically analysis of data showed that there was significant ($p < 0.001$) difference in numbers of pods per plant between soybean cultivars. The interactive effect indicated that interaction of $I_3 \times V_2$ produced maximum number of pods per plant^{-}(31.3) and minimum number (11.6) was recorded with interaction of $I_1 \times V_2$.

P o d l e n g t h (cm). In soybean, the pod size inherits from the parental material; but crop management and the applied inputs also influence pod length (cm), and size of soybean cultivars under various inoculum doses was observed and the results are presented (Table 2). The statistic analysis indicated that there were highly significant differences ($p < 0.001$).

2. Pod length and seed productivity in soybean (*Glycine max* L.) depending on the variety and dose of *Bradyrhizobium japonicum* inoculum (Lasbela University of Agriculture, Water and Marine Sciences, Uthal, Lasbela, Balochistan province, 25.8700°N, 66.7129°E, 2018)

Treatment	Pod length, cm	Seed yield, kg/ha
	M	*M*
A — variety (V):		
V_1 = NARC I	4.5	1033.3 b
V_2 = NARC II	3.6	1160.0 a
SE	0.1432	25.937
LSD_{05}	0.3192^{NS}	57.791**
B — dose of inoculate (I):		
I_1 = 200 g/acre	3.6	917.8 c
I_2 = 400 g/acre	4.3	1122.3 b
I_3 = 600 g/acre	4.3	1249.7 a
SE	0.1754	31.766
LSD 05	0.3909^{NS}	70.779**
C — variety×dose of the inoculate (V×I):		
$V_1 \times I_1$	3.1	876.3 d
$V_1 \times I_2$	3.9	1057.9 c
$V_1 \times I_3$	3.9	1165.7 b
$V_2 \times I_1$	4.1	959.4 cd
$V_2 \times I_2$	4.7	1186.7 b
$V_2 \times I_3$	4.8	1333.8 a
SE	0.2481	44.924
LSD_{05}	0.5528^{NS}	100.10**

N o t и e. Ccolumn means that are not marked with the same letters are statistically significantly different at p = 0.05; ** — high level of significance, ^{NS} —no statistical significance.

The soybean cultivar NARC I produced the highest pod length (4.5 cm) as compared to NARC II (3.6 cm). Whereas maximum pod length (4.3 cm) was recorded when soybean crop was treated with inoculum doses I_3 (600 g) and I_2

(400 g). The minimum pod length (3.6 cm) was noted with inoculum dose per acre I_1 (200 g). The interactive effects indicated that interaction of $I_3 \times V_2$ produced maximum pod length (4.8 cm) and minimum pod length (3.1 cm) was recorded in $I_1 \times V_1$.

S e e d y i e l d ($kg \cdot ha^{-1}$). Seed yield has a linear effect on the soybean production in commercial sense. Results regarding seed yield of soybean varieties as affected by different inoculum doses and their interaction are presented (see Table 2). The analysis of variance revealed the significance level ($p < 0.05$) for varieties, inoculum doses and their interaction. The results show that maximum seed yield (1160.0 $kg \cdot ha^{-1}$) was recorded for NARC II variety and the minimum seed yield (1033.3 $kg \cdot ha^{-1}$) was recorded for NARC I variety. The results for different inoculum doses show that when applying 600 g inoculum, maximum seed yield (1249.7 $kg \cdot ha^{-1}$) was recorded, followed by 1122.3 $kg \cdot ha^{-1}$ for under 400 g inoculum; and the minimum seed yield (917.8 $kg \cdot ha^{-1}$) was recoded when we applied 200 $g \cdot acre^{-1}$ inoculum dose. The interactive effect of the varieties and inoculum doses indicates that the maximum seed yield (1333.8 $kg \cdot ha^{-1}$) was recorded in $I_3 \times V_2$, and the minimum yield of 876.3 $kg \cdot ha^{-1}$ was recorded in $I_1 \times V_1$.

B i o l o g i c a l y i e l d ($kg \cdot ha^{-1}$). The plant biomass is generally associated with plant height and number of branches or leaves; generally, varieties have dominant effect on this trait but the use of inputs and crop management including sowing time is also recognized to affect this parameter. Generally, biological yield of soybean varieties as affected by different inoculum doses and their interaction is presented in Table 3.

3. Bioproductivity, harvest index, nofulation and root length in soybean (*Glycine max* L.) depending on the variety and dose of *Bradyrhizobium japonicum* inoculum (Lasbela University of Agriculture, Water and Marine Sciences, Uthal, Lasbela, Balochistan province, 25.8700°N, 66.7129°E, 2018)

Treatment	Bioproductivity, kg/ha	Harvest index, %	Nodule number per plant	Root length, cm
	M	*M*	*Me*	*M*
A — variety (V):				
V_1 = NARC I	1785.9 b	1.2	54.5 b	20.2 b
V_2 = NARC II	2019.7 a	1.2	64.3 a	23.5 a
SE	34.898	0.0419	0.9950	0.3225
LSD_{05}	77.757**	0.0935^{NS}	2.2171**	0.7185**
B — dose of inoculate (I):				
I_1 = 200 g/acre	1607.3 c	1.1	45.1 c	15.1 c
I_2 = 400 g/acre	1887.2 b	1.3	57.0 b	21.1 b
I_3 = 600 g/acre	2213.8 a	1.3	76.1 a	29.4 a
SE	42.741	0.0514	1.2187	0.3949
LSD_{05}	95.232**	0.1145^{NS}	2.7154**	0.8799**
C — variety×dose of the inoculate (V×I):				
$V_1 \times I_1$	1448.3 e	1.1	42.3 f	13.7 f
$V_1 \times I_2$	1806.7 d	1.2	52.6 d	16.5 e
$V_1 \times I_3$	2102.7 b	1.3	68.6 b	27.9 b
$V_2 \times I_1$	1766.3 d	1.1	48.0 e	19.1 d
$V_2 \times I_2$	1967.7 c	1.3	61.3 c	23.0 c
$V_2 \times I_3$	2325.0 a	1.3	83.6 a	30.9 a
SE	60.445	0.0726	1.7235	0.5585
LSD_{05}	134.68**	0.1619^{NS}	3.8401**	1.2444**

N o t и e. Ccolumn means that are not marked with the same letters are statistically significantly different at $p = 0.05$; ** — high level of significance, ^{NS} — no statistical significance.

The analysis of variance revealed significant differences ($p < 0.05$) for varieties, inoculum doses and their interaction. The results show that maximum biological yield (2019.7 $kg \cdot ha^{-1}$) was recorded for NARC II variety and the minimum biological yield (1785.9 $kg \cdot ha^{-1}$) for NARC I variety.

The results show that for 600 g inoculum dose maximum biological yield (2213.8 $kg \cdot ha^{-1}$) was recorded, followed by 1887.2 $kg \cdot ha^{-1}$) for 400 g inoculum dose. The minimum biological yield, 1607.3 $kg \cdot ha^{-1}$, was recoded when we applied 200 g inoculum per acre. The interactive effect of the varieties and inoculum doses indicates the maximum biological yield, 2325.0 kg · ha^{-1}, for $V_2 \times I_3$ and the minimum biological yield, 1448,3 kg · ha^{-1}, for $V_1 \times I_1$ (see Table 3).

Harvest index (%). Harvest index is one of the major traits that are taken into consideration while a crop variety or specific production technology is developed. It also determines how many photosynthates are converted into economic yield. In soybean, the harvest index describes the percentage of grain/seed achieved from the total biomass weight.

The harvest indeces of soybean varieties as affected by different inoculum doses and their interaction is presented in Table 3. The analysis of variance revealed significant differences ($p < 0.05$) for varieties, inoculum doses and their interaction. The results shows the average harvest index 1.2 % for both NARC II and NARC I varieties.

The results shows that 600 g and 400 g inoculum doses resulted in maximum harvest index (1.3 %). The minimum harvest index (1.1 %) was recorded for 200 g inoculum per acre. The interactive effect (see Table 3) indicates that the maximum harvest index (1.3 %) was recorded in $V_2 \times I_3$, and the minimum harvest index (1.1 %) in $V_1 \times I_1$.

Number of nodules per plant. The soybean plants possess the ability of forming symbiotic association with N-fixing *Rhizobia* bacteria, that develop small swellings on roots described as nodules. In rapid developing soybean plants, formation of nodules starts just after plant emergence. If plant have 6 inches (15 cm) height with first or second trifoliate leaf unfolded, nodules start N-fixing actively and fix N_2 gas into plant available N. Increase in nodulation continues until beginning of seed formation stage and sometimes slightly beyond this stage. Number of nodules per plant in soybean cultivars under various inoculum doses was observed and the results are presented (see Table 3). The soybean cultivar NARC II produced the highest number of nodules per plant (64.3) as compared to NARC I (54.5). Whereas maximum number of nodules per plant (76.1) was recorded when soybean crop was treated with inoculum dose I_3 (600 g per acre), followed by 57.0 nodules woth I_2 inoculation (400 g per acre).

The minimum number of nodules per plant (45.1) was noted with inoculums dose I_1 (200 g per acre). The statistical analysis of data indicated that there was significant ($p < 0.05$) difference in number of nodules per plant between soybean cultivars, inoculum doses and their interactions. The interactive effects of $V_2 \times I_3$ produced maximum number of nodules per plant (83.6), and minimum number of nodules per plant (42.3) was recorded for $V_1 \times I_1$.

Root length (cm). Root length of soybean cultivars under various inoculum doses was observed and the results are presented (see Table 3). The soybean cultivar NARC II produced the highest root length (23.5 cm) as compared to NARC I (20.2 cm). Whereas maximum root length (29.4 cm) was recorded when soybean crop was treated with inoculum dose I_3 (600 g per acre), followed by 21.1 cm noted with inoculum dose I_2 (400 g per acre). The minimum root length (15.1 cm) was noted with inoculums dose I_1 (200 g per acre). The interactive effects indicated that $V_2 \times I_3$ produced maximum root length (30.9 cm) $I_1 \times V_1$ produced minimum root length (13.7 cm). The data processing indicated (see Table 3) that there was significant ($p < 0.05$) difference in root length between soybean cultivars, inoculum doses and their interactions.

Protein content (%). Protein is a macronutrient essentially needed for muscle building in living beings and it is normally found in meat-based products, but other sources of protein are also well recognized which mainly include nuts and legumes. The results on protein content (%) of soybean varieties as affected by different inoculum doses and their interaction are presented (Table 4).

The analysis of variance revealed significant ($p < 0.05$) differences for varieties, inoculums doses and their interaction. The results show that maximum protein content (37.7%) was recorded in NARC II variety and the minimum protein content (34.8%) in NARC I variety.

4. Protein and oil content (%) **in soybean (*Glycine max* L.) depending on the variety and dose of *Bradyrhizobium japonicum* inoculum** (Lasbela University of Agriculture, Water and Marine Sciences, Uthal, Lasbela, Balochistan province, 25.8700°N, 66.7129°E, 2018)

Treatment	Protein content	Oil content
	M	*M*
A — variety (V):		
V_1 = NARC I	34.8 b	32.4 b
V_2 = NARC II	37.7 a	34.5 a
SE	0.4734	0.3497
LSD_{05}	1.0548**	0.7792**
B — dose of inoculate (I):		
I_1 = 200 g/acre	31.2 c	30.4 c
I_2 = 400 g/acre	36.1 b	33.4 b
I_3 = 600 g/acre	41.4 a	36.5 a
SE	0.5798	0.4283
LSD_{05}	1.2919**	0.9543**
C — variety×dose of the inoculate (V×I):		
$V_1 \times I_1$	30.5d	29.8 d
$V_1 \times I_2$	34.0 c	32.3 c
$V_1 \times I_3$	39.9 b	35.1 b
$V_2 \times I_1$	32.0 d	31.1 cd
$V_2 \times I_2$	38.1 b	34.5 b
$V_2 \times I_3$	43.0 a	38.0 a
SE	0.8.	0.6057
LSD_{05}	1.8270**	1.3496**

N o t e. Ccolumn means that are not marked with the same letters are statistically significantly different at $p = 0.05$; ** — high level of significance, ^{NS} — no statistical significance.

The results with different inoculum doses show that when 600 g per acre inoculum was applied maximum protein (41.4%) was recorded, followed by 36.1% protein for 400 g inoculum per acre. The minimum protein (31.2%) was recorded when we applied 200 g inoculum per acre. The interactive effect (see Table 4) of the varieties and inoculums doses indicated that the maximum protein content (43.0%) was in $V_2 \times I_3$, and the minimum protein (30.5%) in $V_2 \times I_1$.

O i l c o n t e n t (%). There are four major fatty acids that compose the soybean oil, the linoleic acid (55%), palmitic acid (10%), oleic acid (18%), stearic acid (4%). Oil content in soybean cultivars under various inoculum doses was assessed and the results are presented (see Table 4). The statistical analysis specified that there was significant ($p < 0.05$) difference in oil content between soybean cultivars, inoculum doses and their interactions.

The soybean cultivar NARC II produced highest oil content (34.5%) as compared to NARC I (32.4%). Maximum oil content (36.5%) was recorded when soybean crop was treated with inoculum dose I_3 (600 g per acre), followed by 33.4% with inoculum dose I_2 (400 g per acre). The minimum oil content (30.4%) was noted with inoculums dose I_1 (200 g per acre). The interactive effects (see Table 4) indicated that interaction $V_2 \times I_3$ produced maximum oil content (38.0%), while $I_1 \times V_1$ minimum oil content (29.8%).

Thus, our experiment conducted in the arid zone of the Arabian Sea coast (Balochistan province, Pakistan) showed that different doses of *Bradyrhizobium japonicum* inoculum significantly affects soybean growth performance.The soybean variety NARC II upon *B. japonicum* inoculation at 600 g per acre produced the maximum seed yield with better growth at all stages of crop development. Maximum nodule formation also occurred upon inoculation at a dose of 600 g per acre.

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