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Irrigation and Bradyrhizobium Japonicum Inoculation Effects on Performance of Soybean Production in Tropical Guinea Savanna Zone of Ghana

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Abstract

A field experiment was conducted to assess the effect of irrigation regimes and *Bradyrhizobium japonicum* strains on the performance of soybean cultivar TGX1440-IE. The study was carried out for two consecutive years during the dry season (February-May) at Tono Irrigation Project site in a Guinea Savannah zone of Ghana. Three irrigation regimes based on soybean crop water requirements (full or normal (W0), half (W1) and one and a half (W2) crop water requirements) and two strains of B. japonicum (LS-50 and TAL-120) along with one uninoculated treatments with three replications were laid out in a split-plot randomized complete block design. The LS-50 strain inoculated soybean (I2) had the highest value in the number of nodulation, growth, yield and WUE, followed by the uninoculated (I0) and the TAL-120 (I1) had the least. The LS-50 strain significantly (P<0.01) increased the number of nodulation, growth, yield and WUE by 15 %, 14 %, 10 % and 12 % respectively over the uninoculated soybean. The one and a half irrigation regime (W2) also had the highest values for all crop parameters determined except WUE followed by the full irrigation regime (W0) and the half irrigation (W1) had the least. W1 however, had the highest WUE, followed by W0 and then W2. The one and a half irrigation regime significantly (P<0.01) increased the number of nodulation, growth and yield by 23%, 28% and 10 % respectively but decreased WUE by 65%, over the full irrigation regime. However, the half irrigation increased the WUE by 36 % over the full irrigation regime. The interaction of LS 50 strain and the one and a half irrigation regime (W2I2) had significant (P<0.05) increase in the growth by 45 % , decrease in WUE by 27 % and insignificant increase in yield over the interaction of uninoculated and full irrigation regime (W0I0). However the interaction of LS 50 strain and half irrigation regime (W1I2) increased the WUE by 95 % over the interaction of uninoculated and full irrigation regime (W0I0).

Keywords: Soybean cultivar, Tono Irrigation Project, Crop water, LS-50 strain, TAL-120 strain.

1. Introduction

Soybean **(Glycine max L. Merill)**, like other leguminous plants, in association with rhizobium species formed root nodules, the site of biological nitrogen fixation (BNF) (Woomer, 2010) to fix atmospheric nitrogen that could contribute to the soil N pool provided that the N-fixation was not restricted by other environmental factors such as water stress (Napoles et al., 2009; Sinclair et al., 2007). According to Argaw et al (2014) and Schipanski et al., (2010), BNF was an effective and efficient source of nitrogen supply to plants and more than 50-83 % of N requirement for soybean could be derived from BNF by symbiotic association with Bradyrhizobium strain. Patra et al., (2012) noted that soil N depleted by 13.4 – 20.2 % in the inoculated soybean field and 29.6% in the uninoculated soybean field. However, Ghanaian farmers especially those in the Guinea Savanna Zone where nitrogen levels were low in the soils relied mostly on chemical fertilizers to meet their crop nitrogen requirement and subsequently the yield.

The increasing cost of chemical fertilizers within the past decades had led to the inability of most of the farmers to optimize their use, and thus exacerbating the low nitrogen problem in the soils of the Guinea savanna zone of Ghana. In this regard, changing elemental atmospheric nitrogen to organic forms by BNF both by symbiotic and asymbiotic microorganisms in the soil had drawn much attention (Solomon et al., 2012). The symbiotic nitrogen fixation could be used to maximum advantage of soybean crop (Solomon et al., 2012) that was intensively cultivated on over 650 ha of land within and around the Tono Irrigation project site in the Guinea savanna zone of Ghana, which yields only ranged between 0.9 to 1.0 $tonha^{-1}$ as compared with 2.1 $tonha^{-1}$ in the Transition, 2.4 $tonha^{-1}$ in the Deciduous Rainforest and 2.0 $tonha^{-1}$ in the Coastal savanna zones in Ghana (ICOUR, 1995). The yields of soybean cultivated within and around the Tono Irrigation site could be improved by artificial inoculation of the soybean seeds with effective strains of rhizobia because not all rhizobial strains were efficient with respect to nitrogen fixation ability (Patra, 2012). There was therefore no doubt that specificity existed between rhizobial strain and the legume, and the compatibility between the two was essential for successful nodulation, and this necessitated using specific soybean species for different rhizobial strains.

Water stress was one of the major causes of reduced growth, development and yield in field crops (Bozorgi, et al., 2011). Li et al., (2004) also noted that under full irrigation regimes plants had higher yields compared with no-irrigation regimes. Water was a factor that affected biological nitrogen fixation (BNF) and in leguminous plants, drought reduced nitrogen fixation and its related traits (Pimratch et al., 2008). According to Napoles et al. (2009) and Sadeghipour et al. (2012), drought stress was a major factor affecting symbiosis and led to decreased nodule formation, reduced nodule size and N-fixation. Sinclair et al., (2007) observed that soybean's symbiotic N-fixation is vulnerable to drought and with declining soil water moisture; soybean had a decrease in N_2 availability to support cell and tissue development throughout the plant. Matheny and Hunt (1983) observed that inoculated non-irrigated soybean can fix 55 and 60 % of atmospheric nitrogen as against 76 and 91 % fixation for inoculated irrigated soybean. Minchin and Pate, (1975) stated that inundation however reduced nodule tissue production and nitrogenase activity due to reduction in oxygen supply.

The Guinea Savannah Zone was characterized by low and erratic rainfall distribution and the occurrence of drought was a common phenomenon. The BNF therefore, could be very successful in the agroecological zone if the soybean was inoculated with **Bradyrhizobium japonicum strains and** put under irrigation regime to optimize the soybean yields. The hypothesis was that irrigation and B. *japonicum* inoculation would improve soybean production in tropical guinea savanna agroecological zone. **Therefore, the objective of the study was to assess** the effects of irrigation regimes and inoculated ***B. japonicum*** **strains** on the growth, nodulation and yield of soybean.

2. Methodology

2.1 Study area

The study was conducted for two consecutive years during the main dry season (February-May) at Tono Irrigation Project site in the Upper East Region of Ghana. The site is located in the Guinea Savannah agroecological zone which is characterized by only one rainy season (June-October) with erratic rainfall, a dry spell of cold, dry and dusty harmattan winds (November-February) (WRRI, 1995). The site lies between latitude 10.75^{o} N and longitude 1^{o} W, along the Navrongo-Tumu road. The mean annual rainfall during the rainy season is between 800 mm and 1,100 mm and the temperature is around 32^{o}C but can drop to 14^{o}C at night during the harmattan season. The relative humidity is about 20 % during the day and 60 % during the night. The wind speed is about 3 m/s (Mdemu et al., 2008). The soils are classified as the Pusiga and the Chuchuliga soil series (Adu, 1969) or lithosols (FAO, 1986), and are shallow, low in fertility and prone to seasonal waterlogging and floods. The irrigation project has a potential area of about 3840 ha with a developed area of about 2490 ha (the developed area is the same as the irrigable area), out of which only 245 ha is under irrigation for the production of rice, sorghum, millet, groundnut, cowpea, soybean and other garden crops by small scale farmers.

2.2 Experimental design and treatments

A split-plot randomized complete block design was used. The treatments were three (3) irrigation regimes (W) and three (3) inoculation levels (I), using soybean (*Glycine max* (L) Merrill) cultivar TGX1440-IE as a test crop. The three irrigation regimes were full irrigation regime i.e. 100 % soybean water requirement, (W0); half irrigation regime i.e 50 % soybean water requirement (W1); and one and a half irrigation regime i.e 150 % soybean water requirement (W2). The three inoculation levels also were zero strain inoculation or uninoculation (I0); *B.* j**aponicum** strain, TAL 102 (I1); and *B.* j**aponicum** strain, LS 50 (I2) inoculations. Each treatment was replicated thrice and this made up a total of 27 plots with each plot measuring 5 m x 3 m.

The crop water requirement (ETc) was determined by Class A evaporation pan method whereby the relative humidity and the wind speed of the study site were considered in estimating the reference crop evapotranspiration (ETo) which is given as (Allen *et al.,* 1998):

$$ET_o = K_p E_{pan} \quad (1)$$

ETo is reference evapotranspiration (mmd^{-1}); Kp is pan coefficient (-) (Kp is 0.70 for the study site at the prevailing relative humidity and wind speed) (Allen *et al.,* 1998); and Epan is pan evaporation (mmd^{-1}). The pan evaporation mean values for February (10.8 mmd^{-1}), March (12.8 mmd^{-1}), April (10.7 mmd^{-1}) and May (7.9 mmd^{-1}) were obtained from a nearby meteorological sub-station (about 200 m away from the study site).

The crop water requirement (ETc) was then determined using (Allen et al., 1998):

$$ET_c = K_c ET_o \quad (2)$$

ETc is crop (soybean) water requirement (mmd^{-1}); Kc is crop factor (soybean Kc during the initial stage is 0.35; the development stage is 0.75; the mid-season stage is 1.10; and the late-season is 0.60) (Allen *et al.,* 1998). The calculated average soybean ETc for February = 2.7 mmd^{-1}; March = 8.1 mmd^{-1}; April = 7.7 mmd^{-1} and May = 3.3 mmd^{-1} were used for the study.

The B. japonicum TAL-102 and B. japonicum LS-50 strains were obtained from University of Ghana, Legon, as two single trains and each strain cultured in yeast extract-mannitol medium. The composition and preparation of the medium was as outlined by Vincent (1970). The medium was then sterilized using method by

Baruah and Barthakur, (1997) to kill all microorganisms in the medium. The medium was then inoculated with the B. japonicum strains and incubated at a temperature of 30^{o}C for 5 days. Soybean seeds were then surface sterilized by dipping in 90 % ethanol for 3 minutes and washed 3 times with distilled water. The sterilized seeds were then dipped into a 10 % sucrose solution for 1 minute and dried on polythene sheet for 5 minutes. The dried seeds were put into the B. japonicum inoculants, shook and allowed to stand for one hour to afford each seed to receive as many rhizobial cells as possible (at least 10^{5}) (Vincent, 1970).

2.3 Fieldwork

The land for the study was then ploughed, harrowed and ridged to obtain well prepared plots with moderate tilth. The soil of experimental field was sandy loam with bulk density 1.48MgM^{-1}, pH 6.5, organic carbon 0.6 %, total nitrogen 0.05%, available phosphorus 32 ppm, exchangeable potassium 0.23cmolkg^{-1} and exchangeable calcium 2.44cmolkg^{-1}. N fertilizer in the form of ammonium sulphate was broadcast at the rate of 20 kgNha^{-1} and incorporated in the ridges by stirring with a hoe. This was to promote rhizobium survival and the full expression of symbiosis. The nitrogen was also used as a starter dose to satisfy the N demand of the plant in the nitrogen hunger period before nodules were developed sufficiently to supply the crops' needs.

Planting (direct sowing) was done in mid February. Two to three inoculated seeds were hand-sown 3 cm deep at row to row and plant to plant distance of 75 cm and 10 cm respectively. Each plot had 4 planting rows with length of 4.5 m, giving a plant population of about 260,000 per hectare. Weed control was done by hoeing at two weeks interval starting from 2 weeks after planting (WAP). Irrigation was done as per treatments with River Tono water of pH 7.4, sodium 7.9 mgl^{-1}, potassium 4.2 mgl^{-1}, calcium 8.7 mgl^{-1}, chloride 3.5 mgl^{-1}, TDS 98.8 mgl^{-1} and EC 1.3 dSm^{-1}.

Six plants per plot were randomly selected on each plot and tagged for growth measurements. The height of each of the six plants above ground surface was measured and the mean height per plot calculated. The heights were taken from 4 to 10 WAP. Leaf area of the tagged plants was measured by tracing the border of a selected leaf on sheet of graph paper, counting the number of whole squares and multiplying by the area of a square and the number of leaves on the plant. The ground area covered by the plant canopy was thereafter calculated. The leaf area index was obtained by dividing the total leaf area of a plant by the ground area covered by the canopy.

The number of days for flowering, podding and maturing were recorded. The number of days for flowering was counted as the days after sowing till 50 % of the plants had one or more flowers (IITA, 1996). Days for podding were the days from planting to when 50 % of the plants had one or more pods. Days to maturity which were the days after planting until 95 % of the pods had changed from yellow colour to tan or grey (IITA, 1996).

Nodule development was assessed by counting the number of nodules along the entire root system on weekly basis from 4 to 10 WAP. Six plants were carefully dug from each plot and soil adhering to the roots was shaken off and the roots washed with water. Number of nodules was determined by visibly counting the number of nodules along the entire root system. Active nodule was assessed by dissecting samples of the nodules with a sharp knife, and the internal colour examined using a hand lens. The nodules with red or pinkish colouration were recorded as active and the percentage determined. After counting the number of nodules, the nodules were removed onto a sheet of paper and the shoot separated from the root using a knife. At physiological maturity, 6 plants per plot were harvested randomly from each plot, and the number of pods per plant, number of seeds per pod and 100 seed weight were recorded. The number of pods and the seeds per plot were then estimated. The pods were then threshed, the seeds weighed and converted to kgha^{-1} to give the grain yield. After removing the pods, the shoots were oven-dried at 65^{o}C to a constant weight and the mean dry weight calculated and converted to kgha^{-1}.

The water use efficiency (WUE) was determined as the ratio of grain yield (kgha^{-1}) to irrigation water volume applied (m^{3}) as outlined by Singh et al (1997).

2.4 Statistical Analysis

Analysis of Variance (ANOVA) was carried using Genstat statistical package, 4th edition. Tests for statistical significance were made at 1 % and 5 % levels using Duncan Multiple Range Test.

3. Results

3.1 Soil and Water Characteristics

The soil at the experimental site had low N level but high available P level . The low soil N level could be due to low organic matter content at the study site, which is typical of tropical savannah soils (Blanchart et al., 2005). This phenomenon was the rationale for the starter N application to assist plant growth during the early seedling period when nitrogen fixation by the plant had not started. The high level of available P could be attributed to the high use of phosphate fertilizers by the farmers at the site (Personal communication) and also the organic matter that could help reduce the P 'fixation' reactions with other cations was low. The pH of the soil was neutral and the harmful effects of soil acidity on the symbionts (Lapinskas, 2007) were not expected. The total dissolved solids and salt concentration in the irrigation water were below harmful levels (Joeng et al., 2016).

3.2 Effects on plant growth

Fig. 1 showed the plant height of uninoculated (I0), TAL-102 strain inoculated (I1) and LS-50 strain inoculated (I2) plants measured from 4 to 10 weeks after planting (WAP). In all the treatments, the plant growth reached the peak at 10 WAP. The I2 plants gave the highest plant height followed by the I0 plants and the I1 plants being the least (Fig. 1) even though the heights of I0 and I1 plants were statistically similar. The irrigation regimes also significantly ($P< 0.01$) had effect on the plant growth. The plant height increased with increasing irrigation regimes (Fig. 2). The one and a half irrigation regime (W2) gave the tallest plant height (45.3 cm) followed by the full irrigation regime (W0) plants (36.2 cm) and half irrigation regime (W1) plants gave shortest height (29.1 cm). The interaction of irrigation and inoculation also significantly ($P< 0.01$) influenced the plant height. At each irrigation regime, I2 plants were the tallest, while I1 plants were shortest (Table 1). The one and a half irrigation regimes with LS-50 strain inoculated plants (W2I2) were tallest while half irrigation regimes with TAL-102 strain inoculated plants (W1I1) were the shortest. Generally the W1 plants produced the least height irrespective of the type of strain inoculation (Table 1).

The leaf area index (LAI) followed similar pattern as the plant height. The I2 plants had the largest leaf area index (4.6) whilst the LAI of I1 and I0 plants were not significantly different (Fig. 3). The differences of LAI for both W0 and W2 were highly significant ($P< 0.01$) from the LAI of W1 from 4 to 10 WAP. However LAI of W0 and W2 only showed significant differences after 7 WAP (Fig. 4). The interactive effect of irrigation regimes and inoculation on LAI showed that there were no significant differences ($P< 0.01$) between the full (W0) irrigation level with strain inoculation and the one and a half (W2) irrigation level with the corresponding strain inoculation (Table 1). However there were significant ($P< 0.01$) differences in LAI between the interactive of half irrigation regime (W1) with inoculation and the interactive of other irrigation regimes with inoculations (Table 1).

There was also no significant difference in days to flowering, podding or maturity between the plants inoculated with LS-50 strain (I2) and TAL-102 strain (I1) inoculated plants and/or the uninoculated plants (I0) (Fig 5). The irrigation regimes, however, had effect on the number of days to podding and maturity but not on the number of days to flowering (Fig 6). The plants supplied with the one and a half irrigation (W2) took the least number of days to reach podding and maturity stages followed by plants with full crop water requirement (W0) and

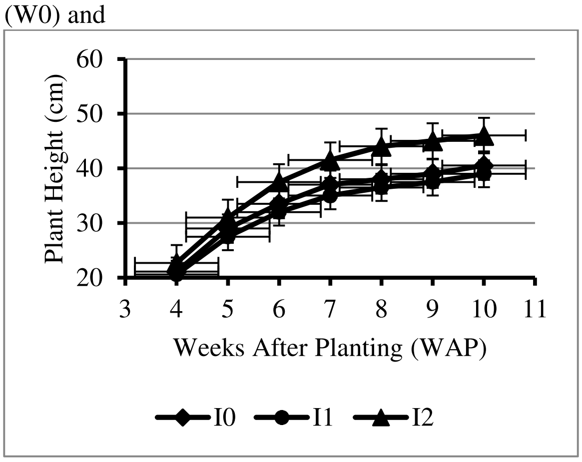

Fig. 1: Plant height from 4 to 10 WAP as affected by Rhizobium inoculation

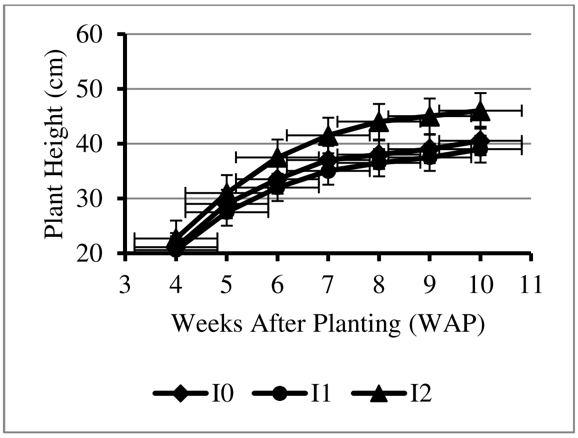

Fig. 2: Plant height from 4 to 10 WAP as affected by different irrigation levels

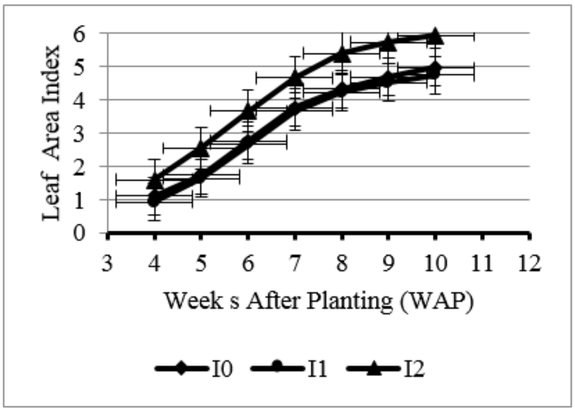

Fig. 3: Leaf Area Index from 4 to 10 WAP as affected by Rhizobium inoculation

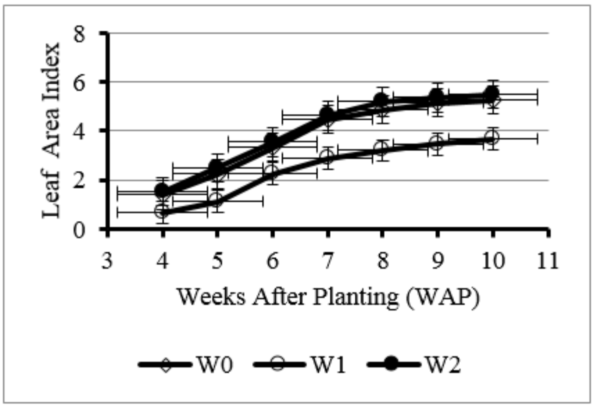

Fig. 4: Leaf Area Index from 4 to 10 WAP as affected by different irrigation levels

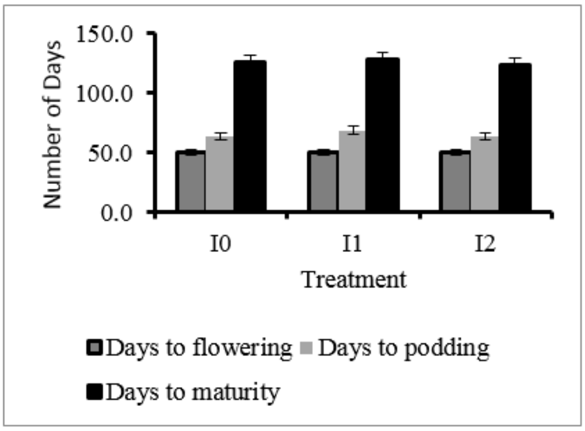

Fig. 5: Number of days to flowering, podding and maturity as influenced by Rhizobium inoculation

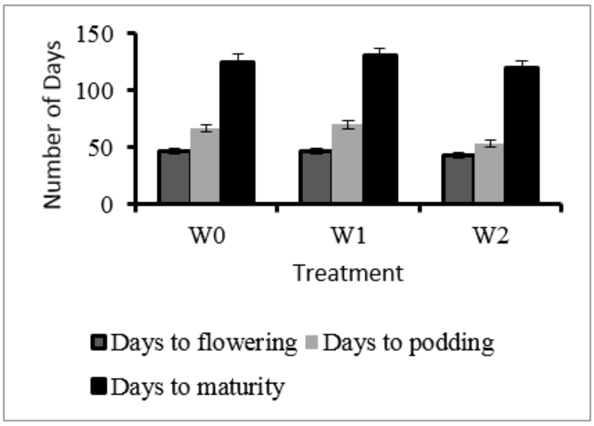

Fig. 6: Number of days to flowering, podding and maturity as influenced by different irrigation levels

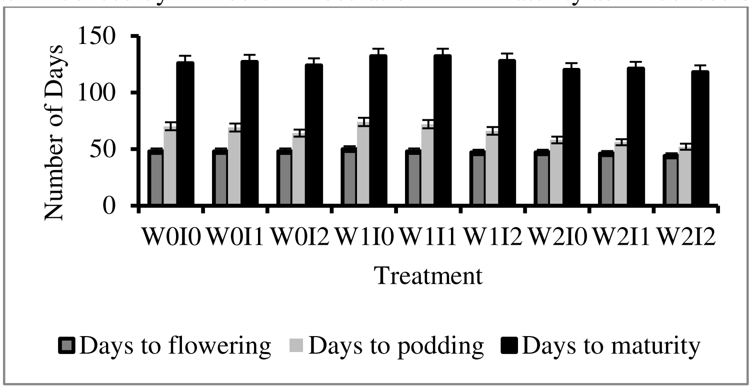

Fig. 7: Interactive effect of irrigation and Rhizobium inoculation on number of days to flowering, podding and maturity.

the plants supplied with half crop water requirement (W1) had more days. This was reflected in the interaction of irrigation and inoculation effect on days to podding and maturity as shown in Fig. 7. The number of days to podding shortened from 74 day at W1I1 to 50 days at W2I1. Similarly, the number of days to maturity also shortened from 132 days at W1I1 to 110 days at W2I2 (Fig. 7). From Fig. 7, it was noted that within the same irrigation regime, the inoculation type did not have any significant effect on number of days to flowering, podding or maturity. Thus within the same irrigation regime, the number of days to flowering, podding or maturity did not change with the different strain of inoculation.

3.3 Effect on number of pods per plot, shoot dry matter and grain yield

The I2 plants had the highest number of pods per plot followed by the I0 plants and the I1 plants having the least number (Table 2). There was significant (P< 0.01) difference between I2 plants and the I0 plants and between the I1 plants and the I0 plants. There were also significant differences of the number of pods per plot between plant with one and a half irrigation regime (W2) and those with either full irrigation (W0) or half irrigation regime (W1); but there was no significant difference in pods per plot between the full irrigation regime (W0) and the half irrigation regime (W1) (Table 3). The number of pods was not affected by the interactive effect of irrigation and inoculation.

Table 1: Interactive effect of irrigation levels and Rhizobium strains on plant height, LAI, shoot dry matter weight and water use efficiency.

Irrigation and Rhizobium interactive	Plant height (cm)	Leaf Area Index	Shoot dry weight ($kgha^{-1}$)	Water Use Efficiency ($kgha^{-1}m^{-3}$)
W0I0	35.5	4.2	130.0	2.2
W0I1	31.5	4.1	120.0	1.8
W0I2	42.7	5.3	133.5	2.5
W1I0	28.5	2.7	115.0	3.7
W1I1	28.2	2.5	110.0	3.3
W1I2	30.9	3.4	111.6	4.3
W2I0	46.4	4.3	133.6	1.3
W2I1	45.6	4.2	131.7	1.25
W2I2	51.8	5.1	146.7	1.56
LSD (0.01)	1.55	0.2	7.36	0.26

Table 2: Effect of Rhizobium strain on number of pods per plot, shoot dry matter weight, grain yield and water use efficiency

Rhizobium strain	Number of pods/plot (x 10^3)	Shoot dry weight ($kgha^{-1}$)	Grain yield ($kgha^{-1}$)	Water Use Efficiency ($kgha^{-1}m^{-3}$)
I0	13	126.7	1.0	2.5
I1	11	120	0.9	2.1
I2	14.5	130	1.2	2.8
LSD (0.01)	0.93	5.7	0.05	0.1

Table 3: Effect of Irrigation levels on number of pods per plot, shoot dry matter weight, grain yield and water use efficiency

Irrigation level	Number of pods/plot (x 10^3)	Shoot dry weight ($kgha^{-1}$)	Grain yield ($kgha^{-1}$)	Water Use Efficiency ($kgha^{-1}m^{-3}$)
W0	12.0	126.5	1.0	2.2
W1	10.5	113.0	0.9	3.8
W2	15.3	136.5	1.2	1.4
LSD (0.01)	0.93	6.32	0.08	1.45

The shoot dry matter at harvest showed trend similar to number of pods per plot. However statistically there was significant difference between I2 plants and I1 plants, and between I0 plants and I1 plants but no significant difference between I2 plants and I0 plants (Table 2). The plants with W2 irrigation regime had highest dry matter, followed by the plants with W0 irrigation regime and the plants with W1 regime being the least (Table 3). The interactive effect of irrigation and inoculation was significantly ($P < 0.01$) different between treatments. Plants with I2 strain and received W2 irrigation regime had the highest dry shoot while all plants with W1 irrigation regime had the least dry shoot (Table 1).

The grain yield differed significantly ($P < 0.01$) between inoculation treatments, with I2 plants producing 25 % more grain over I1 plants which recorded the least grain yield (0.9 kg/ha) (Table 2). The irrigation regimes also significantly ($P < 0.01$) affected the grain yields of the various inoculated plants. Plants with W2 irrigation regimes yielded as high as about 25 % more grain than plants with W1 regime (Table 3). The interactive effect of irrigation and inoculation produced did not change the grain yield.

3.4 Effect on nodulation and water use efficiency (WUE)

Fig. 8 showed the number of nodules developed by the plants of different inoculations from 4 to 10 WAP. The I2 plants had the highest mean number of nodules (53 per plant) developed while the least mean number (37.5 per plant) was recorded by the I1 plants with the I0 plants having a mean number of 42.5 nodules per plant. The peak of the total nodules development by all the plants was reached at 8 WAP and started to decline afterwards.

There was significant (lsd = 0.01) difference between the I2 plants and I0 plants and I1 plants, and between the I0 and I1 plants. The nodulation of the uninoculated plants suggested the presence of a high number of indigenous rhizobia in the study area. Thies, et al (1991) noted that high number of indigenous rhizobia were effective to meet the symbiotic requirements of legumes and could reduce or eliminate an inoculation response of some strain introduced. This was clearly reflected especially when the results produced by the I1 inoculated and I0 plants were compared. Similarly, irrigation regimes also affected nodule development from 4 to 10 WAP, with highest number of nodule formed per plant recorded for plants with W2 irrigation regime, while plants with W1 irrigation regime had the least (Fig. 9). The interaction of irrigation and inoculation with W2I2 plants showing significantly ($P < 0.01$) different number of nodules per plant from W1I1.

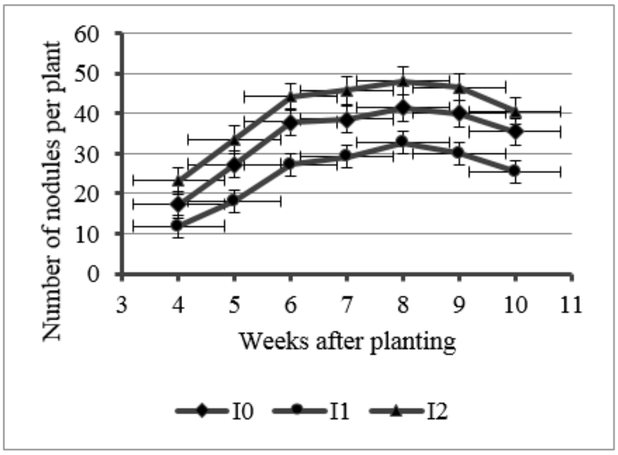

Fig. 8: Number of nodules from 4 to 10 WAP as influenced influenced by Rhizobium inoculation

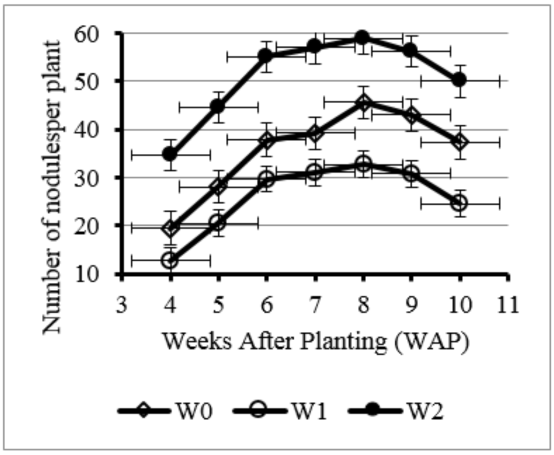

Fig. 9: Number of nodules from 4 to 10 WAP as influenced by irrigation levels

Water use efficiency (WUE) was significantly ($P< 0.01$) affected by both irrigation and inoculation. The I2 plants had the highest WUE, followed by the I0 plants, while the I1 had the least WUE (Table 2). Similarly, the plants with W1 irrigation regime had the highest WUE, followed by plants with W0 irrigation regime whilst the W2 plants had the least (Table 3). The interactive effect of irrigation and inoculation had significant differences between treatments. From Table 1, W1I2 plants had the highest WUE whilst the least WUE was obtained from W2I1 plants. The results showed that WUE decreased with increasing irrigation water level to the extent that WUE of plants with the one and a half irrigation regime was about 65 % less than that of the full irrigation plants whilst the WUE of plants with half irrigation regime was about 36 % higher than that of the full irrigation plants. This could be that with increasing irrigation levels, evapotranspiration and other field losses also increased.

4. Discussion

In this study, water stress (half crop water requirement) decreased soybean plant height, LAI, pods per plot, shoots dry matter weight, grain yield and increased number of days to podding and maturity. The decrease in soybean growth and yield due to water stress has been reported by other researchers (Masoumi, et al, 2011; Sadeghipour and Abbasi, 2012; Shafii et al, 2011). The results revealed that increasing irrigation levels resulted in increased nodulation, growth and yield which could be attributable to increased water supply to the symbionts. Sinclair et al, (2007) observed that soybean symbiotic N-fixation was vulnerable to water stress and with soil moisture decline, the soybean decreased N-fixation rates in advance of declines of other physiological processes, thereby a decrease in N availability to support cell and tissue development throughout the plant.

The results also showed that increasing irrigation regime increased soybean response to inoculation by the two B. japonicum strains, and at each irrigation regime the LS-50 strain was superior to the TAL-102 strain or the uninoculated. The crop growth was observed to be sensitive to irrigation to the extent that the shoot dry matter weight on one and a half irrigation regime (W2) were about 32 % heavier than those on full irrigation regime (W0). The differences in soybean response to the combine effects of irrigation and inoculation reflected the differences in photosynthetic rates of inoculated soybean at high or low water potential in the soil (Bushby and Marshall, 1977). It was observed that soybean plants which were given one and a half crop water requirement and received LS-50 strain inoculation (W2I2) produced higher number of nodules, amount of shoot dry matter and grain yield, and therefore higher nitrogen contribution to the soil than soybean plants that were supplied half crop water requirement (W1) with TAL-102 strain inoculation (I1) produced the least values of these parameters and subsequently least N-contribution to the soil as observed by El-Fayoum et al. (1996).

The performance of the soybean cultivar inoculated with LS-50 in all the irrigation regimes reflected the effectiveness of the strain in relation to the cultivar used (Woomer, 2010), its adaptability to the soil conditions at the study site (Olufajo and Adu, 1992), the quality of the inoculants used (Roughley, 1985; Williams, 1984), the rate of its survival on the seed (Woomer et al., 1992), and its degree of colonization of the rhizosphere and plants roots in the presence of organism antagonistic to it (Giller and Wilson, 1993; Segovia et al., 1991). It was observed that the response of soybean to *B. japonicum* inoculation was constrained by the presence of an effective number of indigenous rhizobial populations (Janice et al. 1991). The soybean cultivar used for the study was promiscuous nodulators. The results in one part were in agreement with Abaidoo et al (1999) who observed that promiscuous cultivars were characterized by significant response to *B. japonicum* inoculation in soils low in N and without significant *B. japonicum* population. The results in another part were also in agreement with the observation by Pulver et al., (1982) that promiscuous soybean cultivars did not require *B. japonicum* inoculation. This clearly indicated that indeed response to inoculation depended on not only promiscuity of the cultivars but also other factors as the type of *B. japonicum* strain, the strain effectiveness and competitive ability, quality of the inoculants, strain tolerance to prevailing condition and soil management practices (Giller and Wilson, 1993; Williams, 1984) as clearly shown in TAL-102 strain inoculated plant.

The poor performance of TAL-102 strain in all the irrigation regimes was probably due to the poor quality of the inoculants (Williams, 1984). According to Roughley (1985), 10^2 strain cells per seed provided a satisfactory inoculant level in r*hizobium*-free soil with good conditions, but where large number of ineffective rhizobia occurred and the conditions were adverse for rhizobium survival, numbers in excess of 10^6 cells per seed could be required. The poor performance could also be attributable to the presence of the indigenous rhizobia which proved to be more effective and competitive than TAL-102 in terms of number of nodulation and the other parameters determined. Both the nodulation of the uninoculated soybean and the previous cropping history of the experimental site are evidence of the presence of sufficient, compatible indigenous rhizobia at the site. Another factor that might have caused the poor performance of TAL-102 strain inoculated soybean could be the absence of a compatible cultivar resulting in the formation of less effective symbiosis which led to poor inoculation response. Also, the seed environment probably did not permit a good survival and colonization of the rhizosphere by the TAL-102 strain, thus resulting in a decline in population of the strain. Woomer et al (1999) reported a similar finding when they released a rhizobian strain into a tropical soil. They found that the population size declined rapidly, becoming non-recoverable or establishing at stable levels.

5. Conclusion

The study revealed that the effects of irrigation and *B. japonicum* inoculation on nodulation formation, growth and yield of soybean were highly significant. The *B. japonicum* strain, LS-50, produced the highest inoculation response in all the parameters investigated, while strain TAL-102 gave the least with the effect of the indigenous strains being moderate irrespective of the amount of irrigation used. The interactive effect of one and half irrigation regime and strain LS-50 was highest in all the parameters assessed except water use efficiency which was greatest when the irrigation regime was halved. The study concluded that soybean production was improved by *B. japonicum* inoculation and more especially when LS-50 strain usage was combined with water application in excess of the crop water requirement but WUE increased when less water than the crop water requirement was applied with LS-50.

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