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Research Article

Snap Bean (*Phaseolus vulgaris*) Response to Deficit Irrigation and Nitrogen Fertilizer and Relationships between Yield, Yield Component, and Protein Content

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Field experiments were conducted at Adami Tulu, Ethiopia, for two successive dry seasons to investigate how nitrogen levels and deficit irrigation affect the yield and its related components, and the protein content of snap beans. The treatments were deficit irrigation with three levels (50, 75, and 100% ETc) and application of nitrogen with four levels (0, 46, 92, and 138 kg·N·ha^{-1}), which were set up as split-plot arrangement, with irrigation being as the main plot and nitrogen levels as subplot, replicated thrice. Results showed that the pod yield had a substantial impact ($p < 0.01$) on the interaction between the two factors; i.e., interaction of 100% ETc and 92 kg nitrogen levels per hectare recorded the highest pod yield (22.69 t·ha^{-1}), but treatment combinations of 50% ETc and no nitrogen application produced the lowest amount of overall pod yield (6.922 tons per hectare). However, the results showed that the application of 75% ETc in combination with 92 kg nitrogen per hectare recorded the highest protein concentration (17.718%) but statistically equivalent to 138 kg nitrogen per hectare combined with the same deficit irrigation level, while the lowest protein concentration (12.24%) was recorded at 50 ETc combined with no fertilizer. Hence, the use of 75% ETc along with 92 kg nitrogen levels per hectare could be optimal in balancing quality and pod output of green beans at Adami Tulu and surrounding areas.

1. Introduction

The snap (green) bean is a variety of common beans, primarily grown for its tender and immature seed pods [1]. The young pods and seeds are raised and offered for sale as fresh, preserved, or frozen products [2]. Vegetable green beans are a fantastic source of vitamins and minerals, as well as protein and soluble fiber, and are little in calories [3]. Legumes are recognized as a significant dietary source next to cereals since they are a sustainable and affordable meat substitute, whereas animal-based proteins are more expensive [4].

Snap bean grows in many parts of Ethiopia, specifically Adami Tulu Jido Komoblcha District, where different vegetables, including green beans, grow using irrigation for export and native market with an irrigation potential of 14,000 hectares of land [5]. In 2018, Ethiopia exported about 1760 tons of green beans, mainly to Europe and also the Near East, bringing 3.228 million dollars in revenue to the country [6]. The global annual production of green beans in 2018 is 24,752,675 tons from 1, 567,394 ha of land, whereas 0.76 million metric ton heaps of fresh pod yield are cultivated on 71,341 ha in Africa [6]. When compared to the average productivity of the world (15.3 tons per hectare) and Africa

(9.37 tons per hectare), Ethiopia's yield was only about 7,384 tons with an average output of 4.1 tons per hectare [7].

The most significant restrictive constraints for agricultural productivity in Ethiopia are soil fertility and water availability [8]. Because green beans are less able than other legume crops to fix atmospheric nitrogen, they have a higher demand for nitrogen fertilizer [9]. Research works also evidenced that applying 100 kg nitrogen per hectare enhanced pod production by 42% compared with the control and by 17% compared with rhizobial inoculation [10]. Additionally, as shown in Ref. [11], the combination of 100 to 150 kg nitrogen per hectare and 2 kg boron per hectare improved snap bean output and pod quality while being economically viable for growers in the Dugda District.

The smallholder farming system, which dominates the Ethiopian agricultural sector, has drawbacks such as lack of resources and deteriorating soil quality, which hinder sustainable crop production [12]. Green bean pod quality and productivity were shown to be influenced by nitrogen fertilizer and irrigation levels. According to Ref. [13], nitrogen treatment to green pods had an impact on the protein and mineral contents of pods. Water stress dramatically reduced the number of pods and seed output but increased the amount of seed protein, according to Refs. [14, 15]. Limited information is available on the effects of nitrogen fertilizer and deficit irrigation on green bean production and quality in Ethiopia but notably in the Central Rift Valley region. Therefore, this study was conducted to examine how green beans respond to nitrogen fertilization levels and deficit irrigation in terms of yield components, protein content, and optimal pod yield.

2. Materials and Methods

2.1. Experimental Site. The research was carried out at the Adami Tulu Agricultural Research Center field site, which lies in the Mid Rift Valley region, 167 kilometers away from the national capital on the Hawassa route. It is situated between 7° 19′ and 7° 40′ N latitude and 38° 35′ and 38° 53′ E longitude. The average annual minimum and maximum temperatures are 12.6°C and 28.6°C, respectively. Its elevation is approximately 1650 m.a.s.l, and its annual rainfall is 727.1 mm (ATARC Meteorological Data, 2000–2019).

2.2. Designing Experiments and Crop Management. The research consists of three deficit irrigation levels (50%, 75%, and 100% ETc) and four nitrogen levels (0, 46, 92, and 138 kg per hectare), and a snap bean variety (Plati) released in the year of 2016 from the Melkassa Research Center used for the experiment. With nitrogen rates serving as the subplot and deficit irrigation serving as the main plot with three replications, the treatments were set up using a split-plot design. The spacing used between plants was 0.1 meter, and the row, 0.5 meter. The experimental plots were 3 by 3 meters in size. Replications and experimental plots were separated by 1 and 0.5 meters, respectively. Samples during data collection were gathered from the middle of each plot.

Snap bean seeds (from the Melkassa Research Center) were seeded following tractor plowing of the ground to level the experimental plots and drip watering of the experiment. As a source of nitrogen, urea ($CO(NH_2)_2$) was employed, and it was treated in two doses: The first half was spread in the seed furrows beneath the seeds at planting time, and the second half was spread as a side dressing during the pre-blooming time. Each hill received two seeds, buried five centimeters deep, but the latter seedling was thinned out when it had two to three leaves. Before sowing, disturbed and undisturbed soil samples were collected. Soil composites were prepared from the soil at a depth of 25 cm, and undisturbed samples were taken using core samplers from soil profiles of 0–30, 30–60, and 60–90 cm. Weeds are controlled regularly by hand in all plots. To manage the fungal disease, mancozeb 80 WP was applied at the rate 2.5 kg/ha mixed with 200–300 liters of water at early stages of development.

2.3. Setup of a Drip System. Within each treatment, the installation and arrangement of various drip system components made of vinyl polymer was done on uniform and leveled plots. There were 36 plots, and each plot contains six laterals, each lateral measuring 3 m in length with 15 emitters (20 cm emitter spacing). In order to supply each treatment with the necessary amount of water, containers (220 liters in capacity) were placed two meters above the ground and linked to each drip system component. In the dry seasons of 2019 and 2020, the drip system's various parts were laid out along the rows of crops.

2.4. Crop Water Requirements and Their Determination. The FAO Penman–Monteith equation [16] was incorporated in the model of CROPWAT 8 [17] to calculate the reference evapotranspiration from the green bean field. The FAO CROPWAT 8.0 model was used to calculate the ETo of the experimental location by providing long-term years (2000–2018) of meteorological data. During the season, the crop evapotranspiration (ETc) was estimated by multiplying the ETo by the crop coefficient (Kc) at each crop development period (Equation (1)). Since the research location lacked a site-specific kc for snap beans, the following FAO [16] values for the four crop growth phases were used:

$$\mathrm{ETc} = \mathrm{ETo} \times \mathrm{Kc}, \tag{1}$$

where ETc, ETo, and Kc stand for crop evapotranspiration in millimeters per day, reference crop evapotranspiration in millimeters per day, and crop coefficient, respectively.

Within the research location, the check crop's complete growth season lasted between 70 and 75 days. Snap bean growth phase was divided into initial, development, middle, and late phases [16]. Initial, development, middle, and late period length in days were 15, 25, 25, and 10, respectively [16].

Equation (1) was used to calculate the quantity of irrigation water required to refill the root zone of the soil back to field capacity for the control, also known as the "no stress" or 100% ETc. The predicted crop water needs to be computed during the growing season served as the basis for water applications for control (100% ETc), while planned water deficit treatments of 75% and 50% ETc were also used. For the type of irrigation employed in this trial, the field application efficiency and wetted area were 90 and 60%, respectively [18]. Due to the fact that irrigation frequency is based on the crop's daily water needs during the whole growing period, it was identical.

The catch test technique was used to decide the emitter flow rate and flow rate fluctuation at an operational pressure head of two meters. Table 1 displays the emitter discharge measurement results. The field distribution uniformity, emitter coefficient of variation, and emitter flow variation were all outstanding based on the advice in Ref.[19], and the emitter uniformity was acceptable based on Ref. [20]. According to Ref. [21], the emitter flow deviation in the trickling approach should not be higher than 20%.

Table 1: Trickle irrigation homogeneity at the testing site.

Variables	Standard
Distribution uniformities (%)	92
Emitter flow deviation (%)	12.95
Coefficient of deviation (%)	5.8
Consistency coefficient (%)	93

Source: own data, 2019.

2.5. Sampling and Evaluation of Soil. Prior to sowing, intact soil tests were conducted at pits of 0–30, 30–60, and 60–90 centimeters of soil at the trial site to establish bulk density (BD), permanent wilting point (PWP), and field capacity (FC).

The bulk density was calculated by taking soil samples at various depths, drying them for 24 hours at 105°C in an oven, and weighing the dry samples to measure their dry weight.

$$\mathrm{Pb} = \frac{\mathrm{Wd}}{\mathrm{Vt}}, \tag{2}$$

where Wd and Vt stand for the volume and mass of the sample, respectively, of an oven-dried soil sample.

Monitoring irrigation requires accurate measurement of the soil moisture variable. The permanent wilting point and soil moisture at field capacity were identified. For this, soil samples were taken at the three depths previously mentioned, dried in the sun, and then crushed before being submerged in water for a day. The moisture content of field capacity and permanent wilting point was determined using pressure plate equipment and pressure membrane tools. For field capacity and permanent wilting point, suctions of −1/3 and −15 bars were exerted, respectively.

Additionally, a mixed soil sample was taken from the investigational site at a depth of 0–20 cm using an auger to ascertain various physicochemical soil parameters. The soil had a loam texture, a pH (7.7), an electrical conductivity of 0.2 ds/m, and total nitrogen of 0.12%. The modified Bouyoucos hydrometer technique was used to establish the soil texture [22]. Using the wet combustion method described by Ref. [23], the soil's organic carbon content was calculated. The CEC method, along with ammonium acetate at neutral pH, was used to calculate cation exchange capacity [24]. From saturated soil paste extracts, the electrical conductivity of the soil was determined [25]. The wet oxidation step of the Kjeldahl technique, as explained by Ref. [26], was used to estimate the soil's whole nitrogen concentration. Using the Olsen method, a 0.5 M sodium bicarbonate extraction solution (pH 8.5) was used to quantify the amount of accessible phosphorus in soils [27].

2.6. Measurements on the Plant

2.6.1. Pod Yield and Its Component. The fresh pods that were picked from the experimental plots' center (2.25 m^2) were weighed, and the measured weight was converted to standard values in hectare bases for the determination of fresh pod yield. The overall production of fresh pods included both marketable and unmarketable pods. Five arbitrary plants were selected for the average plant height, leaf and branch number, pod length, pod diameter, and pod curvature (the ratio of the measure of straight distance between the two tips of each pod to the actual length of pods).

2.6.2. Protein Concentration. Samples for protein concentration were collected for every treatment within the center of experimental plots. For analysis of protein content, the entire nitrogen in green bean pods was determined by sulfuric acid-hydrogen peroxide digestion using a temperature-controlled digestion block [28]. Total nitrogen concentration was then determined using an automated colorimetric analysis of the digest [29]. The analysis was carried out in the Hawassa Agricultural Research Center laboratory. To estimate the dry weight based on protein concentration, the amount of nitrogen in the pod was multiplied by 6.25[30]. To calculate the fresh pod protein concentration, the following formula is used:

$$\text{protein concentration}\,(\%\text{ in FW}) = \left(\frac{\%\text{ protein concentration in DW}}{11.93}\right). \tag{3}$$

2.7. Analysis of Statistics. The SAS 9.0 software was used to perform analysis of variance (ANOVA) on the pertinent data that were gathered from investigational plots. Before beginning the analysis, the data were verified to ensure that all parameters satisfied the assumptions of homogeneity of variance and normality. The Proc GLM was used, with the year acting as a random effect, and irrigation and nitrogen levels acting as fixed factors. The means were also separated using the least significant difference, which was set at 5% (see Table 2).

3. Results and Discussion

Tables 3 and 4 display the mean square values from the Proc GLM ANOVA F-test for measured variables of snap bean (PH, LN, BN, PdL, PdCrv, PdD, PdN, PC, and TPdY) as affected by deficit irrigation levels and nitrogen fertilizer rates.

Table 5 provides seasonal water requirements for the crop, water consumption at different stress levels, and saved depth of water averages of the two years (since no significant differences were shown between years).

3.1. Growth Parameters. The plant height of snap bean plants had a significant ($p < 0.01$) effect on the main effects of irrigation and nitrogen levels, but it showed no significant interaction effect at the 5% probability level (Table 3). The main effects of leaf and branch number had a considerable impact on deficit irrigation at 5% and nitrogen fertilizer levels at 1% probability levels, but the interaction effect of the two factors was not markedly altered at the 5% probability level (Table 3).

3.1.1. Plant Height. According to the outcome, only the main effects of irrigation and nitrogen levels had a statistically significant ($p < 0.01$) impact on plant height (Table 3). When irrigation levels were considered, it was discovered that plants treated with 100% ETc had the tallest plant height (46.38 cm). However, with 50% ETc, the shortest plant height (36.13 cm) was observed (Table 6). In comparison with the 50% ETc, the 100% ETc increased the mean plant height by roughly 28.4%. The physiological processes of the plant, such as photosynthesis and assimilation, are slowed down under soil moisture stressors, which ultimately prevents cell division and results in the shortest plant ever observed at a higher deficit irrigation level. Similar results were found in Ref.[31], which found that soybean plant heights were considerably impacted by limited irrigation treatments. Similar findings were made by Hou et al. [32], who discovered that at various tomato growth stages, plant height rose significantly as irrigation quantity increased.

The highest plant height was measured at 92 $\text{kg}\cdot\text{N}\cdot\text{ha}^{-1}$ (46.5 cm) application in terms of the nitrogen effect, whereas the shortest plant height was measured at no nitrogen fertilizer application (control) (Table 6). Compared with unfertilized plots, the 92 $\text{kg}\cdot\text{ha}^{-1}$ nitrogen level enhanced plant height by roughly 23.4%. The tallest plant height observed under optimal nitrogen fertilization may indicate an increase in plant height as a result of nitrogen fertilizer application, which is obvious given that nitrogen is necessary for plant growth as a component of all proteins and nucleic acids. This result is consistent with that of Ref. [33], which demonstrated that increasing nitrogen levels up to 82 kg boosted the plant height. Ref. [34] also observed that nitrogen fertilization had an impact on bean height. Similar to this, Ref. [35] reported that spinach plants grew taller after receiving nitrogen fertilizer application.

3.1.2. Leaf Number. The primary impacts of irrigation ($p < 0.05$) treatments and nitrogen fertilizer levels ($p < 0.01$) significantly altered the number of leaves on green bean plants. Conversely, at the 5% probability level, the interaction effect of these treatments had no discernible impact on it (Table 3). According to the study, the largest number of leaves plant^{-1} (66.04) was achieved at 100% ETc, which was statistically equivalent to 75% ETc, and the lowest number of leaves plant^{-1} (51), at 50% ETc deficit irrigation (Table 6). This research also showed that leaf number plant^{-1} decreases under water stress, and this might be because cell division is affected by water stress. The outcome is consistent with that of Ref. [36], which showed that irrigation levels had a favorable impact on the vegetative development of green bean plants or the number of leaves.

The data in Table 6 demonstrated that the largest leaf number plant^{-1} (65.89) was observed at 92 $\text{kg}\cdot\text{ha}^{-1}$ nitrogen fertilization, but that 138 $\text{kg}\cdot\text{N}\cdot\text{ha}^{-1}$ fertilization did not show any significant change. The lowest leaf number obtained at control was statistically on par with leaf number attained at 46 kg nitrogen per hectare. As it is possible that nitrogen's participation in the production of proteins and enzymes is necessary for cell division and development, it causes a favorable impact on the number of leaves plant^{-1}. The leaf number per plant in response to nitrogen fertilizer is in line with the results of Ref. [37], which noted that all growth measurements of snap beans were increased significantly with the addition of higher levels of nitrogen fertilizer.

3.1.3. Branch Number. The average number of branches plant^{-1} was strongly impacted by the main impacts of irrigation levels ($p < 0.05$) and nitrogen rates ($p < 0.01$) (Table 3). This study showed that 100% ETc gave the highest branch number (13.625) of snap beans, but it was statistically on par with 75% ETc. A significantly higher (58.7%) branch number was obtained as a result of the application of 100% ETc as compared to the 50% ETc irrigation level. In general, the branch number per plant increased with lowering stress level (Table 6). This could be due to the fact that water is essential for the intake and transportation of nutrients, thereby increasing the vegetative growth of a crop. Similarly, Refs. [38, 39] reported that increasing water application enhanced practically all plant development metrics including the number of branches plant^{-1}.

The addition of 92 $\text{kg}\cdot\text{N}\cdot\text{ha}^{-1}$ (13.167) had a substantial impact on the number of branches plant^{-1} as well, with the lowest number of branches attained at control (9.167) (Table 6). Since nitrogen is necessary for plant development and higher output, an increase in the number of branches per plant may be due to the addition of nitrogen to the plant. The outcome is in line with that of [40], which concluded that the nitrogen application increases plant height and branch count. Similarly, Ref [41] reported that nitrogen application at 123 $\text{kg}\cdot\text{N}\cdot\text{ha}^{-1}$, which was statistically comparable to 82 $\text{kg}\cdot\text{N}\cdot\text{ha}^{-1}$ treatments, produced the highest number of main branches. The outcome, however, is in contradiction to the assertion of Ref.[42] that consecutive applications of nitrogen fertilizer, i.e., up to 164 $\text{kg}\cdot\text{ha}^{-1}$ nitrogen, have significantly increased branch number plant^{-1}.

Table 2: Average field capacity, permanent wilting point, total available water (TAW), bulk density, and textural class of the experimental site at different soil depths.

Soil depth (cm)	FC vol (%)	PWP vol (%)	TAW (mm)	BD (g/cm^3)	Textural class			
					Sand	Silt	Clay	Textural category
0–30	36.93	21.00	47.79	1.10	34.98	45.65	19.39	Loam
30–60	34.07	23.44	31.89	1.13	30.17	48.0	21.32	Loam
60–90	29.13	16.81	49.28	1.15	43.12	41.37	15.51	Loam

Source: own data, 2019.

Table 3: Mean squares for snap bean plant height (PH), leaf number (LN), branch number (BN), pod length (PdL), and pod curvature (PdCrv) (*F*-test).

Source of variation	DF	PH	LN	BN	PdL	PdCrv
Y	1	15.13	217.01	46.72	4.21	0.008
R (Y)	4	7.71	10.57	3.36	0.59	0.0005
Ir	2	640.5**	1432.54*	156.29*	54.46**	0.08**
Y*Ir	2	6.17	29.01	4.6	0.16	0.0003
Error Ir	8	8.73	16.84	2.01	1.28	0.0007
N	3	319.46**	616.61**	52.37**	12.37**	0.012**
Y*N	3	3.13	20.72	0.94	0.05	0.00004
Ir*N	6	10.28^{NS}	7.47^{NS}	0.77^{NS}	0.44^{NS}	0.0003*
Y*Ir*N	6	3.83	7.72	0.82	0.12	0.00004
Residual	36	2.15	10.16	0.4	0.06	0.00007
Total	71					

NS = nonsignificant at the 5% probability level. * and ** indicate significant differences at 5% and 1% levels of probability, respectively.

Table 4: Mean squares of the snap bean's pod diameter (PdD), pod number (PdN), protein concentration (PC), and total pod yield (TPdY) (*F*-test).

Source of variation	DF	PdD	PdN	Pc	TPdY
Y	1	0.003	465.13	1.66	101.08
R (Y)	4	0.002	38.04	4.09	8.99
Ir	2	0.11**	2198.29**	43.19*	479.05**
Y*Ir	2	0.00004	20.79	0.74	4.56
Error Ir	8	0.0008	19.4	0.2	4.7
N	3	0.094***	652.57**	39.22**	145.1**
Y*N	3	0.00007	1.61	0.28	0.33
Ir*N	6	0.0001*	26.85**	1.11**	7.5**
Y*Ir*N	6	0.00003	1.94	0.043	0.43
Residual	36	0.0004	3.56	0.29	0.71
Total	71				

*, **, and *** indicate significant differences at 5%, 1%, and 0.1% levels of probability, respectively.

3.2. Yield and Its Associated Attributes

3.2.1. Pod Diameter. The main effect of nitrogen levels and irrigation treatment had a substantial ($p < 0.001$) effect on the snap bean plants' pod diameter. Additionally, a significant change ($p < 0.05$) in pod diameter was seen as a result of the interaction between irrigation and nitrogen (Table 4). At the interaction between 100% ETc and 92 kg·ha^{-1} nitrogen level, the largest mean pod diameter (0.8567 cm) was observed. However, the lowest measurement (0.5617 cm) was obtained at 50% ETc combined with control (unfertilized) treatment.

There was no discernible difference between the pod diameter measured at 46 kg·N·ha^{-1} level combined with 100% ETc, 138 kg·N·ha^{-1} level combined with 75% ETc, and 92 kg·N·ha^{-1} level combined with 50% ETc (Table 7). An increase in pod diameter together with reduced stress levels and optimally greater nitrogen levels as a result of decreased stress levels may improve plant water condition, improve stomatal conductance, and increase the efficiency of nitrogen usage, which eventually reflects on photo-assimilated production.

Similar findings in Refs.[34, 43] indicated that increasing nitrogen fertilizer rates up to the ideal level on snap beans while they were fully irrigated caused an increase in the diameter of the pod. The results are also in parallel to those in Ref. [33], which claimed that under full irrigation conditions, the largest pod diameter was measured at 82 kg·N·ha^{-1}.

3.2.2. Pod Length. Both irrigation and nitrogen levels had a substantial impact on the average snap bean pod length ($p < 0.01$ and $p < 0.001$, respectively) (Table 3). The longest mean pod length (13.23 cm) was recorded at 100% ETc, while the shortest (10.22 cm) was obtained at 50% ETc irrigation level. Comparing the 50% ETc with the 100% ETc, the mean pod length was reduced by roughly 22.7% (Table 6). Generally speaking, as stress levels decline, the mean pod length also rises, possibly as a result of the soil's adequate moisture availability; this leads to improved physiological processes, such as better nutrient uptake and a higher rate of photosynthesis, which may be reflected in more leaves, and a higher yield [44]. The result obtained is in accordance with the findings of Ref. [45], which demonstrated that brief drought stress at every developmental stage reduces the length of pods. Similar to Ref. [46], which discovered that the maximum green bean pod lengths were produced at 100% ETc at ten-day irrigation intervals, the length of pods in this site is low in contrast to the Rift Valley region of Ethiopia, which varies between 10.6 and 12.8 cm [13 as cited by Ref. [46]].

The smallest pod length (10.7 cm) was achieved from control treatments, while the maximum pod length (12.65 cm) was obtained at 92 kg·ha^{-1} nitrogen level. However, a further increment within the levels of applied nitrogen from 92 kg·ha^{-1} nitrogen level resulted in a decrease in pod length(Table 6). Similar findings were also

Table 5: Seasonal water consumption at different stress levels.

Treatments	Total seasonal moisture demand (mm)	Percentage of water savings (%)
100% ETc	206	
75% ETc	162.5	21.1
50% ETc	118.9	42.3

Source: own data, 2020.

Table 6: Main impacts of irrigation and nitrogen levels on height of plant, number of leaves plant^{-1}, number of branches plant^{-1}, and length of pods.

Treatment	Plant height (cm)	Number of leaves plant^{-1}	Number of branches plant^{-1}	Pod length (cm)
Irrigation levels				
50% ETc	36.13^{c}	51.00^{b}	8.583^{b}	10.22^{c}
75% ETc	42.37^{b}	61.58^{a}	11.792^{a}	11.75^{b}
100% ETc	46.38^{a}	66.04^{a}	13.625^{a}	13.23^{a}
LSD (0.05)	0.86	6.69	2.66	0.49
Nitrogen (kg·N·ha^{-1}) levels				
0	37.33^{d}	53.11^{b}	9.167^{d}	10.7^{d}
46	39.0^{c}	56.33^{b}	10.944^{c}	11.53^{c}
92	46.5^{a}	65.89^{a}	13.167^{a}	12.65^{a}
138	43.67^{b}	62.83^{a}	12.056^{b}	12.07^{b}
LSD (0.05)	0.99	4.83	1.03	0.226
CV (%)	3.52	5.35	5.6	2.06

Means of the same letter within the column are not significantly different at the 5% probability level using the least significant difference.

Table 7: Effects of irrigation and nitrogen levels on the diameter and curvature of the pods.

Irrigation levels	Nitrogen (kg·N·ha^{-1}) levels	Pod diameter (cm)	Pod curvature
50% ETc	0	0.5617^{k}	0.7033^{h}
	46	0.6023^{j}	0.7300^{g}
	92	0.7273^{de}	0.7533^{f}
	138	0.6203^{i}	0.7417^{fg}
75% ETc	0	0.6503^{h}	0.7550^{f}
	46	0.7027^{f}	0.7850^{e}
	92	0.8307^{b}	0.8167^{d}
	138	0.7217^{e}	0.7967^{e}
100% ETc	0	0.6918^{g}	0.8150^{d}
	46	0.734^{d}	0.8367^{c}
	92	0.8567^{a}	0.8900^{a}
	138	0.7613^{c}	0.8600^{b}
LSD (0.05)		0.022	0.00949
CV (%)		0.0093	0.0138

Means of the same letter within the column are not significantly different at the 5% probability level using the least significant difference.

reported in Ref.[47], which concluded that the largest pod length was seen following the administration of 92 kg N and 69 kg P_2O_5 of fertilizers. On the contrary, Ref. [48] found that okra pod length was significantly increased with nitrogen levels up to 100 kg nitrogen per hectare.

3.2.3. *Pod Curvature.*

The results of the analysis of variance revealed that the main effects of nitrogen levels and deficit irrigation, as well as their interactions, significantly ($p < 0.01$) influenced pod curvature (Table 3). The plots at 92 kg·N·ha^{-1} coupled with 100% ETc had the lowest average pod curvature (0.89), while the highest average pod curvature (0.7033) was obtained from nonfertilized treatment combined with 50% ETc. In comparison with the combination of 92 kg·N·ha^{-1} and 75% ETc, the pod curvature measured at 0 kilograms·of N·ha^{-1} combined with 100% ETc did not significantly differ. Additionally, there was no discernible difference between the control mixed with 75% ETc, 138 kg·N·ha^{-1} combined with 50% ETc, and 92 kg·N·ha^{-1} combined with 50% ETc (Table 7). When the value of pod curvature decreases, the pod becomes more curved and curved, but when the value of pod curvature increases, it becomes linear (straight pod). Insufficient moisture availability may be the cause of their cells not being completely turgid, as seen by the rise in pod curvature brought on by the combination of increased deficit irrigation and decreasing nitrogen levels. The result obtained is in line with that of Ref.

Table 8: Effects of irrigation and nitrogen levels on number of pods per plant, total pod yield, and protein concentration.

Irrigation levels	Nitrogen levels (kg·N·ha^{-1})	Pod number (plant^{-1})	Total pod yield (t·ha^{-1})	Protein concentration (%)
50% ETc	0	14.167^{h}	6.922^{g}	12.242^{f}
	46	17.500^{gh}	8.335^{fg}	12.557^{f}
	92	24.500^{de}	11.548^{de}	13.997^{cde}
	138	20.333^{efg}	9.655^{ef}	14.485^{c}
75% ETc	0	24.000^{ef}	11.292^{de}	14.395^{cd}
	46	27.833^{de}	13.070^{d}	14.658^{c}
	92	36.000^{c}	16.845^{c}	17.718^{a}
	138	33.500^{c}	15.730^{c}	17.115^{ab}
100% ETc	0	28.500^{d}	13.350^{d}	13.587^{de}
	46	34.833^{c}	16.322^{c}	13.482^{e}
	92	47.667^{a}	22.690^{a}	16.510^{b}
	138	41.667^{b}	19.707^{b}	16.418^{b}
LSD (0.05)		2.2079	1.3575	0.6304
CV (%)		4.289	2.267	0.873

Means of the same letter within the column are not significantly different at the probability level indicated ($p < 0.05$) using the least significant difference.

[45], which concluded that the majority of bent pods were generated during the flowering stage under brief drought stress.

3.2.4. Number of Pods. The analysis of variance revealed that the main effects of deficit irrigation and nitrogen levels, besides their interactions ($p < 0.01$), substantially influenced pod number (Table 4). The combination of 92 kg·N·ha^{-1} and 100% ETc produced the most pods (47.667 per plant), according to the study, whereas the combination of 0 kg·N·ha^{-1} (control treatment) and 50% ETc produced the fewest pods (14.167 per plant), which was statistically equivalent to the interaction between 46 kg·N·ha^{-1} and 50% ETc. There was no discernible variation among 46 kilograms·of N·ha^{-1} combined with 100% ETc, 138 kg N ha^{-1} combined with 75% ETc, and 92 kg·N·ha^{-1} combined with 75% ETc. Additionally, there was no significant difference among unfertilized treatment combined with 100% ETc, 46 kg·N·ha^{-1} combined with 75% ETc, and 92 kg·N·ha^{-1} combined with 50% ETc (Table 8).

The reduction in pod number caused by a combination of higher water deficit levels and no nitrogen application could be due to drought-induced dropping of undeveloped pods and flowers [49]. This conclusion is consistent with that of Ref. [50], which discovered that a blend of vermicompost and biochar applied at a 100% PWR produced most fruits plant^{-1}. Ref. [51] showed that the amount of water stress caused a substantial decrease in the number of faba bean pods plant¯1, and Ref. [13] claimed that the use of nitrogen fertilizer boosted the number of pods plant^{-1}, while Ref.[45] showed that drought stress during the blooming stage decreased the number of pods plant^{-1}.

3.2.5. Pod Yield. The overall pod output was significantly ($p < 0.01$) impacted by the irrigation and nitrogen levels, both individually and in combination (Table 4). The highest total pod yield (22.69 t·ha^{-1}) was obtained from 100% ETc coupled with 92 kilograms·of N·ha^{-1}, whereas the lowest value (6.922 t·ha^{-1}) was attained at 50% ETc combined with no nitrogen fertilizer addition but statistically comparable with the interaction between 50% ETc and 46 kg·N·ha^{-1}. With 46 kilograms·of N·ha^{-1} combined with 100% ETc, 138 kilograms·of N·ha^{-1} combined with 75% ETc, and 92 kilograms·of N·ha^{-1} combined with 75% ETc, there was no appreciable change. There was also no significant variation among no nitrogen fertilization combined with 100% ETc, 46 kg·N·ha^{-1} combined with 75% ETc, no nitrogen fertilization combined with 75% ETc, and 92 kg·N·ha^{-1} combined with 50% ETc (Table 8).

The quantity of assimilation tissues that could be partitioned to the storage organs (increased pod width and mean pod length) rose with the plant's increased photosynthetic area due to the plant's height and leaf count, which led to a higher total pod yield. The pod and tap roots are regarded as a sink throughout development, in contrast to other plant organs [52]. The current outcome aligns with that of Ref. [53], the application of 123 kg nitrogen per hectare produced the maximum marketable pod production and was statistically equivalent to the application of 82 kg nitrogen per hectare under full-irrigation conditions. Ref. [54] showed that French bean plants' yield was severely reduced when fertigation was reduced by half (50%).

3.3. Protein Concentration. The impact of irrigation-by-nitrogen interaction on the protein content was significant ($p < 0.01$). In combination with the two factors (Table 4), the protein content in pods ranged from 1.01 to 1.5% (fresh weight) and from 12 to 18% (dry weight). The lowest protein concentration of snap bean pods (12.242%) was obtained from an unfertilized plot combined with 50% ETc, but there was no discernible difference between 46 kg nitrogen per hectare and the same irrigation level, and the highest protein concentration of snap beans (17.718%) was attained from 92 kg nitrogen per hectare combined with 75% ETc. Among 92 kg nitrogen per hectare coupled with 100% ETc, 138 kg nitrogen per hectare combined with 100% ETc, and 138 kg nitrogen per hectare combined with 75% ETc, there was no discernible variation in the protein content. Additionally, there was no statistically significant difference among the combinations of 46 kilograms·of N·ha^{-1} with 75% ETc, unfertilized plot with 75% ETc, 138 kg·N·ha^{-1} with 50% ETc, and 92 kg·N·ha^{-1} with 50% ETc (Table 8).

Nitrogen and irrigation water management are essential not only to help in achieving improved quality and optimum snap bean yield but also to help in mitigating greenhouse gas emissions from the crop fields. The current finding is consistent with that of Ref. [55], which claimed that adequate nitrogen supplies may significantly increase protein and oil yields by raising maize's grain yield under both full and restricted watering circumstances. Ref. [56] also showed that the combination of 80% ETc (DI_{20}) and N_{30} (the highest nitrogen treatment) was optimal in balancing the yield and quality of peanut. Similarly, Ref. [57] revealed that faba beans provided the highest protein percentage in comparison with lupin chickpea and lintel at the maximum water stress (80% depletion). Ref. [58] has shown that green beans' uptake of nitrogen from the soil boosted the protein content of pods.

4. Conclusion

Both nitrogen fertilizer and irrigation had a large impact on the yield and its components, and the protein content of snap beans. The interaction between 92 kg nitrogen per hectare and 100% ETc resulted in the maximum pod number (47.667 per plant), whereas the interaction of unfertilized plot (control treatment) with 50% ETc resulted in the lowest pod number (14.167 per plant). Similarly, the control (100% ETc) in combination with 92 kg nitrogen per hectare produced the maximum total pod yield (22.69 tons per hectare), whereas the interaction between no nitrogen and 50% ETc produced the lowest total pod yield (6.92 tons per hectare). The use of 75% ETc combined with 92 kg nitrogen per hectare recorded the highest protein concentration (17.718%) and also saved water by 21.1% compared with 100% ETc of seasonal moisture demand. Even if the highest pod yield was attained at the control combined with 92 kg nitrogen per hectare, the use of 75% ETc together with 92 kg nitrogen per hectare could be optimal in balancing pod yield and protein concentration of snap bean at Adami Tulu and in similar agroecological areas.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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