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Optimizing Soybean Crop Performance through the Integrated Application of Organic and Chemical Fertilizers: A Study on Alkaline Soil in Afghanistan

Abdul Basir Turabi [1], Safiullah Habibi [2,*], Kifayatullah Kakar [3], Shafiqullah Aryan [3], Mohammad Daud Haidari [4] and Sabqatullah Alipour [5]

1 Department of Agronomy, Faculty of Agriculture, Wardak University, Wardak 1303, Afghanistan; ab.turabi@wu.edu.af
2 Faculty of Agriculture, Tokyo University of Agriculture and Technology (TUAT), Saiwai-cho 3-5-8, Fuchu-shi 183-8509, Tokyo, Japan
3 Faculty of Agriculture, Nangarhar University, Jalalabad 2601, Afghanistan; kifayatullahkakar@gmail.com (K.K.); shafiqaryan@gmail.com (S.A.)
4 Department of Soil Science and Irrigation, Faculty of Agriculture, Kabul University, Kabul 1001, Afghanistan; m.daud.haidari@gmail.com
5 Department of Agronomy, Faculty of Agriculture, Ghazni University, Ghazni 2301, Afghanistan; alipour.sbh@gmail.com
* Correspondence: fr2133@go.tuat.ac.jp

Abstract: The excess application of chemical fertilizer contributes to environmental pollution. Therefore, this study aims to explore the integrated use of animal manure and chemical fertilizer to identify a more sustainable and environmentally friendly alternative to nitrogen fertilizer. Two experiments were conducted in 2018 and 2019 at Kabul University, Afghanistan, using an LD04-13265 soybean variety. The integration of animal manure and chemical fertilizer was categorized into six treatments: (1) control (no fertilizer), (2) animal manure low dose (AMLD), (3) animal manure high dose (AMHD), (4) chemical fertilizer (CF), (5) CF 50% + AMLD, and (6) CF 75% + AMLD. The results revealed that AMHD and its integration with 75% chemical fertilizer greatly influenced the vegetative growth of soybean plants in experiments I and II. The number of pods per plant and pod length significantly ($p < 0.05$) increased under the CF 75% + AMLD treatment. In experiment I, soybean yield increased the most with the CF treatment, followed by CF 75% + AMLD. In contrast, in experiment II, the highest yield per hectare was observed in the CF 75% + AMLD treatment, followed by CF. The CF 75% + AMLD treatment significantly increased the SPAD value in both experiments. Consequently, a strong relationship was observed between the SPAD value and yield (r = 0.74) in experiment I and between SPAD and pod length (r = 0.82) in experiment II. Incorporating animal manure with chemical fertilizer significantly impacted soybean growth and yield, offering a potential possibility for reducing reliance on nitrogen fertilizer application to mitigate environmental pollution.

Keywords: animal manure; nitrogen fertilizer; soybean; SPAD value; yield

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1. Introduction

Soybean (*Glycine max* L. Merr.), a crucial legume and oil crop recognized for its high nutritional value, is extensively grown globally [1,2]. The widespread cultivation of soybean is driven by its importance in agribusiness and the food industry and by its contribution to enhancing food security and soil fertility [3,4]. This growth trend is observed across diverse climate conditions in various regions worldwide [5]. Given the context of population growth and the challenges of food insecurity, especially in undeveloped countries, enhancing soybean productivity emerges as a viable strategy to attain food security, promote agricultural sustainability, and conserve the environment [6–8]. Through the biological nitrogen fixation (BNF) process facilitated by rhizobia symbiosis, soybeans contribute a substantial quantity of atmospheric nitrogen (N_2) to plants in the form of NH4+ [9]. Nitrogen, as a macronutrient, plays a vital role in normal plant growth and achieving desirable yields. It is an important constituent of amino acids, chlorophyll, enzymes, and other essential metabolic and physiological processes such as carbohydrate metabolism within plants, root development, and uptake of other nutrients [10]. Therefore, BNF stands as an economically valuable process for agroecosystems and the environment, resulting in elevated yields of legume crops without the need for nitrogen fertilizer application. However, intensive application of chemical fertilizers significantly increases environmental pollution, including the soil microbial community, soil acidification, greenhouse gas emissions, and groundwater nitrate contamination [11–15]. Therefore, BNF and organic fertilizers might be useful for substituting or mitigating chemical fertilizers. In addition, soybeans can elevate soil organic matter (SOM) levels by promoting biomass production, organic carbon content, and the population of root nodule-forming bacteria (Rhizobia). This, in turn, enhances nitrogen availability. Soil organic matter is crucial in improving micronutrient availability and facilitating plant uptake [3]. Additionally, it contributes to the development of favorable soil physical properties, such as porosity and aggregate stability [16]. Furthermore, soil organic matter directly influences the nourishment and diversity of soil microbial and faunal communities.

Moreover, soybean in relay cropping and intercropping with other crops, such as maize [17–19] and wheat [20], resulted in a considerable increase in growth attributes and yield components of cultivated crops, as well as improving soil properties [21]. Similarly, a crop rotation of soybean and rice improved nutrient availability and soil microbial diversity and had synergistic effects on the growth of other plants [22].

Soybean is viewed as a recent legume crop in Afghanistan [23], and there is insufficient evidence about this crop's adaptation and cultivation in the country's different agricultural zones. However, besides the Ministry of Agriculture, Irrigation and Livestock (MAIL), some international non-governmental organizations such as the Food and Agriculture Organization of the United Nations [24] and Nutrition and Education International [25], as well as non-governmental organizations, including the Coordination of Humanitarian Assistance Organization [26], are undertaking to improve soybean productivity by providing certified seeds, cultivation technology, and farming techniques to smallholder farmers, in addition to linking them to markets [27]. Moreover, strengthening soybean production may result in food security and food system development, particularly for the most vulnerable and food-insecure people across the country [28]. These initiatives have encouraged local farmers to gain practical knowledge about soybean farming and derive economic, soil, and environmental benefits. It is worth mentioning that soybean farming in Afghanistan is remarkably beneficial due to the insertion of this crop in the crop rotation and support of wheat, rice, and maize staple crops in the country. Thus, soybean forming is a cost-effective, eco-friendly, and effective strategy to minimize inorganic fertilizer applications, reduce environmental pollution, and support Afghan farmers' food security and livelihoods [4,29].

The climate in Afghanistan is mostly arid and semi-arid, with cold winters and dry summers [30]. The soil tends to be alkaline, with a pH > 8 [31]. Usually, in Afghan soils, the levels of organic carbon and nitrogen (N) are low, phosphorus (P) varies based on location, and potassium (K) is at adequate levels [32]. Therefore, high amounts of inorganic fertilizers of low quality are imported annually from neighboring countries [32,33] and used to boost agricultural productivity, which remains a major concern for environmental pollution [34]. In addition, the higher pH of the soils in Afghanistan results in some micronutrient deficiencies, like iron (Fe), and only macronutrient fertilizers will not be adequate to fulfill the nutrient requirements of soybean farming. Consequently, an alternative way to provide balanced nutrients to soybean crops is the combined application of organic and inorganic fertilizers to maximize the yield of soybeans and promote the quality of soybean grains. While agricultural productivity in Afghanistan depends on utilizing both organic and inorganic fertilizers, limited research data indicate the optimal application ratios for these fertilizers. Additionally, there is limited evidence from existing research data to guide the integrated application of organic and inorganic fertilizers specifically for soybean cultivation in Afghanistan. Furthermore, the expense associated with chemical fertilizers prompts certain farmers to rely solely on organic alternatives, which do not adequately fulfill the nutritional requirements of their crops. Conversely, opting for higher volumes of chemical fertilizers would prove economically impractical for farmers and could adversely affect the environment and soil properties. Therefore, in this study, we aimed (1) to study the individual and integrated application of inorganic fertilizer (urea) and organic fertilizer (cow manure) on the growth and yield of soybeans in Afghanistan, (2) to find out the effectively integrated amounts of organic and inorganic fertilizers, and (3) to determine the usability of this method for farmers within the county.

2. Materials and Methods

2.1. Experimental Site and Treatments

Two experiments were carried out at the Faculty of Agriculture, Kabul University, Afghanistan, in 2018 (experiment I) and 2019 (experiment II). These experiments utilized different fertilizer sources and were conducted within the experimental farm. The first experiment was conducted in pots (one plant per pot) based on a completely randomized design (CRD) with ten replications under controlled net-house conditions, each measuring 25 cm in width and 40 cm in height. In contrast, experiment II occurred in an open field environment, offering a more natural setting for the study. The site was positioned at GPS coordinates N 34.517175 and E 69.139377, with an altitude of 1789 m above sea level. The descriptions of air temperature and precipitation rate for both experiments in this study are shown in Figure 1. Experiment II was laid out using a Randomized Complete Block Design (RCBD) with three replications. Within each experimental plot, the plants were cultivated with a 20 cm and 50 cm spacing between plants and rows, respectively. The plot size was 6 m^{-2}. This integrated strategy was arranged into six distinct treatments, as outlined in Table 1. The aim of using animal manure and chemical fertilizer was to explore the synergistic effects and potential benefits for agricultural practices. The same amount of fertilizer was considered for experiments I and II. The animal manure was applied before pot and land preparation. All essential agronomic practices were carefully applied throughout the experiment. This included regular irrigation to avoid water stress and hand weeding to eliminate competition for nutrients with the main crop.

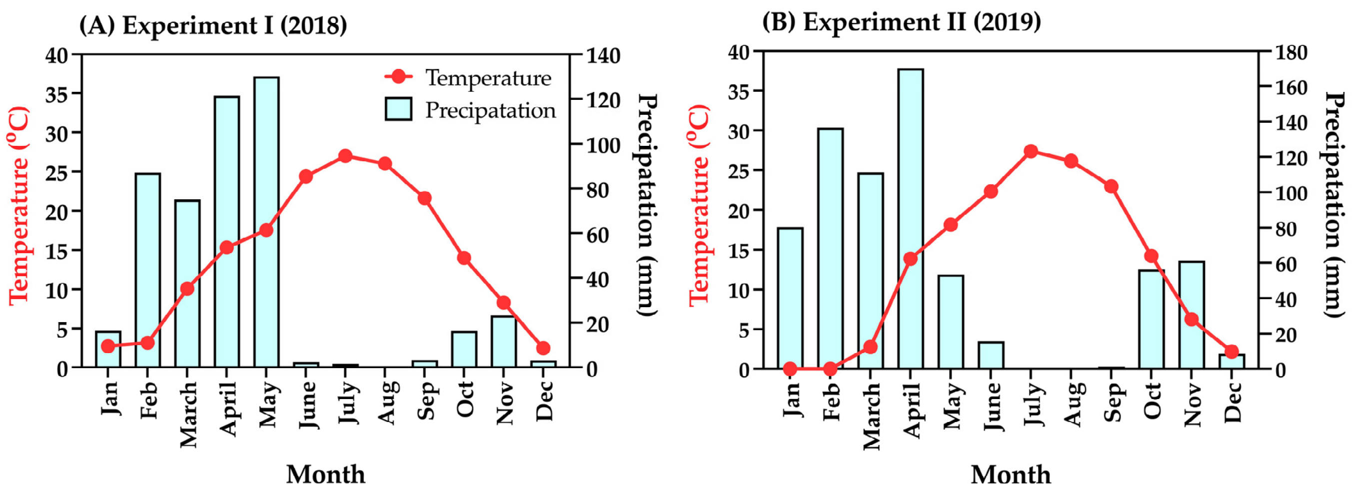

Figure 1. The average air temperature (°C) and precipitation rates (mm) for experiment I (**A**) and II (**B**) in the years 2018 and 2019, respectively. The data were received from a global source [35].

Table 1. The descriptions provide details on the treatments and the sources of fertilizers employed in the experiments.

Treatment	Source	Description
Control	No fertilizer	-
Animal manure light dose (AMLD)	Animal manure	5 t ha^{-1} of well-decomposed animal manure was utilized.
Animal manure heavy dose (AMHD)	Animal manure	10 t ha^{-1} of well-decomposed animal manure was utilized.
Chemical fertilizer (CF)	Urea (46% nitrogen)	110 kg Urea/ha.
CF 50% + AMLD	Urea + animal manure	55 kg Urea/ha + 5 t ha^{-1} animal manure.
CF 75% + AMLD	Urea + animal manure	82.5 kg Urea/ha + t ha^{-1} animal manure.

This study utilized the "LD04–13265" soybean variety, and the seeds were sourced from the Agriculture Research Institute of Afghanistan (ARIA). This particular variety is favored among farmers due to its remarkable characteristics, including a high yield of 2.3 t ha^{-1}, excellent nutritional value, and a medium duration for maturity. The soybean seeds were planted during the first week of May and harvested in the second week of October. This identical sowing and harvesting schedule was maintained for 2018 and 2019.

Before cultivation, an initial soil test was conducted to assess soil fertility, as shown in Table 2. Each plot underwent the collection of three soil samples, which were thoroughly mixed. The analysis, including measurements of soil pH, electrical conductivity (EC), organic matter % (OC), available NPK, Mg, S, and Ca, was carried out at the central Badam Bagh Research Station laboratory in Kabul, Afghanistan.

Table 2. The results of the initial soil test include pH, EC, OM, available NPK, Ca, S, Mg, and soil texture.

Soil Characteristic	Value
pH	8.10
EC (dS/cm)	17.0
OM (%)	0.6
N (ppm)	8.3
P (ppm)	9.3
K (ppm)	68.2
$CaCO_3$ (%)	14.1
S (ppm)	6.4
Mg (ppm)	10.1
Soil texture	Silty loam

2.2. Plant Measurements

Ten plants were selected from each treatment in experiments I and II before flowering to measure chlorophyll content using a SPAD value meter (SPAD-502 Plus; Spectrum Technologies, Aurora, IL, USA). Plant growth parameters including plant height, number of leaves per plant, and number of nodes per plant were measured 45 days after sowing (DAS) and 100 DAS. In addition, the number of pods per plant, pod length (cm), number of seeds per pod, 100-seed weight (g), and yield were assessed in both experiments I and II after final harvesting.

2.3. Statistical Analysis

The data were analyzed based on one-way analysis of variance (ANOVA) and correlation matrix analysis using R language (version 3.6.1) software. The data presented in the tables and figures are expressed as means followed by their respective standard deviations. A Tukey post hoc test was conducted at a 5% significance level to determine the statistical significance of the means.

3. Results

3.1. Effects of Integrated Animal Manure and Chemical Fertilizer on Soybean Growth Attributes and Yield Components

The impact of integrated animal manure and chemical fertilizer exhibited varied responses regarding soybean growth and yield attributes. Plant height showed significant variations ($p < 0.05$) among the treatments both 45 and 100 days after sowing (DAS) in both experiment I and II, except for 45 DAS in experiment II (Table 3). The percentage differences ranged from 4.4% to 7.4% at 45 DAS and from 2.8% to 10.9% at 100 DAS in experiment I compared to the control treatment. The highest plant height in experiment I at 45 DAS was observed in 75% + AMLD, followed by CF treatment. However, in experiment II, the differences were 12.5% to 20.4% at 45 DAS and 11.8% to 27.2% at 100 DAS compared to the control. In experiments I and II at 100 DAS, the highest plant height was observed in CF and CF 75% + AMLD treatments. The number of leaves per plant exhibited variations among treatments in both experiments I and II at 45 and 100 DAS. At 45 DAS in experiment I, the CF treatment demonstrated the highest number of leaves per plant, followed by the CF 75% + AMLD treatment. Meanwhile, in experiment II, the CF 75% + AMLD treatment displayed the highest value, followed by CF. Moving to 100 DAS, in experiment I, the highest number of leaves per plant was observed in the CF treatment, followed by CF 75% + AMLD. In experiment II, a similar result was observed in which the CF treatment displayed the highest number of leaves per plant, followed by CF 75% + AMLD (Table 3). The number of nodes per plant exhibited significant variations ($p < 0.001$) among treatments at 45 and 100 DAS. At 45 DAS in experiment I, the highest value was observed in CF, followed by CF 75% + AMLD. In experiment II, CF 75% + AMLD displayed the highest value, followed by CF. The percentage differences in the number of nodes per plant at 45 DAS ranged from 16.3% to 37.8% in experiment I and from 13.9% to 49.3% in experiment II compared to the control treatment. However, at 100 DAS, CF showed the highest values in both experiments I and II (Table 3).

In addition to soybean growth parameters, the yield components were also influenced by various doses and animal manure and chemical fertilizer integration. The CF treatment in experiment I exhibited the highest number of pods per plant, followed sequentially by CF 50% + AMLD, AMHD, CF 75% + AMLD, AMLD, and control treatments. Contrastingly, in experiment II, the number of pods per plant increased in the CF 75% + AMLD treatment, followed by CF, AMHD, AMLD, CF 50% + AMLD, and the control. Compared to the control, the percentage increase was 34.5% in CF 75% + AMLD, 32.5% in CF, 23.6% in AMHD, 23.0% in AMLD, and 13.0% in CF 50% + AMLD (Table 4). The length of pods exhibited significant variations among treatments in both experiments I and II. In experiment I, the CF 75% + AMHD treatment recorded the highest value, followed sequentially by CF, CF 50% + AMLD, AMHD, AMLD, and the control. In addition, under field conditions in experiment II, the highest pod length was observed in the CF 75% + AMHD treatment, followed by the CF treatment, representing a different trend compared to experiment I.

The number of seeds per pod and 100-seed weight exhibited significant ($p < 0.05$) variations among treatments in experiment I, while no significant differences were observed in experiment II. The CF treatment displayed the highest number of seeds per pod, with a percentage difference of 16.3% compared to the control treatment. Notably, this treatment demonstrated substantial increases compared to other treatments in experiment I. Furthermore, in experiment I, the 100-seed weight reached its highest value in the CF treatment, followed by CF 75% + AMLD and CF 50% + AMLD treatments. In contrast, in experiment II, CF 75% + AMLD showed the highest 100-seed weight, followed by CF and CF 50% + AMLD treatments, as shown in Table 4.

Table 3. The effects of integrated animal manure and chemical fertilizer on growth attributes of soybean at 45 and 100 DAS.

Treatment	Plant Height (cm)				Number of Leaves per Plant				Number of Nodes per Plant			
	45 DAS		100 DAS		45 DAS		100 DAS		45 DAS		100 DAS	
	Experiment I	Experiment II	Experiment I	Experiment II	Experiment I	Experiment II	Experiment I	Experiment II	Experiment I	Experiment II	Experiment I	Experiment II
Control	21.3 ± 2.4 b	32.2 ± 2.9 b	34.7 ± 5.4 a	57.9 ± 4.2 b	23.7 ± 6.8 c	34.4 ± 7.7 b	63.5 ± 21.1 b	147.8 ± 16.3 b	10.2 ± 3.4 ab	12.3 ± 2.3 c	23.2 ± 2.3 c	38.3 ± 3.4 d
AMLD	22.1 ± 1.1 ab	36.6 ± 2.2 ab	36.5 ± 3.3 a	71.2 ± 6.3 ab	27.6 ± 6.1 b	41.3 ± 5.3 ab	71.7 ± 11.2 ab	187.0 ± 7.8 ab	13.2 ± 5.3 ab	18.3 ± 3.1 abc	26.7 ± 4.3 abc	53.6 ± 4.2 ab
AMHD	22.4 ± 1.9 ab	36.8 ± 2.0 ab	36.5 ± 7.8 a	72.9 ± 4.6 ab	33.7 ± 15.0 b	41.5 ± 6.1 ab	81.0 ± 7.8 ab	179.7 ± 10.2 ab	12.5 ± 4.8 a	16.6 ± 1.7 bc	26.2 ± 1.2 bc	49.3 ± 5.2 bc
CF	23.5 ± 2.9 ab	39.8 ± 1.3 a	39.0 ± 11.2 a	78.9 ± 7.1 a	46.5 ± 6.2 a	52.041.5 ± 4.2 a	93.0 ± 6.9 a	194.7 ± 9.8 a	16.6 ± 2.1 a	22.0 ± 5.4 ab	35.0 ± 3.2 a	59.349.0 ± 6.1 a
CF 50% + AMLD	23.0 ± 1.2 ab	36.8 ± 1.3 ab	35.7 ± 9.9 a	65.7 ± 5.1 ab	34.7 ± 5.1 b	37.8 ± 7.2 ab	79.7 ± 10.0 ab	169.2 ± 12.4 ab	9.7 ± 1.2 b	14.3 ± 2.1 c	25.7 ± 1.9 c	41.0 ± 2.8 cd
CF 75% + AMLD	23.7 ± 2.3 a	40.5 ± 1.4 a	38.7 ± 8.1 a	79.6 ± 8.5 a	38.0 ± 12.2 b	52.7 ± 3.4 a	91.581.0 ± 6.1 a	190.3 ± 11.1 ab	12.7 ± 2.3 ab	24.3 ± 3.6 a	33.7 ± 2.6 ab	57.3 ± 2.7 ab
p-value	*	*	ns	*	***	*	**	*	*	***	***	***

The data is presented are means followed by standard deviations. Different letters denote significant differences among the six treatments. Significance was determined at the 5% level, with *, **, and *** indicating $p < 0.05$, $p < 0.01$, and $p < 0.001$, respectively. The ns represents not significant.

Table 4. The effects of integrated animal manure and chemical fertilizer on yield attributes of soybean.

Treatment	Number of Pods per Plant		Pod Length (cm)		Number of Seeds per Pod		100-Seed Weight (g)	
	Experiment I	Experiment II	Experiment I	Experiment II	Experiment I	Experiment II	Experiment I	Experiment II
Control	20.6 ± 4.3 b	58.8 ± 5.7 b	2.7 ± 0.9 b	2.8 ± 0.2 c	2.3 ± 0.3 b	3.9 ± 0.1 a	3.4 ± 0.3 c	8.2 ± 1.4 a
AMLD	25.3 ± 3.6 ab	76.4 ± 8.6 ab	3.3 ± 0.4 ab	3.4 ± 0.4 bc	2.5 ± 0.0 ab	3.9 ± 0.1 a	4.8 ± 0.1 b	9.3 ± 1.1 a
AMHD	27.5 ± 5.0 ab	77.2 ± 6.9 ab	3.4 ± 0.8 ab	4.2 ± 0.6 ab	2.7 ± 0.7 ab	4.1 ± 0.0 a	5.3 ± 0.5 ab	9.3 ± 0.6 a
CF	33.7 ± 6.2 a	87.1 ± 9.5 ab	4.0 ± 1.0 ab	4.5 ± 0.3 ab	3.0 ± 0.8 a	4.1 ± 0.2 a	6.3 ± 0.6 a	9.5 ± 0.3 a
CF 50% + AMLD	27.5 ± 3.5 ab	67.6 ± 8.9 ab	3.6 ± 1.1 ab	4.3 ± 0.7 ab	2.7 ± 0.3 ab	4.0 ± 0.1 a	5.6 ± 0.3 ab	9.5 ± 0.5 a
CF 75% + AMLD	29.0 ± 5.5 ab	89.9 ± 4.7 a	4.1 ± 0.6 a	4.7 ± 0.9 a	2.8 ± 0.1 ab	4.3 ± 0.3 a	6.0 ± 0.8 ab	11.8 ± 1.1 a
p-value	**	*	*	***	*	ns	***	ns

The data are presented as means followed by standard deviations. Different letters denote significant differences among the six treatments. Significance was determined at the 5% level, with *, **, and *** indicating $p < 0.05$, $p < 0.01$, and $p < 0.001$, respectively. The ns represents not significant.

3.2. Impacts of Integrated Animal Manure and Chemical Fertilizer on Yield and SPAD Value of Soybean

Significant differences ($p < 0.05$) in yield were observed among treatments in both experiments I and II (Figure 2). In experiment I, the highest yield per plant was recorded in the CF treatment, followed sequentially by CF 75% + AMLD, CF 50% + AMLD, AMHD, AMLD, and the control treatment. Conversely, in experiment II, the highest yield was observed in the CF 75% + AMLD treatment, followed by AMHD, AMLD, CF, and CF 50% + AMLD. These findings underscore the impact of treatment variations on soybean yield, demonstrating the importance of tailored agricultural practices for optimal crop productivity. In contrast, in experiment II, the differences ranged from 5.1% to 27.7% among treatments compared to the control.

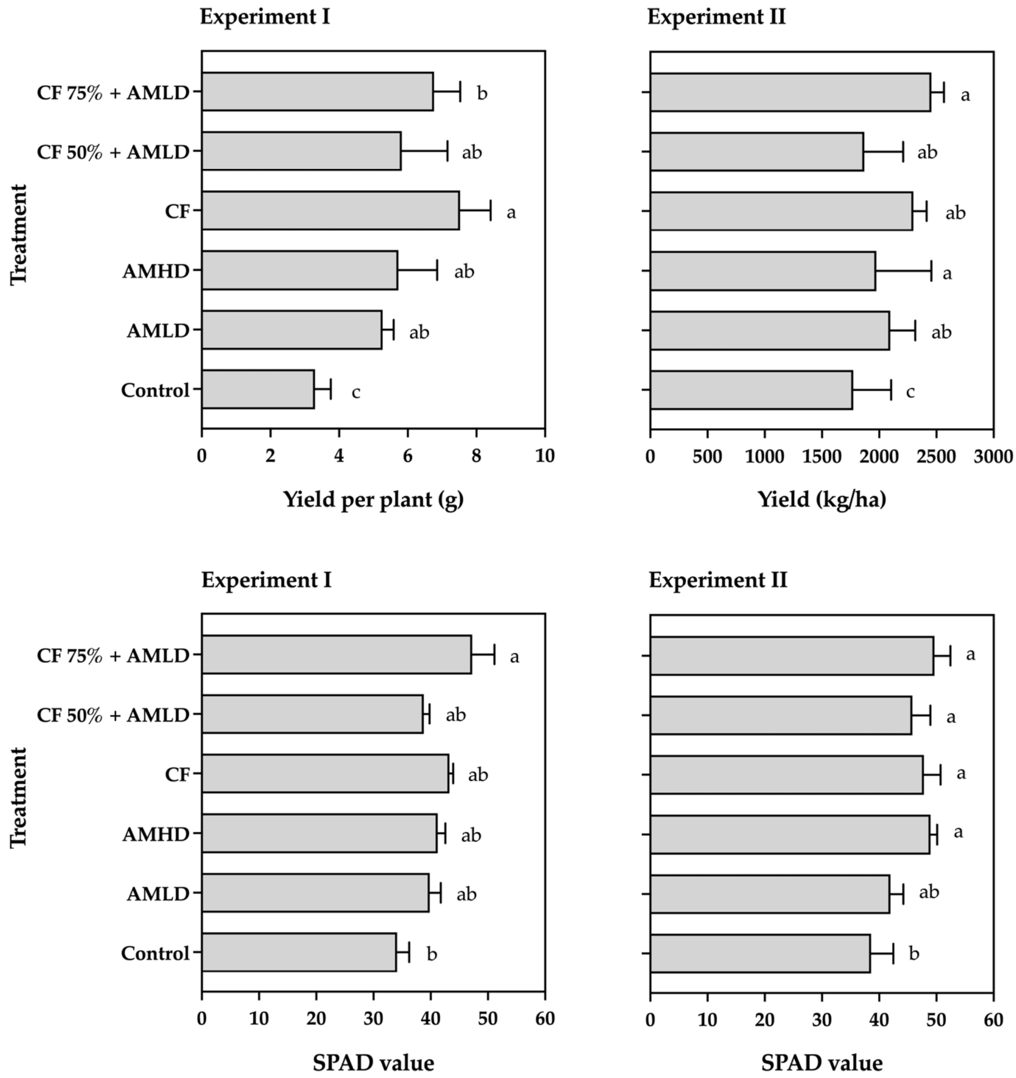

Figure 2. The effects of integrated animal manure and chemical fertilizer on both experiments (I and II) yield and SPAD value. The bars in this graph show mean values, and error bars stand for standard deviation (SD). Different letters indicate Tukey's test at a 5% level.

In this study, animal manure, chemical fertilizer, and their integration influenced the SPAD values of various treatments. The SPAD value serves as a significant indicator of the impact of nitrogen elements on crop growth, representing a standard for comparison among treatments. In experiment I, the CF 75% + AMLD treatment exhibited the highest SPAD value, surpassing the control by 27.8%. This was followed by CF, AMHD, AMLD, and CF 50% + AMLD, with percentage differences of 21.1%, 17.2%, 14.3%, and 12.0%, respectively. Experiment II demonstrated a similar trend in SPAD values, with the CF 75% + AMLD treatment exhibiting the highest value, at 22.3%, followed by AMHD, at 21.2%. The percentage differences compared to the control were 19.3%, 15.7%, and 18.2% for CF, CF 50% + AMLD, and AMLD, respectively (Figure 2). These findings emphasize the significance of SPAD values as an effective measure of the influence of different fertilization practices on crop growth.

3.3. Correlation of Vegetative Growth with Yield Attributes

The correlation matrix analysis depicted in Figure 3 for both experiment I and II reveals a strong relationship between increasing SPAD values and various parameters. In experiment I, the SPAD value exhibited a significant positive correlation with the number of leaves per plant at 100 DAS (r = 0.57) and yield per plant (r = 0.74). Additionally, there was a remarkable relationship, with a strength of r = 0.64, indicating an increase in pod length with the 100-seed weight. Conversely, in experiment II, the integration of animal manure and chemical fertilizer greatly influenced the SPAD value and its correlation with other parameters. Mainly, a strong relationship (r = 0.82) was observed between the SPAD value and pod length. Moreover, pod length positively correlated with the number of leaves per plant (r = 0.49). The inter-relationships between the increase in SPAD value and other attributes are comprehensively illustrated in Figure 3.

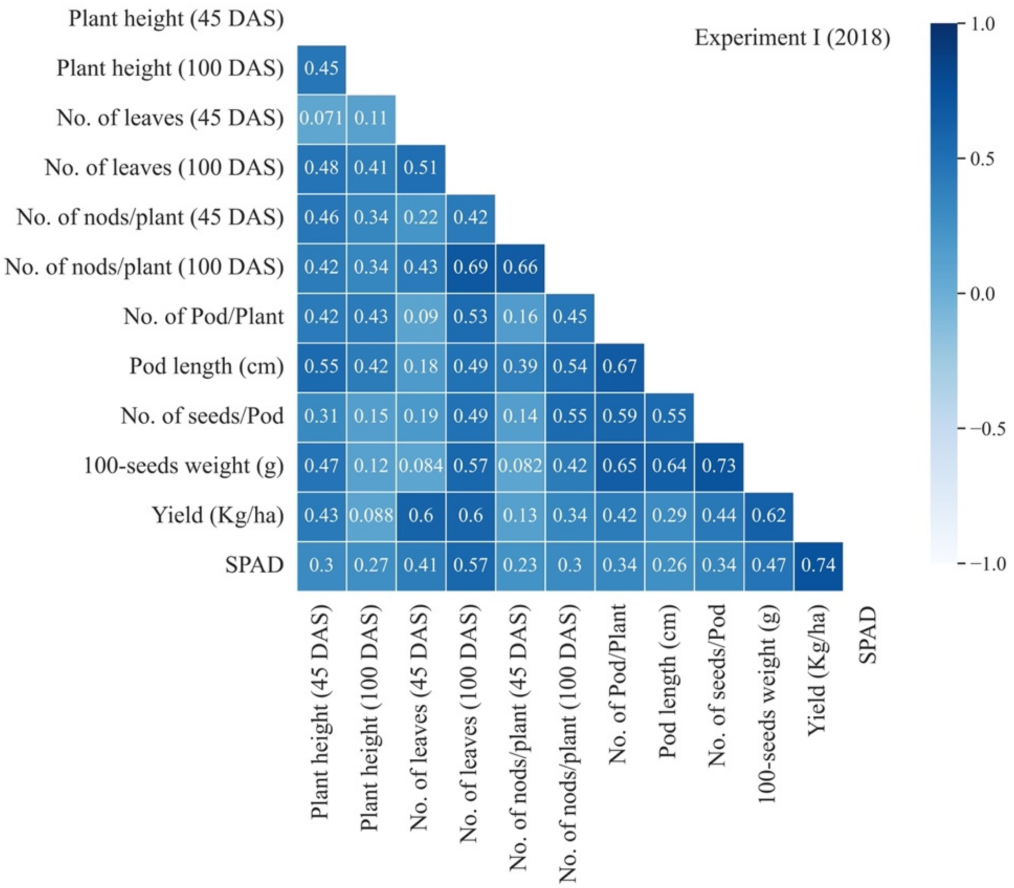

Figure 3. *Cont.*

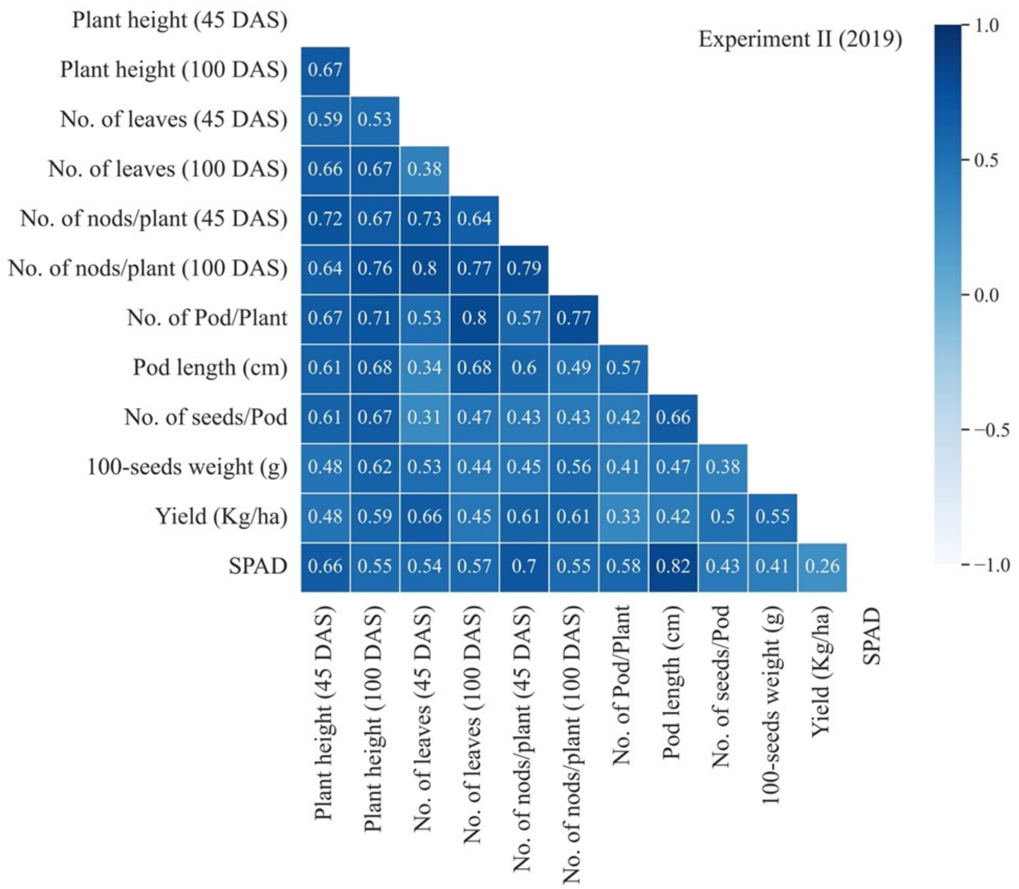

Figure 3. The correlation matrix analysis involves experiments I (2018) and II (2019), considering all growth parameters and yield and its components. In this analysis, SPAD is soil–plant analysis development.

4. Discussion

Fertilizers provide essential nutrients to crops for normal growth and optimum yield. This investigation focused on the influence of various levels of organic and inorganic fertilizers on the growth and yield of soybeans. The fertilized plots consistently demonstrated superior growth characteristics and yielded higher crop results compared to the unfertilized control plot. In both experiments, the sole application of organic fertilizer (AMHD) and a combination of organic and inorganic fertilizers (CF 75% + AMLD) exhibited more substantial effects on both plant growth and yield components. The maximum and significant plant heights for two years were measured in pot and field experiments using a combination of organic and inorganic fertilizers (CF 75% + AMLD) and only chemical fertilizer treatments (except for CF in 2018). Results indicated that treatments containing major amounts of chemical fertilizer (urea) were more effective in comparison to the sole application of organic fertilizer and low doses of combined chemical fertilizer (CF 50% + AMLD). The application of urea and transformation to $NH4^{+}$ as the most efficient nitrogen nutrient for plant growth at the primary stage might be the main factor for the incrementation of plant heights [36]. The effect of chemical and organic fertilizers on plant heights was reported in previous studies [37–39]. The authors of [10] reported that the application of urea (90 kg ha^{-1}) resulted in the highest plant height (46.08 cm) after 28 days of growing amongst the isolates under glasshouse conditions. Similarly, this finding is supported by [40], the authors of which conducted two separate field experiments in 2009 and 2010 and found that urea and compost application had similar effects on soybean growth. These researchers observed the highest plant heights of 24.20 cm and 23.4 cm with a single application of urea and compost at 45 DAS and 32.65 cm and 32.0 cm with the same treatments at 75 DAS. Moreover, the authors of [41] found that the combined application of inorganic fertilizer and farmyard manure (125% RDF + FYM @ 5 t ha^{-1}) resulted in the highest plant heights in various soybean growth stages. The increase in soybean leaf numbers by applying various fertilizers highly varied in both experiments. The significant effects of treatments on the number of leaves per plant were recorded at 45 and 100 DAS under the CF treatment, which was more effective, followed by CF 75% + AMLD-fertilized pots and plots. Past research has inferred the positive effect of urea fertilizer on the enhancement of the number of soybean leaves per plant [42]. In addition, the authors of [41] demonstrated that the integrated impacts of organic and inorganic fertilizers (125% RDF+ FYM @ 5 t ha^{-1}) significantly increased the number of soybean leaves per plant (33.83) at 45 DAS. Regarding nodes/plant, a similar pattern was seen, particularly for CF and CF 75% + AMLD treatments. The authors of [12] also noted that a combined application of organic manure (2000 kg/ha) and urea fertilizer (100 kg/ha) significantly increased the number of nodes (9.13) 30 days after plantation under field conditions. Considering the analyzed data concerning the growth attribute, it seems that CF and CF 75% + AMLD treatments effectively improved soybean growth attributes. The fertilized results could be due to the rapid uptake of nitrogen in the earlier stage and the gradual degradation of organic manure, which made nutrients more accessible to soybean plants [43]. Previous studies have repeatedly reported the advantages of organic matter for soil, including the development of soil physical properties and biological fertility [43–47]. Moreover, our study contributes to the elucidation of the consequences and scenarios of organic and inorganic fertilizers and their competition in the growth of crops, particularly soybeans.

In this study, fertilized pots and plots with various amounts of organic and inorganic fertilizers revealed different yield component results. In experiment I, a significant increase in the number of pods per plant and number of seeds per pod was recorded by the application of CF treatment. In contrast, in experiment II, the effect of CF 75% + AMLD was more visible and considerably increased the number of pods per plant and pod length, in addition to a substantial impact on the 100-seed weight. With respect to the effect of sole chemical fertilizer application on the number of pods per plant, the authors of [10] reported a similar finding and noted that regardless of the genotype, the use of urea (90 kg N ha^{-1}) resulted in the highest number of pods per plant (34.19). Furthermore, they mentioned that using different nitrogen sources significantly affected the number of seeds per pod and the weight of 100 grains compared to the control. The integrated effects of chemical and organic fertilizers significantly affected the increment of pods per plant and the weight of 100 seeds [48]. They reported that $O_2K_1A_2$ and $O_2K_3A_2$ treatments, which consisted of 1000 kg ha^{-1} and 3000 kg ha^{-1} compost + 100 kg of urea ha^{-1}, respectively, showed the maximum number of pods per plant (26.9–27.0 pods). In contrast, the authors of [38] reported no significant differences pertinent to the effect of various amounts of chemical and organic fertilizers on the number of pods/plants and the number of seeds per pod.

The SPAD value as a chlorophyll index was evaluated in both experiments. In experiment I, the SPAD value showed a range of 12.0% to 27.8%, while these changes varied from 8.1% to 22.3% in experiment II compared to their respective controls. The CF 75% + AMLD treatment, a combined treatment of organic and organic fertilizers, exhibited the highest SPAD value among the treatments in 2019, followed by chemical fertilizer in 2018. However, the authors of [10] reported that after 42 and 56 days, urea (90 Kg N ha^{-1}) showed significantly higher results, with SPAD values of 40.2 and 41.7, respectively. Consequently, SPAD seems to have time-limited values and change during the plant growth season. Yield, as one of the most essential parameters, displayed a significant increase following the application of various amounts of chemical and organic fertilizers. In experiment I, this increment varied from 37.3% to 56.1%, with a significantly high yield of chemical fertilizer per plant among the treatments, whereas yield productivity in the field experiment fluctuated from 5.1% to 27.7%, and the 75% + AMLD treatment showed the highest yield (2455.6 kg/ha). The tendency of plant growth and yield increment changed during the growth stages of soybeans under both conditions and may depend on the availability of nitrogen and other nutrients to crops. The results of experiment I substantiate the findings of [49], the authors of which indicated that the use of 90 kg N ha^{-1} and 50 kg P ha^{-1} rates resulted in higher values of seed yield and its components. In contrast, the results of experiment II were consistent with those reported in [41], the authors of which noted that the application of integrated fertilizers, namely $O_2K_2A_1$ and $O_2K_1A_2$ compost application (1000–2000 kg ha^{-1}) with urea (50–100 kg ha^{-1}), resulted in an increase in seed yield of 35–38%, with profit reaching USD 333–340 ha^{-1} in comparison to the standard treatment. Furthermore, the authors of [38] found a substantial increase in soybean biological yield (5611.81 Kg/ha) using an application of chemical and organic fertilizers (125% RDF + FYM @5 t ha^{-1}) in soybean field trial research. The correlation matrix of growth and yield parameters displayed a positive relationship between the SPAD values and growth and yield components, showing the effective impacts of organic and inorganic fertilizers on soybean growth and yield. In our study, fertilization significantly influenced the major growth and yield parameters, and treatment with integrated organic and inorganic fertilizers (CF + 75% AMLD) resulted in more stable results under the field conditions. In addition, the differences between the effects of organic and inorganic fertilizers might be highly related to the time of application, soil physical and chemical properties, soil microbial community, and field water content.

Considering the harmful effects of inorganic fertilizers on the environment, unsustainable sources, and high costs, the tendency is to reduce agrochemical applications, particularly inorganic fertilizers in the agricultural sector [47]. Therefore, the use of inorganic fertilizers in combination with organic fertilizers could be an effective way to maintain crop productivity and soil fertility under field conditions. The combined use of cow manure and urea seems more feasible and applicable to Afghanistan's farmers. Furthermore, the application of organic fertilizers will provide more essential nutrients to plants, increase nutrient availability by reducing pH, and improve soil physical properties and biological fertility.

5. Conclusions

The results of our study showed that the integrated application of organic and inorganic fertilizers (CF + 75% AMLD) and the sole application of chemical fertilizers (CF) significantly increased numerous soybean growth and yield parameters, including plant height, the number of leaves per plant, number of nods per plant, number of pods per plant, pod length, SPAD values, and yield, under pot and field conditions. In addition, the 75% CF + AMLD treatment exhibited more effective results under field conditions. Thus, the integrated application of inorganic and organic fertilizers is recommended as a fertilization strategy to enhance soybean growth and yield. Our study might be the first attempt to elucidate the effects of integrated application of organic and inorganic fertilizers on soybean growth and yield under the agro-climatic conditions of Afghanistan, and our efforts are sequentially in progress to explore the potential and efficacy of the utilization of various integrated fertilizers (organic, inorganic, and microbial fertilizers) and their mechanistic interactions with respect to soybean performance.

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