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Assessing the Efficacy of Wheat-Soybean Based Intercropping System at Different Plant Densities in Bambili, Cameroon

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Abstract

Wheat is one of the most important cereals in the world, serving as a staple for millions globally. In the wake of the geopolitical crisis between Russia and Ukraine, it has become incumbent for many countries to invest in wheat production. Improving cropping systems for wheat production is paramount. Intercropping cereals with legumes has tremendous advantages. Therefore, this study was designed to optimize wheat production by intercropping it with soybean at different densities. Between March and August 2023, a randomized complete block design trial was conducted in Bambili, North West of Cameroon with treatments T1 (wheat monocrop at 200,000 plants ha^{-1}), T2 (soybean monocrop at 250,000 plants ha^{-1}), T3 (200,000 wheat and 125,000 soybean ha^{-1}), T4 (100,000 wheat and 250,000 soybean ha^{-1}), T5 (200,000 wheat and 250,000 soybean ha^{-1}) and T6 (100,000 wheat and 125,000 soybean ha^{-1}). Results revealed that growth parameters of wheat were not significantly influenced by monocrop or intercrop. The yield of wheat was significantly higher in the monocrop than the intercrop treatments, with slight variation amongst the intercrop treatments. Soybean yield was higher in the monocrop than in the intercrop, with no variations amongst the intercrop treatments. Only the land equivalence ratio (LER) for T5 was greater than 1.0. The competitive ratio for T5 was 0.54 for wheat and 1.90 for soybean, comparatively lower than the other monocrop treatments. Intercropping wheat and soybean at 200,000:250,000 ratio is recommended.

Keywords

Competitive Ration, Land Equivalence Ration, Intercrop, Soybean, Wheat

1. Introduction

Wheat (*Triticum aestivum*), belonging to Poaceae (Graminae) is one of the important cereals of the world [1]. Wheat serves as a staple food crop for millions all over the world after rice [2]. Wheat plays a very important role in global economy as it is used to make flour for bread, cookies, biscuits, leavened, breakfast cereals, cake, pasta, fermented alcoholic beverages (beer), noodles and bio-fuel [4]. Wheat provides a nutritive fiber component for human and livestock [3] [5]. Wheat contributes more than 30% of global whole grain demand. The increasing global population has necessitated the augmentation of wheat productivity and proper distribution to avoid future world food insecurity crisis [6]. China, India, and Russia are the three largest producers of wheat accounting for about 41% of world's total wheat production [7]. Russia and Ukraine together account for 30% of the global wheat trade [8]. The conflict between Russia and Ukraine has derailed global wheat supplies, leading to high prices, worsened hunger and malnutrition for many in about 36 - 53 countries especially in the developing world [9] [10]. To avoid future food crisis, Mottaleb *et al.* [10] opined that developing countries should expand domestic wheat production in the potential cases.

Over a period of two decades (2000-2019), Shillie *et al.* [11] reported that annual wheat production in Cameroon was 840 metric tonnes. At the same time, wheat importation to Cameroon was 513,850 metric tonnes annually [11]. This highlights a huge gap between local production and consumption needs filled through importations, with Ukraine supplying about 60% of wheat consumed in Cameroon [12]. Cameroon has the requisite agro-ecological conditions for wheat production; therefore engaging in local wheat production can create jobs and avoid food insecurity [11]. In 2022, the government of Cameroon invested 15 million USD (10 billion CFA) to grow more wheat [12]. In order for such initiatives to be successful, especially in areas where farmers have limited knowledge of wheat cultivation, it is important to ensure that wheat is cultivated under sustainable farming systems. One of such sustainable farming systems to consider is intercropping, also known as mixed cropping or polyculture. This farming practice emphasizes diversified crop cultivation that uses comparatively low inputs and improve the quality of agro-ecosystem [13], which is very useful for small farms. Intercropping is known to produce stable yields from diversified crops with less use of inputs for nutrient and plant protection in a healthy environment [14]. According to Mousavi and Eskandari [15], intercropping is a form of sustainable agriculture that guarantees food supply for the people and future generations through more utilization of resources, increase in the quality and quantity of yield as well as minimizing pests, disease and weed attacks. In fact, meta-analysis studies have demonstrated that intercropping agricultural systems are climate resilient and clear benefits for pests and pathogen control and overall gross profitability [16] [17]. In events when a legume e.g. soybean is used as a component crop in the intercropping systems, the legume plays pivotal role like biological nitrogen fixation and soil quality enhancement, yield including protein yield from legume [13]. However, growing two crops at the same time in the same field has its own challenges such as competition for resources [13]. Therefore, this study is designed to optimize wheat production in a wheat-soybean intercropping farming systems. We hypothesized that different wheat densities in a wheat-soybean intercropping will affect wheat growth and yield parameters differently. The objectives of this study were to assess the effect of wheat-soybean intercropping system at different densities on (i) growth parameters and (ii) yield parameters of wheat. Further, we present the land equivalence ratio (LER), which is a competitive index used to evaluate the performance of intercropping [18]. According to Maitra *et al.* [19], the LER is a mathematically derived proportionate land area required under a pure stand of crop species to yield the same output as will be under an intercropping system given the same management practices.

2. Material and Methods

2.1. Location of the Experimental Site

This research was carried out in The University of Bamenda research farm located in the Northwest Region of Cameroon (Western Highlands agro-ecological zone III of Cameroon) in the University of Bamenda campus. It has geographical coordinates of 5˚59′0″ North, 10˚15′0″ East, with an altitude of 1558 m above sea level. This area has temperature ranging from 18˚C - 30˚C, characterized by annual rainfall of 2230 mm and average humidity of 70% and 52% in the rainy season and dry season respectively [20]. The soil type is Ferralitic with sandy loam soil which can promote wheat/soybeans cultivation. The topography of this location is hilly but with gentle slopes and deep valleys filled with alluvial soils. The weather parameters during the study period (March - August, 2023) are reported in **Table 1**, obtained from institute of agricultural research for development (IRAD), Bambili, Cameroon.

Table 1. Weather parameters of study site.

Months	Temperature (˚C)	RH (%)	Rainfall (mm)
March	26.87	69.6	133
April	22.75	74.15	143
May	21.19	83.90	216
June	20.02	88.22	254

Continued

July	19.08	90.99	367
August	18.61	87.75	382

RH-Relative humidity.

Table 2. Treatments: wheat and soybean intercropping pattern and plant densities.

Treatment code	Treatment	Plant spacing	Plant density (plant ha^{-1})
T1	Wheat	25 cm × 20 cm	200,000
T2	Soybean	20 cm × 20 cm	250,000
T3	Wheat-soybean	25 cm × 20 cm - 40 cm × 20 cm	200,000 - 125,000
T4	Wheat-soybean	50 cm × 20 cm - 20 cm × 20 cm	100,000 - 250,000
T5	Wheat-soybean	25 cm × 20 cm - 20 cm × 20 cm	200,000 - 250,000
T6	Wheat-soybean	50 cm × 20 cm - 40 cm × 20 cm	100,000 - 125,000

2.2. Treatments

This experiment was conducted from March to August 2023. The planting materials used included the wheat variety Allexander Wander, obtained from the department of Crop Production Technology, University of Bamenda, Cameroon. The soybean variety MAK Soy-4N was obtained from Institute of Agricultural Research for Development (IRAD), Bambili, Cameroon. The treatments in this study were wheat and soybean grown solely or in combinations as shown in **Table 2**.

2.3. Experimental Design

The experiment was conducted using a randomized complete block design (RCBD) with four replicates. Each replicate (R) consisted of 6 experimental units (R1 to R4). Each experimental unit was a ridge made by handheld hoe measuring 3 m × 1 m (3 m^2). A path of 0.5 m separates the replicates and a path of 0.5mseparates the experimental units on a surface area of 15.5 m × 12.5 m (193.5 m^2). A border ridge of 1 m wide was constructed round the experimental universe to control for any border effect.

2.4. Site Preparation and Establishment

The land was cleared using a cutlass and the plant residues were gathered away from the experimental site. The field was plough and level using a handheld hoe. Ropes, tapes and perks were used to map out the area to be ploughed in order to come out with the various blocks and experimental units. Two kg of poultry manure was weighed and applied on each experimental unit, then mixed thoroughly

Figure 1. Net covering experimental universe to prevent bird infestation.

with the soil and allowed for 14 days so that the manure should decompose before planting.

Planting was done according to the various planting distances with 20 cm spacing between rows in each treatment (T1 to T6) in each block (R1 to R4). Three seeds of soybeans and four seeds of wheat were planted in each experimental unit at a depth of 3 cm - 5 cm. After 21 days when crops had emerged, 5 g of NPK (20:10:10: obtained from Farmer's Pharmacy, Bambili, Cameroon) was applied on each plant in an experimental unit to boost the growth of the crops.

First weeding was done alongside molding using hoe, and second and third weeding was done three times manually by removing the weeds from the plots with hands. Pesticides were applied in the field to prevent insect pests from cutting and eating up the plants.

Pest and diseases were controlled by applying MOCAP (Ethoprophos) before planting to prevent nematodes and insects from damaging the seeds. Aerial spray insecticide (MAMIRA SUPER90 EC: Lambda-cyhalothrin) and fungicide (NORDOX 75 WG and MONCHAMP 720 WP) was done biweekly for 2 months. At the 6^{th} week, the field was covered with nets to prevent pests like birds from eating the wheat (**Figure 1**).

2.5. Data Collection and Description

2.5.1. Vegetative Parameters

Vegetative parameters were recorded on plant emergence, plant height, number of tillers, and area of the leaves. Four plants were randomly selected in experimental units on which data were collected.

1) Plant emergence: Plant emergence was collected 21 days after planting. The number of plants that emerged were collected and recorded.

2) Plant height: The four plants randomly sampled were measured 30 days after planting. An average of the four plants was calculated and recorded as plant height for each treatment.

3) Number of leaves: The number of leaves of four plants randomly sampled was counted 30 days after planting for wheat and soybean. An average of the four plants was calculated and recorded as number of leaves for each treatment.

In addition, the leaf length of two leaves from a wheat plant was recorded and the average calculated.

4) Area of leaves: The area of the soybean leaves of four plants randomly sampled were counted 30 days after planting. An average of the four plants was calculated and recorded as area of leaves for each treatment.

5) Number of tillers: The number of tillers of the four sampled plants was collected 60 days after planting. An average of the four plants was calculated and recorded as number of tillers for each treatment.

2.5.2. Yield Parameters

Yield parameters were recorded on number of spikelet's/pods, spike length, number of filled grains per spikelet's/pods, number of empty grains/pods, and weight of the grains. Four plants were randomly selected in experimental units on which data were collected.

1) Number of spikelets and pods

The number of spikelets and pods of four randomly sampled plants were collected 112 and 126 days after planting. An average was calculated and recorded as number of spikelets and pods for each treatment.

2) Number of filled grains per spikelet and pods

The number of filled grains/pods per plants was collected 112 and 126 days after planting. An average was calculated and recorded as number of filled spikelets and pods for each treatment.

3) Number of empty spikelets and pods

The number of empty spikelet and pods of four sampled plants were collected 112 and 126 days after planting from four randomly selected plants. An average was calculated and recorded as number of empty spikelets and pods.

4) Weight of the grains

The grains were weighed using an electronic balance. An average weight calculated for each treatment was recorded as weight of grains of wheat and soybeans.

2.5.3. Competitive Indices

1) Land equivalence ratio

The LER (equation 1) of intercropped plots is estimated for each component crops separately by adding the estimated total of wheat (*LERw*) and soybean (*LERs*); the LER of the sole crop is taken as unity (1).

$$LER = LERw + LERs = \frac{Yws}{Yww} + \frac{Ysw}{Yss} \tag{1}$$

where, Yws is the yield of wheat grown in association with soybean and Ysw is the yield of soybean grown in association with wheat. Yww and Yss represent the yields of wheat and soybean grown in a monocrop, respectively.

2) Competitive ratio

In an intercropping system, competitive ratio (*CR*) denotes the competitive ability of the component species. The *CR* can be calculated by the following formulae (equation 2 and equation 3)

$$CRw = \frac{LERw}{LERs} \times \frac{Zsw}{Zws} \quad (2)$$

$$CRs = \frac{LERs}{LERw} \times \frac{Zws}{Zsw} \quad (3)$$

where, *CRw* and *CRs* are indicative of the competitive ratios of wheat and soybean and *LERw* and *LERs* are the *LER* of the wheat and soybean respectively. *Zws* is the sown ratio of wheat in mixture with soybean and *Zsw* is the sown proportion of the soybean in mixture with wheat. If the value of *CR* is < 1, there is a positive benefit and it means there is limited competition between component crops and therefore they can be grown as intercrops. If the *CR* value is more than one ($CR > 1$), there is a negative impact.

2.6. Data Analyses

Homogeneity of variance and normality tests were conducted using Levene's test and Kolmogorov-Smirnov in SPSS (ver 23), respectively. The data were subjected to one-way analysis of variance (ANOVA) test. Where means were significantly different, they were separated using Tukey honestly significantly difference (Tukey HSD) *posthoc test* at alpha (α) level of 0.05 using SPSS (ver. 23). Where the blocking effect was not statistically significant, the ANOVA was redone with the blocking effect removed in order to increase the degree of freedom of the error term, thus increasing the reliability of the analysis [21].

3. Results

3.1. Vegetative Parameters

3.1.1. Plant Emergence

Plant emergence did not vary across wheat planting densities ($F = 0.378$, df = 4, 15, $P = 0.821$; Figure 2). The wheat emergence ranged from 76.36% (T5) to

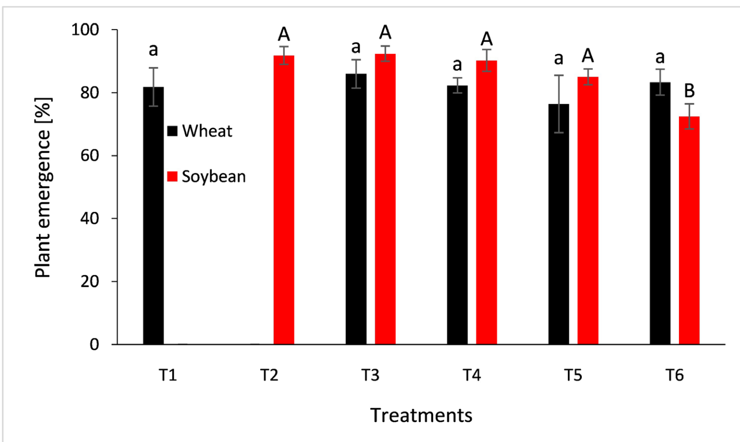

Figure 2. Wheat and soybean emergence in mono and mixed cropping systems at different densities. Mean bars with the same letters are not significantly different (Tukey's HDS, $P < 0.05$). Uppercase letters compare emergence across soybean and lowercase letters compare emergence across wheat.

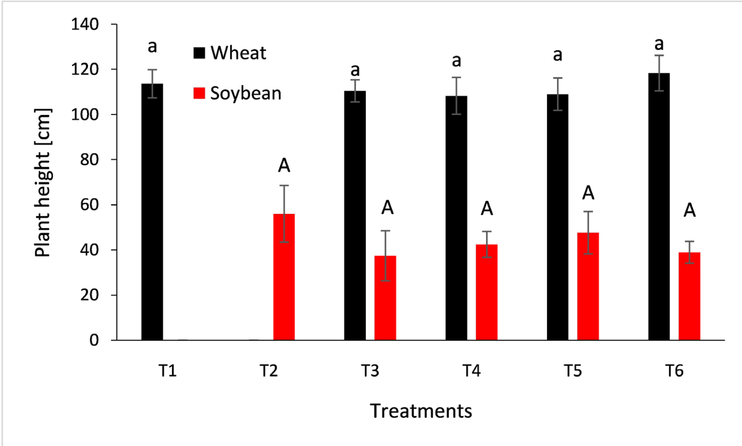

Figure 3. Wheat and soybean plant height (cm) in mono and mixed cropping sy stems at different densities. Mean bars with the same letters are not significantly different (Tukey's HDS, $P < 0.05$). Uppercase letters compare plant height across soybean and lowercase letters wheat.

85.94% (T3). The wheat emergence was 81.77%, 82.29% and 83.33% from T1, T4 and T6, respectively (Figure 2). Soybean emergence across treatments (F = 7.258, df = 4, 15, $P = 0.002$). Soybean emergence greater than 90.0% observed from T3, T2 and T4 (Figure 2). Soybean emergence was 85.0% and 72.45% from T5 and T6, respectively (Figure 2).

3.1.2. Plant Height

Plant height (cm) of wheat 30 days after planting did not vary (F = 0.352, df = 4, 15, $P > 0.838$; Figure 3). The wheat plant height ranged from 108.25 cm from T4 to 118.38 cm from T6. The wheat plant height from T5, T3 and T1 were 109.0 cm, 110.50 cm and 113.63 cm, respectively (Figure 3). Similarly, no significant variations were observed for the soybean plant height after 30 days (F = 0.675, df = 4, 15, $P > 0.05$; Figure 3). The plant height was 56.0 cm, 37.38 cm. 42.4 cm, 47.58 cm and 38.87 cm from T2, T3, T4, T5 and T6, respectively (Figure 3).

3.1.3. Leaf Related Parameters

Wheat number of leaves 30 days after planting did not show significant variations (F = 0.75, df = 4, 15, $P > 0.05$; Table 3). Wheat from all treatments had 4 leaves by 30 days after planting. Similarly, the wheat leaf length did not differ significantly (F = 0.802, df = 4, 15, $P > 0.05$; Table 3). The wheat leaf length ranged from 13.73 cm from T3 to 17.80 cm from T5. The wheat leaf length was 14.38 cm, 15.28 cm and 15.98 cm, from T6, T4 and T1, respectively (Table 3).

The numbers of soybean leaf per plant varied significantly (F = 11.72, df = 4, 15, $P = 0.034$) across treatments, with the highest number of leaves 28, observed from T2, T4 and T5 (Table 3). The number of leaves from T6 was 23 (Table 2). Also, the leaf area for soybean showed significant variations across treatments (F = 7.859, df = 4, 15, $P = 0.047$; Table 2). The highest leaf area was 34 cm^2, recorded by T4. This was followed by 29.02 cm^2, 28.82 cm^2 and 28.70 cm^2 from T3, T1 and T5, respectively. The leaf area for T6 was 25.33 cm^2 (Table 3).

Table 3. Some leaf related parameters of wheat and soybean in sole and wheat-soybean intercropping system.

Treatment	Number of leaves of wheat	Leaf length of wheat (cm)	Number of leaves of soybean	Leaf area of soybean (cm^2)
T1	4 ± 0.97	15.98 ± 3.88	-	-
T2	-	-	28 ± 4.74a	28.82 ± 6.14ab
T3	4 ± 0.0	15.73 ± 2.03	23 ± 2.32b	29.02 ± 3.44ab
T4	4 ± 0.5	15.25 ± 4.31	28 ± 5.72a	34.90 ± 5.48a
T5	4 ± 0.5	17.80 ± 1.98	28 ± 1.71a	28.70 ± 6.23ab
T6	4 ± 0.5	16.38 ± 4.53	23 ± 1.03b	25 .33 ± 3.46b
F	0.75	0.802	11.715	7.859
P	0.573	0.542	0.034	0.047

Means (± standard deviation) within a column with different letters are significantly different (Tukey's HSD, $P < 0.05$).

3.1.4. Number of Tillers

The number of wheat tillers 60 days after planting differed significantly (F = 3.326, df = 4, 15, $P = 0.041$). The number of tillers was 3 for T1 and T3 (**Figure 4**). The number of tillers was 2 for T4, T5, and T6 (**Figure 4**).

3.2. Yield Parameters

3.2.1 Spikelet and Bean Pod Parameters

The spikelet length of wheat was not significantly influenced by cropping system (F = 1.775, df = 4, 15, $P = 0.185$) (**Table 4**). The spikelet length ranged from 14.38 cm to 15.26 cm. the number of spikelets varied across cropping systems (F = 7.633, df = 4, 15, $P = 0.001$) (**Table 4**) with the highest value (42) observed T1 and T6 had the highest number of filled spikelets, followed by T5. No significant variations were observed in the number of unfilled spikelets amongst the treatments.

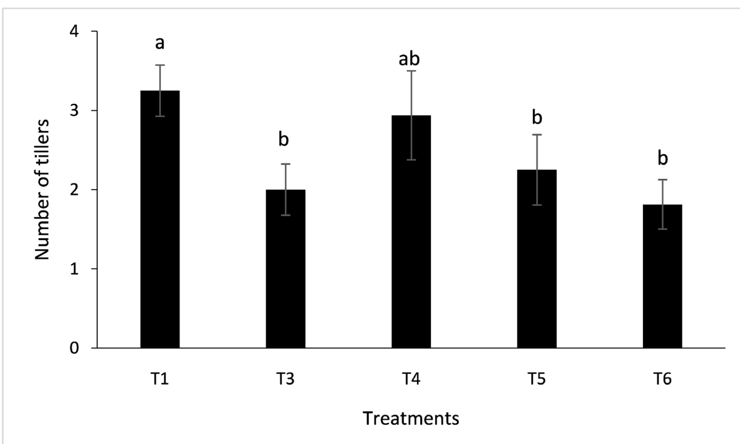

Figure 4. Wheat number of tillers in mono and mixed cropping systems at different densities. Mean bars with different letters are significantly different (Tukey's HDS, $P < 0.05$).

Table 4. Some yield related parameters of wheat and soybean in monocrop and intercrop systems.

Treatments	Length of spikelet (cm)	Number of spikelet	Number of filled spikelet	Number of unfilled spikelet	Number of pods	Number of filled pods	Number of unfilled pods
T1	15.26 ± 0.30a	42 ± 1.68a	35 ± 2.21a	7 ± 1.18a	-	-	-
T2	-	-	-	-	29 ± 2.52bc	28 ± 2.43bc	1 ± 0.24a
T3	14.38 ± 0.69ab	26 ± 2.11c	21 ± 1.48c	5 ± 0.98a	32 ± 3.09bc	31 ± 2.99bc	1 ± 0.16a
T4	13.55 ± 0.44b	28 ± 2.95bc	24 ± 2.39b	4 ± 1.08a	37 ± 1.48ab	35 ± 1.23ab	2 ± 1.03a
T5	14.49 ± 0.33ab	29 ± 1.12bc	25 ± 2.99b	4 ± 2.11a	26 ± 3.18c	25 ± 3.48c	1 ± 0.34a
T6	14.83 ± 0.49ab	35 ± 3.00ab	31 ± 1.30ab	4 ± 2.05a	42 ± 4.06a	41 ± 3.74a	1 ± 0.38a

Means (± standard deviation) within a column with different letters are significantly different (Tukey's HSD, $P < 0.05$).

The number of pods for soybean was significantly influenced by cropping systems ($F = 4.755$, df = 4, 15, $P = 0.011$) (Table 4). The intercropping treatments produced the highest number of pods compared to the monocrop: T6 (42), T4 (37), T3 (32) and T2 (29). The same pattern was observed for the number of pods filled ($F = 4.399$, df = 4, 15, $P = 0.015$) (Table 4). No significant variation was observed for the number of unfilled pods ($F = 1.508$, df = 4, 15, $P = 0.250$) (Table 4).

3.2.2. Yield of Wheat and Soybean

The yield of wheat and soybean are presented in Figure 5. The yield for the wheat monocrop out performed that from the intercrop systems. Thus, comparison amongst the intercrop treatment revealed that T5 (0.323 t ha^{-1}), and this

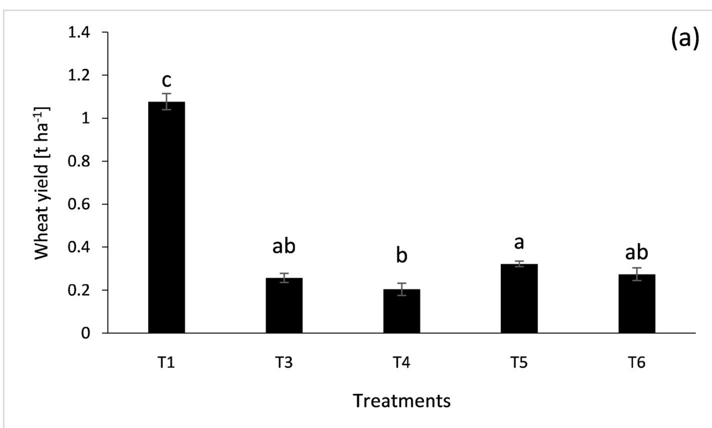

Figure 5. Wheat and soybean yield (t ha^{-1}) mono and mixed cropping systems at different densities. Mean bars with different letters are significantly different (Tukey's HDS, $P < 0.05$).

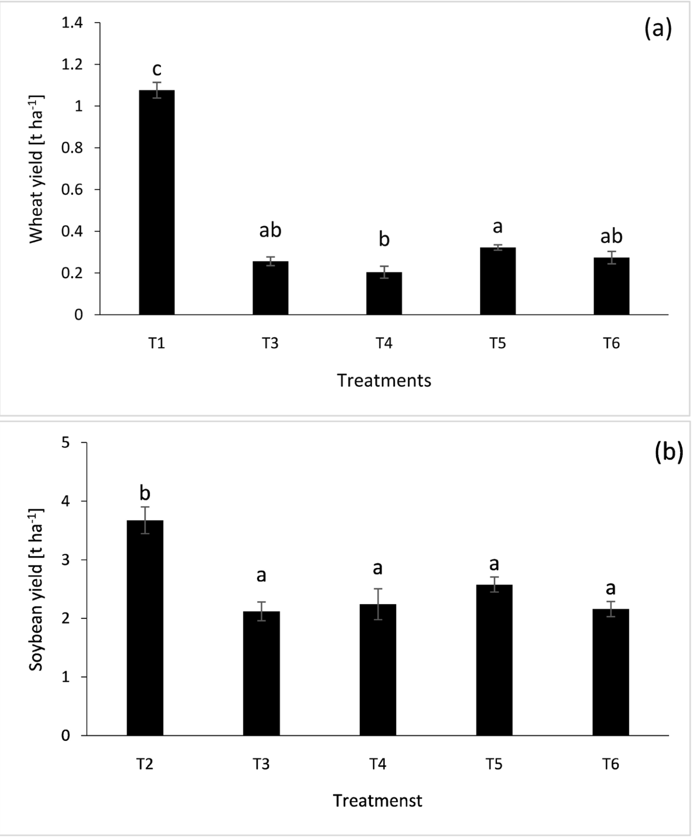

Figure 6. LER at different densities. Mean bars with different letters are significantly different (Tukey's HDS, $P < 0.05$).

was significantly higher that from T4 (0.202 t ha^{-1}) (F = 179.390, df = 4, 15, P = 0.001). Similarly, the yield of the monocrop soybean out performed those of the intercrop patterns. Comparison amongst the intercrop soybean revealed no significant variations amongst them (F = 1.352, df = 3, 12, P = 0.304).

The yield of soybean was 3.673 t ha^{-1} (T2), 2.58 t ha^{-1}, 2.25 t ha^{-1} (T4), 2.16 t ha^{-1} (T6) and 2.12 t ha^{-1} (T3).

3.3. Competitive Indices

3.3.1. Land Equivalence Ratio

The land equivalence ratio is reported in Figure 6. Only the LER of T5 was greater than 1.0, and it was significantly higher than the others (F = 5.578, df = 3, 12, P = 0.041). The LER were 0.86 (T6), 0.82 (T3) and 0.81 (T4) (Figure 6).

3.3.2. Competitive Ratio

The comparative ratio for wheat varied across treatment (F = 4.451, df = 3, 12, P = 0.025) (Table 5). The lowest value was 0.27, observed from T3, while the highest value was 0.80, recorded from T4. Similarly, the competitive ratio for soybean varied across treatments (F = 7.988, df = 3, 12 P = 0.003) with the highest value 4.06 recorded from T3. The other values were 2.04 (T6), 1.89 (T5) and 1.3 (T4) (Table 5).

Table 5. Competitive ration (CR) of wheat-soybean intercropping system.

	Competitive Ration	
Treatment	**Wheat**	**Soybean**
T1	-	-
T2	-	-
T3	0.27 ± 0.10b	4.06 ± 1.24a
T4	0.80 ± 0.31a	1.37 ± 0.44b
T5	0.54 ± 0.08ab	1.90 ± 0.32b
T6	0.57 ± 0.25ab	2.04 ± 0.98b
F	4.451	7.988
P	0.025	0.003

Means (± standard deviation) within a column with different letters are significantly different (Tukey's HSD, $P < 0.05$).

4. Discussion

The study revealed that plant emergence was not affected by different plant combinations for both wheat and soybean. Similar plant emergence could be indictive of viable seeds planted and good agronomic practices [22], especially given that severe competition would not have arisen at the time of emergence. Mugi-Ngenga *et al.* [23] did not record significant changes in plant emergence in a maize-legume intercrop trial in Tanzania, similar to the wheat-soybean results observed in the current study.

Like plant emergence, plant height of wheat in the intercrop was not significantly different from the monocrop even though slight differences in plant height was observed between sole wheat and wheat-soybean (T6), which could be related to resource utilization [24]. The plant height for soybean remained fairly the same over all treatments. Although it is widely reported that intercropping cereal crops such as maize or wheat with a legume such as soybean improves the growth performance of cereals [25], our study did not show that for wheat plant height. Our observations are similar to those of Mugi-Ngenga *et al.* [23] in maize-legume intercrop trial. In the case of our study, the wheat and soybean were planted at the same time, creating a scenario of interspecific competition. Such competition could have limited the optimal advantageous intercrop performance of wheat, resulting in no distinguishable height difference for between monocrop and intercrop. For optimal utilization of the benefits of cereal-legume intercrop systems in terms of growth parameters, some researchers have suggested that legumes be planted 2 - 4 weeks after cereals sowing to help in the prevention of interspecific competition among crop species [26].

The number of leaves for wheat was not affected by intercropping systems. The number of leaves for wheat was the same across all treatment. In addition, the wheat leaf length did not show any significant variations across treatments. The same arguments on the plant height could be made for the number of leaves and the leaf length. In spike of the fact that significant differences were not observed, small differences in number of leaves and leaf length were recorded in favour of intercropping systems for wheat. In a wheat density trial conducted by Dornbusch *et al.* [27], they reported that increased wheat population density as in the case of monocrop let to shorted adult leaves and vice versa, as in the case of intercrop. Our study is on par with the observations of Dornbusch *et al.* [27]. We further hypothesize that the increased leaf length of wheat from the intercrop is due to the incorporation of soybean, a legume that improves the physico-chemico-biological properties and soil fertility and increase resource use efficiency, leading to improved growth (leaf length) performance [28]. The number of leaves for soybean did not show a clear distinct pattern between monocrop and intercrop, rather, differences showed in relation to density. We observed that the densely planted soybean (T2, T4, and T5), irrespective of monocrop or intercrop had more leaves compared to the less dense scenario (T3 and T6). For the soybean leaf area, no clear distinction was observed based on monocrop/intercrop systems nor on the plant density. Many studies indicate that soybean plant density have resulted into variable growth pattern such as in leaf numbers, leaf area and number of branches [29] [30] [31].

The number of tillers, spikes, length of spikelets, whether or not the spikelets filled are crucial parameters to determine yield of wheat [32] [33]. In the current study, the number of tillers was generally higher in the monocrop than in the intercrop, even though when wheat density was the same. It is suggested that wheat population density, temperature, soil salinity and availability of nitrogen can influence tiller development alongside other agronomic practices [34] [35]. The monocrop field has the smallest density of plants (wheat and soybean) per unit area relative to the other treatments, allowing for more photosynthetic active radiation (PAR) in the wheat monocrop than in the intercrop. Evers *et al.* [36] reported that high-density planting reduces PAR intensity and this results in cessation of tiller development, explaining the lower tiller numbers in intercrop treatments (high-density planting). We observed here that the number of tillers was not favoured by agronomic practices such as intercropping. The same pattern of numbers of tillers was recorded for the length of spikelet and number of spikelet. However, the proportion of unfilled spikelet was higher in the monocrop compared to the intercrop. It is widely reported that spikelet growth and development is profoundly influenced by nitrogen [37] [38]. We hypothesized that spikelet development was better (*i.e.* In relation to unfilled spikelet) in intercrop that monocrop because of the nitrogen fixing potential soybean (legume) [39] [40], which made nitrogen available to wheat. Unlike wheat, the overall soybean performance in relation to number of pods and number of pods filled was significantly higher in intercrop than in monocrop. In particular, T3 and T6 (with lower soybean density) outperformed all other soybean treatments with higher densities. It could be suggested that intraspecific competition between soybean, rather than interspecific competition between soybean and wheat is responsible for this performance. Our finding is in line with that of Anusha *et al.* [31].

It was also observed that the yield of wheat in the monocrop was higher than in the intercrop, same as the soybean. Therefore, some competitive indices were assessed to ascertain the importance of wheat-soybean intercrop.

Land equivalency ration (LER) denotes the benefits of an intercropping system to utilize the resources available against their pure stands [41]. Only the LER of T5 (*i.e.* 200,000 wheat and 250,000 soybean per hectare) was greater than 1, indicating an advantage of the intercropping system [42], and closely followed by T6 (*i.e.* 100,000 wheat plants and 125,000 soybean plants). The competitive ratio (*CR*) in intercropping systems denotes a measure of intercrop competition, to indicate how one crop is more or less competitive than the other between different crop species [43]. All competitive ratios for wheat were positive indicating that wheat was dominant crop [44]. Furthermore, the low *CR* of wheat in T5 and corresponding low value in soybean implied the competition from soybean was less compared to the other soybean treatments [13] [44].

5. Conclusion

The current study underscores the importance of intercropping on wheat-soybean intercropping systems. The result showed that growth parameters of wheat were not significantly impacted by intercropping with soybean; however, the evaluation of some competitive indices revealed an advantage of planting wheat-soybean as far as yield is concerned. We therefore recommend intercropping wheat and soybean in a 200,000 - 250,000 wheat-soybean density.

Further study is recommended on the role of alternating planting dates for the wheat and soybean in the intercropping system.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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