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Weeds Spectrum, Productivity and Land-Use Efficiency in Maize-Gram Intercropping Systems under Semi-Arid Environment

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Abstract: To ensure food security on sustainable basis, reducing weeds interference and boosting land use efficiency are critical. A field study was conducted at research farm of University of Agriculture Faisalabad, Pakistan, to sort out the most productive maize-gram intercropping system under semi-arid environment. Treatments included sole maize in single row (60 cm apart) (T_1) and double rows (90 cm apart) (T_2) strips, sole black (T_3) and green gram (T_4) crops, six single rows (60 cm apart) of maize with twelve double rows (20 cm) of black (T_5) and green gram (T_6), three double rows (90 cm apart) of maize with three sets of quadratic rows (20 cm apart) of black (T_7) and green gram (T_8). The experiment was executed in regular arrangement of randomized complete block design with three replications. The results revealed that T_1 produced the highest grain yield (6.97 t ha^{-1}) of maize and significantly lower weeds infestation compared to wider row spacing (T_2). Among intercropping systems, T_8 significantly decreased weeds density (16.33 plants m^{-2}) and their fresh (20.93 g m^{-2}) and dry weights (5.63 g m^{-2}), while the maximum land use efficiency as indicated by unmatched land equivalent ratio and intercropping advantage were recorded by T_7 and T_8. Interestingly, green gram in intercropping recorded over 58% higher productivity than black gram. We conclude that maize-green gram intercropping hold potential to impart sustainability to maize production by reducing weeds infestation (431% lower than sole maize) and could be a viable option for smallholder farmers in semi-arid environment.

Keywords: sustainable intercropping; companion crops; *Vigna mungo*; *Vigna radiata*; living mulch; land equivalent ratio

1. Introduction

Intensive agriculture is providing substantial yields of cereals but has caused serious environmental degradation, largely owing to excessive use of mineral fertilizers and chemical pesticides [1]. For ensuring nutritional security on sustainable basis under changing climate, developing innovative farming systems for cereals are indispensable especially in Asian countries like Pakistan, India, Saudi Arabia, China and Bangladesh. These countries are confronting profound environmental degradation as evident through global warming and unpredictable variation in precipitation regimes which have adversely affected the farming systems across the continent [2]. The development of farming systems that are biologically viable, economically attractive, farmer friendly, technologically adoptable and environmentally sustainable are direly needed. Intercropping of cereals like maize (*Zea mays* L.) with legumes (green and black grams) may improve resources (light, moisture, mineral nutrients etc.) utilization efficiency due to complementary use of inputs in temporal and spatial dimensions [3]. In addition, intercropping systems exploit complementarities of species to attain sustainable intensification by multiplying crops outputs per unit of land area with substantial slicing of anthropogenic inputs. Maize plants hold competitive advantage over legumes by virtue of deeper and rapidly spreading roots system, while legumes fulfill a greater part of their nitrogen requirement from biological nitrogen fixation process [4,5]. Furthermore, it was reported that strip cropped maize with legumes developed deeper and extended roots network into the soil for exploring lower soil horizons owing to competition for moisture uptake [6]. Although overall productivity on intercropping systems remained on higher side, however, maize and legume intercrops witness individual yields reduction in intercropping systems [1,3,4], which constitutes the most pertinent challenge especially in semi-arid environment. Moreover, changing climate requisites evaluating atypical maize production systems that may potentially boost productivity without requiring additional farm inputs.

The choice of legume for intercropping with maize determines the productivity of intercropping systems by ensuring compatibility in utilizing growth resources [1]. Compared to solo crop equivalents, overall intercropping systems productivity and land use efficiency as indicated by land equivalent ratio were significantly (23–47%) increased [7,8]. Similarly, green gram (*Vigna radiata* L.) and black gram (*Vigna mungo* L.) may impart sustainability to maize-legume intercropping system by enhancing land use efficacy attained through higher utilization efficiency of farm applied inputs. However, optimization of intercropping system may potentially reduce the degree of inter and intra species competition and boost the added benefits offered by cereal-legume intercropping systems [9–13], which continues to remain an unexplored aspect under irrigated conditions of semi-arid environment. This is of the utmost importance as numerous types of species-specific mechanisms alter the physiological response of intercrops and directly determine the extent of added advantage offered by intercropping system.

Recently, the changing climate and global warming scenarios have given rise to various types of exotic and indigenous weeds along with causing intensification of their infestation [14,15]. Weeds such as awn-less barnyard grass (*Echinochloa colona*), field-bind weed (*Convulvulus arvensis*) etc. keep on emerging and produce abundant quantities of seeds until they are managed by tillage, weedicides, or employing crop competition through intercropping [1,16]. Herbicides are being used extensively to manage weeds in maize and green or black gram; however, there are very scant post emergence options, especially for perennial weeds. In addition, persistent herbicides usage having similar modes of action may potentially lead to the evolution of resistance in weeds. Many summer weeds including *Sonchus oleraceaus* L. have developed resistance to commonly used herbicides like glyphosate [17–19]. Besides ecosystem disruption, injudicious use of herbicides has serious health consequences due to high shelf-life of their active ingredients. Moreover, the lack of new effective herbicides release on commercial scale has caused shifts in weed population, growing environmental concerns owing to pollution, and skyrocketing prices of herbicides which have necessitated curbing and limiting the use of herbicides. Under these conditions living mulch as an intercrop may prove beneficial in controlling weeds and increase yield per unit of land without damaging the environment. Cereal-legumes intercropping systems reduced yield attributes (plant height, stem girth, leaf area, plants fresh and dry weights etc.) and biomass productivity of intercrops, however overall yield per unit area was increased by over 37% [1]. Additionally, legumes intercropping with cereals intensified the competition for growth resources which reduced intercrops yield by 23–37% and therefore, it was suggested to select legume intercrops having compatibility with cereals for growth resources utilization in temporal and spatial dimensions [10,11]. Moreover in cereal-legume intercropping systems, it has also been reported that cereals like maize and sorghum hold competitive advantage in acquiring growth resources by virtue of superior agro-botanical traits compared to most of legumes companion crops [1,12,20]. Legumes such as black and green gram sown in appropriate intercropping systems with maize might potentially reduce weeds infestation by providing them lesser space for growth.

Moreover, challenges posed by climate change and declining soil fertility have multiplied the risks of crop failure for small land holders in Indo-Pak subcontinent [21]. The quest has peaked to find out the cropping systems which provide yield stability along with being sustainable in long run. Therefore, there has been increasing interest in integrating cultural practices like intercropping to reduce our reliance on herbicides and develop a more effective and biologically viable weed control strategy. It was hypothesized that maize may perform differently in intercropping with legume intercrops owing to variability of growth resources utilization in temporal and spatial dimensions, while optimization of intercropping system could potentially suppress weeds infestation due to interspecies competition and lesser growth space available to weeds flora. So, this multi-year field experiment was performed with dual objectives to optimize intercropping systems of green and black gram with maize for suppressing weeds infestation and to quantify the impact of different intercropping systems on the productivity of intercrops and land use efficiency.

2. Materials and Methods

2.1. Experimental Site and Treatments Details

The experiments were performed at the Agricultural Graduate Research Farm, University of Agriculture, Faisalabad, Pakistan (31.4504° N, 73.1350° E, altitude of 186 m) [20]. The sowing of the experiment was done after the harvest of winter wheat crop. The mean temperature and rainfall of the experimental site during both growing seasons (April-August) remained 27.7 °C and 83 mm respectively, as per meteorological observatory located at the close vicinity of our experimental site. The field trial was executed to study the comparative weed control potential of green and black gram intercropping in maize. The experiment was comprised of treatments including sole maize in single row (60 cm apart) strips (T_1), sole maize in double rows strips (90 cm apart) (T_2), sole black (T_3) and green gram (30 cm apart rows) (T_4), six single rows (60 cm apart) of maize with twelve double rows (20 cm) of black gram (T_5), six single rows (60 cm apart) of maize with twelve double rows (20 cm apart) of green gram (T_6), three double rows (90 cm apart) of maize with three sets of quadratic rows (20 cm apart) of black gram (T_7) and three double rows (90 cm apart) of maize with three quadratic rows (20 cm apart) of green gram (T_8). The schematic presentation of treatments regarding maize intercropping with green and black gram under varying row placements has been given in Figure 1. The field experiments were arranged in randomized complete block design with three replications, while net plot size (excluding field bunds, sub water channels and field pathways) area (length × width) was maintained at 5.0 m × 3.6 m. There were eight experimental plots per replication, while the experiment was comprised of total 24 plots.

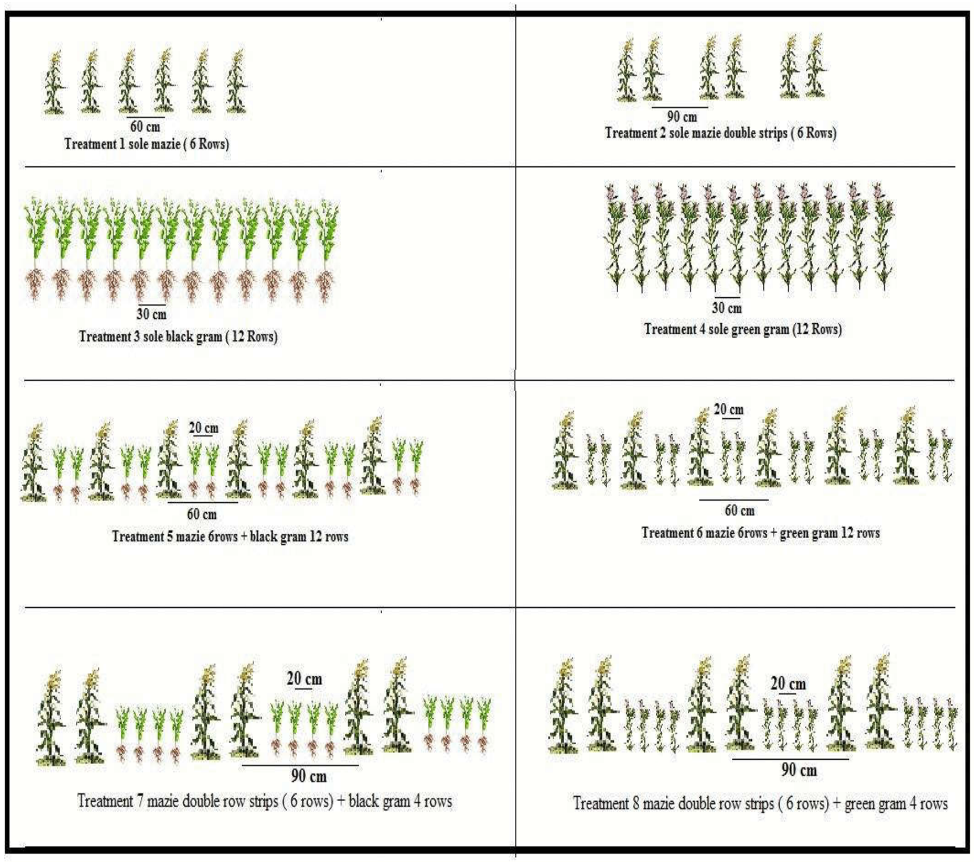

Figure 1. Schematic sketch of row placement of black and green grams in maize at various planting patterns in the field.

2.2. Site Physico-Chemical Properties

Pre-experiment soil analyses were performed by taking the soil samples from experimental site at two different depths (0–15, 0–30) from four corners and center of experimental block that were thoroughly homogenized for subsequent analyses. All the samples were air dried, grounded and sieved using 2 mm sieve. The glass electrode pH meter was used for measuring the pH of soil samples (soil and water in 1:2.5 ratio) [22] while electrical conductivity (EC) was determined with the help of conductivity meter [23]. Wet oxidation method was used for determining the organic carbon (OC) volumetrically. The soil organic matter (OM) was estimated by following Walkley–Black methodology [24]. For estimating total nitrogen (N) content, distillation in Kjeldahl apparatus was performed that was followed by titration with the concentrated H_2SO_4 [25]. Additionally, Olsen's method (0.5 N $NaHNO_3$ at 8.5 pH by maintaining soil: extractant ratio of 1:10) using spectrophotometer at 882 nm wavelength in a sulfuric acid system) was used for determining the available phosphorous (P) content [26], while standard procedure (ammonium acetate extraction involving air dried soil samples shaking with 0.5 M ammonium acetate solution for 30 min which effectively displaced positively charged K ions that were determined using flame photometer) as outlined by [27] was put into use to calculate potassium (K). Among micronutrients, available iron (Fe) was extracted using 1 N NH_4OAC at pH of 3.0. Subsequently, the extract was subjected to analysis using spectrophotometer at 510 nm wavelength by colorimetric method. Moreover, boron, zinc, copper and manganese contents in soil samples were estimated using diethylenetriaminepentaacetic acid extraction method [28–30].

Soil of the experimental site had a loam texture with pH of 8.1, while OM was only 0.51% indicating severely exhaustive utilization of soil. The soil had EC and bulk density of 0.42 dS m^{-1} and 1.40 cm^{-3} respectively. The NPK contents were 71, 4.3 and 110 mg kg^{-1} respectively. The micronutrient B, Mn, Fe, Cu and Zn were 1.02, 20.4, 10.1, 1.9 and 1.1 mg kg^{-1} of soil, respectively.

2.3. Planting Material and Crop Husbandry

Maize hybrid (DK-919) was sown manually using the recommended kernel rate of 25 kg ha^{-1}, while erect type cultivars of black gram (cv. Arooj-97) and green gram (cv. AZRI Mung-2006) were sown using the recommended seed rate of 30 and 25 kg ha^{-1}, respectively. The plant-plant spacing for maize was maintained at 25 cm, while 10 cm was the distance between green and black gram plants. Hoeing was done manually after 20 days of sowing to remove the early weed-crop competition. Fertilizers (urea, di-ammonium phosphate and potassium sulphate) were applied at the rate 150, 100, 80 kg ha^{-1} N-P-K, respectively. Full doses of P and K, while one-third of N fertilizer, were applied at the time of seed bed preparation. The remaining N was applied in two equal splits with irrigations at 15 and 30 days after sowing (DAS). All the other agronomic practices were performed uniformly in all experimental plots.

2.4. Weeds Dynamics

The densities of individual weeds (*Echinochloa colona, Trianthema portuclacastrum, Convulvulus arvensis and Convulvulus esculentus*) and total weeds were counted (from an area of 1 square meter) per experimental unit using a rectangular quadrate at 20, 40, 60 DAS and at the time of crop harvesting. Weeds were cut with the help of sickle and weighed using an electric balance. Subsequently, weeds were sun dried for one week then kept in an oven at 42 °C and weighed repeatedly until constant dry weight was achieved after 24 h. Thereafter, all the samples were weighted individually and collectively using a digital balance. All intercrops after harvesting were left in the field for two weeks for sun drying and thereafter tied into bundles and stocked for four week. Then maize cobs were separated from the stalks and allowed drying in sunshine for five days to achieve 10% grain moisture content before shelling. Randomly, ten plants from each plot were used to record thousand grains weight and their average was worked out. The biological yield (grain yield + stalks yield) and grain yield were recorded on per plot basis to determine the harvest indices of maize, black and green gram using Formula (1);

$$\text{Harvest Index} = \text{Grain Yield}/\text{Biological Yield} \times 100 \quad (1)$$

2.5. Land Use Efficiency

Land use efficiency was measured using land-equivalent ratio which was calculated as described by Formula (1).

$$\text{LER} = \text{LER (Maize)} + \text{LER (green/black bean)} \quad (2)$$

$$\text{LER (Maize)} = \text{Grain yield of intercropped maize}/\text{Grain yield of sole maize} \quad (3)$$

$$\text{LER (black gram)} = \text{Grain yield of intercropped black gram}/\text{Grain yield of sole black gram} \quad (4)$$

$$\text{LER (green gram)} = \text{Grain yield of intercropped green gram}/\text{Grain yield of sole green gram} \quad (5)$$

2.6. Statistical Analysis

The collected data were subjected to analyses of variance (ANOVA) technique and subsequently to assign significance among treatment means, Tukey's Honest significance test was employed at 5% probability level with the help of "SAS" statistical package. The correlation analyses (n = 8) for determining the direct or inverse relationship between weeds density and their fresh and dry weights with grain yield of intercropped green gram and black gram were conducted using Microsoft's Excel program [31].

3. Results

3.1. Weeds Infestation

The results revealed that monocultures of maize (60 cm spaced single row strips and 90 cm spaced double rows strips) differed significantly in terms of weeds infestation as wider row spacing (T_2) recorded higher weeds density along with their fresh and dry biomasses compared to T_1 during both seasons. In addition, it was noted that weeds density was significantly reduced by maize-gram intercropping systems in comparison to T_1 and T_2 treatments (Table 1). Among maize intercropping systems with green gram and black gram, T_8 remained superior by recording the minimum weeds density along with their fresh and dry weights, while the highest corresponding values of weeds density, fresh and dry weights were exhibited by T_5 during both years. Among weed species at final harvest, the highest presence of *Echinochloa colona* and *Trianthema portuclacastrum* were noted for T_2, while T_7 remained effective in suppressing the infestation of these weeds (Figure 2). Contrarily, T_8 remained superiorly unmatched by recording the minimum infestations of *Convulvulus arvensis* and *Convulvulus esculentus*, while their highest infestations were recorded in T_2 (Figure 1).

Table 1. Weeds density (WD), fresh (WFW) and dry (WDR) weights in maize, black gram and green gram sole crops and in maize-gram intercropping systems under semi-arid conditions.

Treatments	WD (m^{-2})		WFW (g m^{-2})		WDW (g m^{-2})	
	2018	2019	2018	2019	2018	2019
T_1	60 ± 0.93 b	61 ± 1.13 b	112 ± 1.23 b	113 ± 0.54 b	27 ± 0.09 b	27 ± 0.62 b
T_2	85 ± 0.18 a	84 ± 0.94 a	121 ± 0.65 a	120 ± 0.19 a	33 ± 0.84 a	32 ± 1.27 a
T_3	53 ± 1.01 c	53 ± 0.14 bc	68 ± 0.18 c	69 ± 1.01 c	20 ± 0.39 c	21 ± 0.75 bc
T_4	46 ± 0.62 d	45 ± 019 c	64 ± 0.53 c	65 ± 0.34 cd	17 ± 0.91 cd	16 ± 0.91 c
T_5	37 ± 0.81 e	38 ± 1.05 d	49 ± 0.74 c	48 ± 0.66 d	14 ± 0.84 de	14 ± 0.28 d
T_6	31 ± 0.15 f	30 ± 0.24 e	41 ± 0.08 e	40 ± 1.14 e	13 ± 0.22 e	13 ± 1.05 de
T_7	27 ± 1.11 f	28 ± 0.81 e	39 ± 1.27 e	39 ± 0.29 ef	12 ± 1.11 e	12 ± 0.22 e
T_8	16 ± 0.43 g	15 ± 1.17 f	20 ± 0.17 f	20 ± 1.25 f	5 ± 0.35 f	5 ± 1.27 f

In each column, standard deviations followed by unalike letters differ significantly from each other at $p \leq 0.05$.T_1 = sole maize in 60 cm distanced single rows, T_2 = sole maize in 90 cm distanced double row strips, T_3 = sole black gram in 30 cm distanced single rows, T_4 = sole green gram in 30 cm distanced single rows, T_5 = six single rows (60 cm apart) of maize with twelve double rows (20 cm) of black gram, T_6 = six single rows (60 cm apart) of maize with twelve double rows (20 cm) of green gram, T_7 = three double rows (90 cm apart) of maize with three sets of quadratic rows (20 cm apart) of black gram, T_8 = three double rows (90 cm apart) of maize with three sets of quadratic rows (20 cm apart) of green gram).

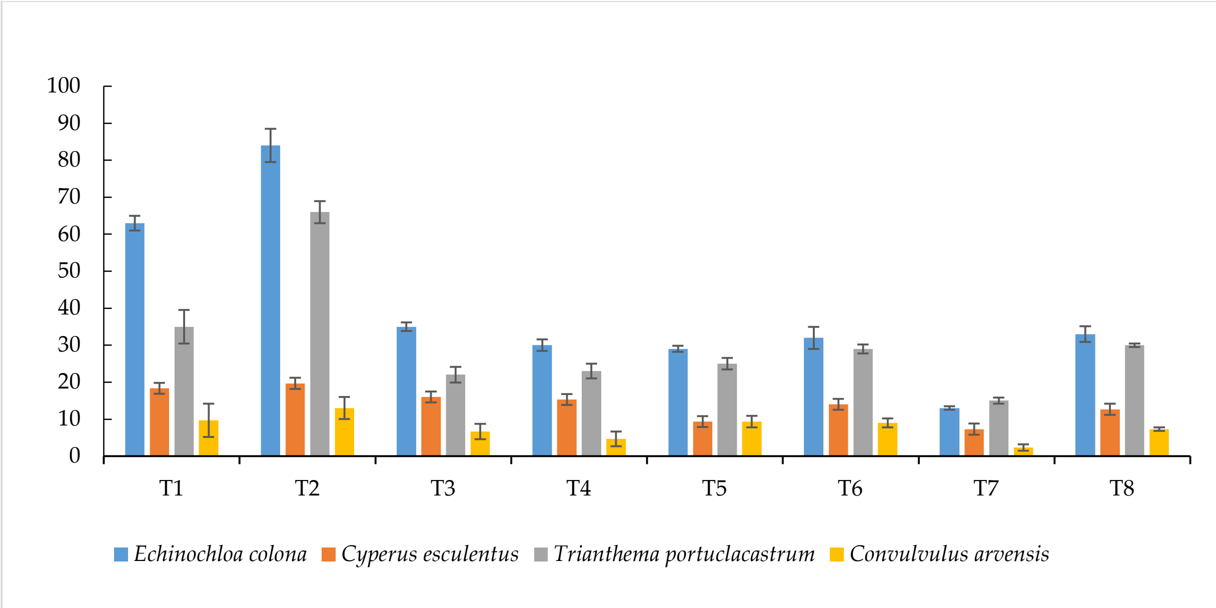

Figure 2. Density (m^{-2}) of different weed species in sole and maize-gram intercropping systems at final harvest. (T_1 = sole maize in 60 cm distanced single rows, T_2 = sole maize in 90 cm distanced double row strips, T_3 = sole black gram in 30 cm distanced single rows, T_4 = sole green gram in 30 cm distanced single rows, T_5 = six single rows (60 cm apart) of maize with twelve double rows (20 cm) of black gram, T_6 = six single rows (60 cm apart) of maize with twelve double rows (20 cm) of green gram, T_7 = three double rows (90 cm apart) of maize with three sets of quadratic rows (20 cm apart) of black gram, T_8 = three double rows (90 cm apart) of maize with three sets of quadratic rows (20 cm apart) of green gram).

3.2. Yield Attributes, Grain and Biological Yields and Harvest Index of Maize

Solo maize crops performed differently as T_1 remained the most superior treatment by recording the highest 1000 grains weight along with grain and biological yields during both crop growing seasons (Table 2). Among intercropping systems, green and black gram sown as living mulch significantly reduced 1000 grains weight, grain and biological yields of maize. However, T_8 exhibited the heaviest 1000 grains weight, grain and biological yields. Contrarily, T_7 could not perform at par to other intercropping systems by recording the least 1000 grainS weight, grain and biological yields of maize. Moreover, T_1 gave numerically higher harvest index, however it remained non-significant among solo and intercropping treatments.

Table 2. 1000 grains weight (GW), grain yield (GY), biological yield (BY) and harvest index (HI) of sole maize and in intercropping systems with green gram and black gram under semi-arid conditions.

Treatments	GW (g)		BY (t ha^{-1})		GY (t ha^{-1})		HI (%)	
	2018	2019	2018	2019	2018	2019	2018	2019
T_1	242.67 ± 1.71 a	244.31 ± 0.21 a	16.91 ± 0.37 a	16.51 ± 1.12 a	6.97 ± 1.04 a	6.84 ± 0.24 a	41.02	41.42
T_2	238.67 ± 0.94 ab	239.05 ± 0.31 b	16.19 ± 0.18 b	16.10 ± 1.05 b	6.56 ± 0.99 b	6.49 ± 0.24 b	40.48	40.31
T_3	-	-	-	-	-	-	-	-
T_4	-	-	-	-	-	-	-	-
T_5	227.33 ± 0.19 cd	225.08 ± 1.05 cd	15.19 ± 0.55 cd	15.23 ± 0.98	6.00 ± 1.12 cd	6.10 ± 0.29 cd	39.16	0.40
T_6	221.33 ± 0.84 cd	223.64 ± 0.16 cd	14.82 ± 0.81 cd	14.76 ± 0.43 cd	5.72 ± 0.67 cd	5.66 ± 0.17 cd	38.58	38.32
T_7	216.67 ± 0.71 d	213.991.14 d	14.78 ± 0.52 d	14.61 ± 1.18 d	5.69 ± 0.53 d	5.61 ± 1.15 d	38.49	38.11
T_8	231.00 ± 1.13 c	2.290.34 c	15.32 ± 1.10 c	15.16 ± 0.55	6.06 ± 0.94 c	6.00 ± 0.15 c	39.86	38.76

In each column, standard deviations followed by unalike letters differ significantly from each other at $p \leq 0.05$.T_1 = sole maize in 60 cm distanced single rows, T_2 = sole maize in 90 cm distanced double row strips, T_3 = sole black gram in 30 cm distanced single rows, T_4 = sole green gram in 30 cm distanced single rows, T_5 = six single rows (60 cm apart) of maize with twelve double rows (20 cm) of black gram, T_6 = six single rows (60 cm apart) of maize with twelve double rows (20 cm) of green gram, T_7 = three double rows (90 cm apart) of maize with three sets of quadratic rows (20 cm apart) of black gram, T_8 = three double rows (90 cm apart) of maize with three sets of quadratic rows (20 cm apart) of green gram). T_3 and T_4 did not contain maize crop, so presented as (-) in the table.

3.3. Grain Yield of Sole and Intercropped Black and Green Gram Crops

The intercropping of legumes with maize significantly reduced the grain yield of both green gram and black gram compared to their sole crop equivalents (Tables 3 and 4). The results revealed that solo crops of black gram (T_3) and green gram (T_4) recorded the maximum grain yields than intercrops yields. In intercropping systems with maize, the maximum yields of black and green gram were noted for T_7 and T_8 respectively. Interestingly, T_5 and T_6 remained the most inferior intercropping systems as far as grain yield of both intercrops was concerned as yield reduction of black and green were 37–39% and 38–41% in comparison to their sole crop equivalents during both cropping seasons.

Table 3. Grain yield (GY) of black gram sown as sole crops and in intercropping systems with maize under semi-arid conditions.

Treatments	GY (t ha^{-1})	
	2018	2019
T_3	0.81 ± 1.14 a	0.80 ± 0.34 a
T_5	0.51 ± 0.34 c	0.52 ± 1.01 c
T_7	0.62 ± 0.97 b	0.61 ± 0.18 b

In each columns given means followed by unalike letters are differ significantly from each other at $p \leq 0.05$. T_3 = sole black gram in 30 cm distanced single rows, T_5 = six single rows (60 cm apart) of maize with twelve double rows (20 cm) of black gram, T_7 = three double rows (90 cm apart) of maize with three sets of quadratic rows (20 cm apart) of black gram.

Table 4. Grain yield (GY) of green gram sown as sole crops and in intercropping systems with maize under semi-arid conditions.

Treatments	GY (t ha^{-1})	
	2018	2019
T_4	0.86 ± 0.67 a	0.84 ± 1.18 a
T_6	0.53 ± 0.18 c	0.51 ± 0.93 c
T_8	0.65 ± 0.73 b	0.66 ± 0.23 b

In each columns given means followed by unalike letters are differ significantly from each other at $p \leq 0.05$. T_4 = sole green gram in 30 cm distanced single rows, T_6 = six single rows (60 cm apart) of maize with twelve double rows (20 cm) of green gram, T_8 = three double rows (90 cm apart) of maize with three sets of quadratic rows (20 cm apart) of green gram).

3.4. Land Equivalent Ratios and Intercropping Advantage

The results revealed that maize-green gram and maize-black gram intercropping systems exhibited land equivalent ratio (LER) of over 1, which indicates substantial yield advantage of intercropping over mono cropping system of maize (Table 5). The maximum LER of maize was exhibited by T_8 which was at par to rest of the intercropping treatments. As far as LERs of green and black gram intercrops were concerned, T_7 and T_8 showed the highest LER for black and green gram intercrops respectively. In terms of total LER (LER of maize + LER of intercrop), T_8 and T_7 remained superior by recording the maximum total LER as well as intercropping advantage (IA) of maize-gram intercropping systems. Moreover, T_5 remained inferior to the rest of intercropping systems by recording the minimum total LER along with IA.

Table 5. Land equivalent ratio (LER) of maize, green gram and black gram as affected by maize-pulses intercropping systems under semi-arid conditions. (Means of 2-years data).

Intercropping Systems	Maize LER	Black Gram LER	Green Gram LER	Total LER	IA (%)
T_5	0.86	0.63	-	1.49	49
T_6	0.87	-	0.63	1.50	50
T_7	0.87	0.76	-	1.63	63
T_8	0.87	-	0.77	1.64	64

T_5 = six single rows (60 cm apart) of maize with twelve double rows (20 cm) of black gram, T_6 = six single rows (60 cm apart) of maize with twelve double rows (20 cm) of green gram, T_7 = three double rows (90 cm apart) of maize with three sets of quadratic rows (20 cm apart) of black gram, T_8 = three double rows (90 cm apart) of maize with three sets of quadratic rows (20 cm apart) of green gram). T_5 and T_7 treatments did not include green gram, while black gram was not included in T_6 and T_8 treatments, so their absence is presented with (-).

3.5. Correlation of Weeds Infestation and Gram Yield

The correlation analysis was conducted to determine interrelationship (direct or inverse) between weeds infestation and grain yield of intercrops. The variation in weeds density (Figure 3A), fresh weight (Figure 3B) and dry weight (Figure 3C) were inversely proportional to grain yield of intercropped black gram and green gram crops indicating the effectiveness of intercropping systems in suppressing the weeds biomass. Correlation model analysis displayed that enhancement in every 1 g m^{-2} grain yield of intercropped pulses decreased weed density 1.18 m^{-2}, fresh weight 1.5 g m^{-2}, and dry weight 0.52 g m^{-2} of weed infestation.

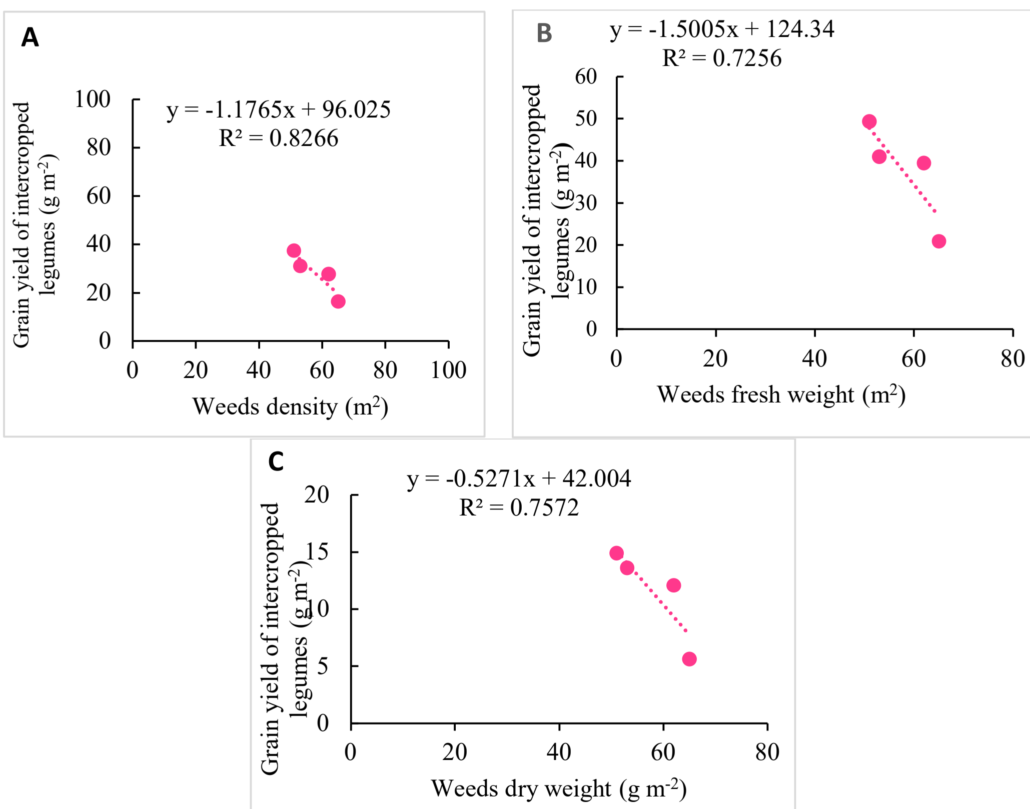

Figure 3. Interrelationship of weeds density and their fresh and dry weights with grain yield of intercropped pulses. Sole crop were excluded and mean values of following four intercropping systems have been used for correlation; T_5 = six

single rows (60 cm apart) of maize with twelve double rows (20 cm) of black gram, T_6 = six single rows (60 cm apart) of maize with twelve double rows (20 cm) of green gram, T_7 = three double rows (90 cm apart) of maize with three sets of quadratic rows (20 cm apart) of black gram, T_8 = three double rows (90 cm apart) of maize with three sets of quadratic rows (20 cm apart) of green gram).

4. Discussion

The research findings were in line with postulated hypothesis as maize in intercropping with black or green gram suppressed weeds infestation. Our results exhibited that weeds density and biomass were significantly suppressed by intercropping systems particularly three double rows (90 cm apart) of maize sown with three quadratic rows (20 cm apart) of green and gram (T_7 and T_8) remained superior compared to maize monocultures (Table 1). Less weeds interference in intercropping systems might be attributed to severe competition offered by intercropped legumes for vital resources like space, light, nutrients and moisture which put most of the weeds out of competition [32]. Additionally, shading effects rendered by intercrops (green and black gram) canopies have been previously inferred to impart adverse impacts on weeds germination, growth and biomass production, which led to reduced fresh and dry weights of weeds flora [33,34]. Contrastingly, monocultures recorded significantly higher weeds density and biomass probably owing to lesser competition for growth resources and availability of abundant sunlight for photosynthesis in the absence of spreading canopies of intercrops especially in maize monoculture having 90 cm apart rows. These findings corroborate with those of [35], who inferred that in comparison to cereals monocultures, cereal-legumes intercropping effectively suppressed weeds growth by restricting space and mineral nutrients availability which boosted growth and grain yields of companion crops. Similar findings were also reported by [33], whereby intercropping resulted in a lower weed biomass and maximized the yield in a biologically viable way. Weeds suppression effect owing to lesser available space available in cereal-legumes intercropping system was increased by closely spaced row strips of companion crops [35]. In another study, weeds suppression up to 65% was reported in cereal-legumes intercropping under semi-arid conditions [2].Moreover, intercropping of cereals with spreading types of legumes (cowpea, cluster bean etc.) remained effective in reducing weeds incidence by reducing weed-seeds bank in the upper soil horizons [36]. Contrastingly, it was inferred that although legumes as intercrops enhanced weed control but also caused significant reduction in crops yield [13,15], therefore exploring compatibility among intercrops needs further studies.

The yield attributes especially 1000 grains weight is one of the vital indicator of maize grain yield which may be utilized as a reliable indicator to project grain yield (GY) of cereals including maize. The monoculture of maize (T_1) outperformed T_2 treatment by recording the maximum 1000 grains weight along with GY and biological yield (BY) (Table 2). This might be attributed to lesser weeds infestation and fragile interspecies competition for soil and environmental growth resources which assisted in higher partitioning and translocation of more assimilates towards reproductive plant parts. However, 1000 grains weight along with GY and BY of maize were significantly reduced in intercropping systems especially with green gram compared to sole maize. This might be due to less plant competition in monoculture for soil derived growth resources especially moisture and nutrients along with environmental resources (light and CO2) in contrast to intercropping systems [37–40]. The reduction in intercropped maize BY might be attributed to allocation of resources in different direction than uni-directional movement in sole cropping system [41,42]. More inter-row and inter-crop competition for resource utilization tended to disturb the source to sink relationship [43,44] and ultimately GY of maize was reduced in intercropping with green and black gram. Intercropping of maize with black and green gram non-significantly improved the harvest index which is in contradiction with the findings of [1,10,11].

As far as GY of legumes were concerned, sole crops of green and black grams remained unmatched while their grain yields were significantly reduced by three double rows (90 cm apart) of maize with three sets of quadratic rows (20 cm apart) of green or black gram (Table 3). Comparatively higher productivity of legumes monocultures might be due to better aeration, more ground area available for nutrition uptake and less shading effect of maize strips [45–48] which ultimately slashed the GY of inter-seeded legumes. These results are in agreement with [1,10,11], who reported that in cereal-legumes intercropping, legumes remained recessive compared to cereals in terms of acquiring growth resources which led to reduction in their yields compared to solo crops. It was also suggested that added advantage of intercropping could only be achieved by ensuring compatibility of intercrops in temporal and spatial dimensions, whereby intercrops peak their requirements at different times.

Land use efficiency for intercropping systems is measured as LER which indicates added advantage of intercropping if their values are above 1 [1,11]. Our results exhibited total LER of over 1 for all intercropping systems, while three double rows (90 cm apart) of maize with three sets of quadratic rows (20 cm apart) of green gram expressed the highest LER as well as intercropping advantage which remained statistically at par to T_7 (Table 4). High LER and IA of maize and gram intercropping systems might be attributed to enhanced and efficient exploitation of available resources such as land, light, moisture and fertilizer etc. [49,50]. The LERs of all intercropping system greater than one indicated higher efficiency and more productive use of all environmental resources by gram intercrops [7,40]. Additionally, sole legumes probably intercepted more radiation compared to monoculture of maize, while the interception by intercrops remained in between monocultures of legumes and maize which led to higher IA. It was recorded by [1,51,52] that intercrop converted the intercepted radiation into grain yield more efficiently which led to higher land use efficiency by maize-legumes intercropping systems.

The correlation analyses indicated inverse association among grain yield of pulses with weeds infestation. The increase in weeds density and their biomass (fresh and dry weights) resulted in sequential decline pulses grain yield. It might be attributed that weeds flora (*Echinochloa colona*, *Trianthema portuclacastrum*, *Convulvulus arvensis* and *Convulvulus esculentus*) sliced the growth resources share of green and black gram crops as weeds hold advantage in acquiring mineral nutrients from soil solution and moisture by virtue of their superior botanical traits [53–55]. Previously, crop losses caused by weeds ranged up to 71% depending on infestation level, diversity, availability of nutrients and moisture as well as competitive potential of crop species [33–35].

5. Conclusions

The research findings were in line with the postulated hypothesis as maize intercropping with green and black gram significantly suppressed weeds infestation as indicated by low weeds interference especially by three double rows (90 cm apart) of maize with three sets of quadratic rows (20 cm apart) of black and green gram intercrops. Likewise, row spacing was also proved a vital factor which significantly affected the productivity of monocultures and intercrops along with weed flora. Solo crops of maize and gram (green and black) exhibited higher grain yield in comparison to intercropping systems. Maximal reduction in weed infestation, the highest 1000 grains weight, biological and grain yields were attained by intercropping system encompassing three double rows (90 cm apart) of maize with three sets of quadratic rows (20 cm apart) of green gram. This intercropping system is recommended for general adoption in semi-arid regions of South Asia as it seems to have high resource use efficiency. Moreover, our findings re-emphasized that maize-green gram intercropping might be developed as eco-friendly and biologically viable strategy for suppressing weeds infestation and imparting sustainability to maize production under semi-arid conditions.

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