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Research article

Modifying row-configuration and vermicompost application reduces intercropped peanut (*Arachis hypogaea* L.) yield instability and penalty in sorghum at Babile, Eastern Ethiopia

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ABSTRACT

The yield of intercropped peanut (*Arachis hypogaea* L.) in cereal crops was drastically reduced by 20–55 %, presumably due to high interspecific competition caused by illogical field layout and imbalanced fertilizer application. Field experiments were conducted in the Babile district of Eastern Ethiopia during the main cropping seasons of 2021 and 2022 to assess the possibilities of minimizing the peanut yield penalty and instability while improving sorghum production. The treatments consisted of two monocrops (SM = sole sorghum, GM = sole peanut), three row-configurations (S1G1 = 1-row sorghum with 1-row peanut, S1G2 = 1-row sorghum with 2-row peanut, MBILI = Managing Beneficial Interactions in Legume Intercrops via modifying 2-rows of sorghum with 2-rows of peanut), and four vermicompost levels (0, 1.5, 3, and 4.5 t/ha), which were factorial arranged in a randomized complete block design and replicated three times. Peanut under MBILI with 4.5 t/ha vermicompost boosted peanut seed/pod and dry pod yield by 17.5 % and 20 %, respectively, with a corresponding rise of sorghum grain yield by 72 % and net profit by 48 %. Unlike GM, intercropping peanut with sorghum significantly increases yield with time, which shows the high yield stability and sustainability of intercropping over monocropping. Interestingly, peanut yield in this treatment was statistically on par with pure stand, supporting the concept that MBILI row-configuration is necessary for maintaining the potential yield of the peanut crop. Similarly, the assessment of bio-ecological indices infers the superiority of the MBILI in terms of land use efficiency, yield advantage, and profitability compared to other combinations. This implies that modifying the planting geometry along with balanced nutrient supply could alleviate the detrimental effects of sorghum over peanut by minimizing interspecific competition, thereby giving better yield and economic value for subsistence farmers.

1. Introduction

Peanut or groundnut (*Arachis hypogaea* L.) is an important source of plant-based protein that aids in alleviating nutritional insecurity in semiarid regions [1,2]. In terms of production area, it ranks third in the world and second among lowland oilseed crops in Ethiopia [3]. Numerous studies have reported that the productivity of peanuts in Sub-Saharan Africa (SSA) is substantially lower (1.8 t/ha) than the global average potential yield (3.5–8.0 t/ha) [1,4]. The current production of peanut in the world and in Ethiopia is

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mainly attributable to the expansion of agricultural fields, particularly in a monocropping system [5]. This strategy is not only unfeasible but also inaccessible in Ethiopia, where more than 90 % of farmers are smallholders with less than 1 ha of arable land per household [2,6].

In this regard, numerous studies have proposed multiple cropping systems as the most promising approach for minimizing those challenges [7,8]. This eco-friendly strategy provides resilient farming systems [9] and food production for the anticipated population growth [10]. Furthermore, incorporating legumes into cereal crops is an effective way to reduce the usage of synthetic nitrogen fertilizers and associated fossil energy use [11,12] due to their capacity to fix atmospheric N and excrete organic acids in their rhizosphere that enhance the availability of P and N [12].

Despite the relevance of this system, the current deployment of intercropping in Ethiopia is nearly nonexistent [13–15]. On the other hand, the yield of intercropped peanut declined by about 20–55 % compared to its pure stand [16,17], thereby wrongly proposing the disadvantage of mixed cropping. This high yield penalty of intercropped peanut is due to the over-dominance of cereal [11,18,19], inappropriate planting geometer [20], and unbalanced species proportion [7]. Aside from these concerns, Ethiopia's intercropping system is further hampered by: (i) a lack of research attention [13,14]; (ii) a lack of appropriate fertilizer recommendations [3]; and (iii) rapid soil organic matter decline [13]. Moreover, the peanut is an exhaustive crop that requires a higher amount of light and nutrients to produce high-quality protein and oil [21,22], which exacerbates its yield deterioration in mixed systems [23,24]. These complex problems were suggested as the main causes for the relatively low adoption of interopping systems [25,26].

In order to maximize the use of cereal/legume intercropping systems, it is therefore possible to reduce interspecific competition and increase the complementarity of associated crops by choosing compatible species [19], providing balanced nutrients [9,27], and utilizing well-designed geometry [12,20]. Nevertheless, it is impossible to balance all essential nutrients through the use of inorganic fertilizers and low quality organic manure [28]. Owing to the toxicity and salinity-induced plant stress caused by their overuse, applying them to sandy soil may exacerbate the impacts on the economy and lead to water contamination [29,30]. Furthermore, it is incredible to use low-quality organic fertilizers like farmyard manure (FYM) and crop residue in Ethiopia because over 80 % of the former is used as fuel for cooking and roughly 35 % of the latter is used for building, feed, and fuel [28]. The over-reliance on organic products as fuel instead of fertilizer has caused Ethiopia's agricultural gross domestic product (GDP) to decline by 7 % [31], leading to unsustainable agricultural production [12,32].

Application of vermicompost, which has been shown to be superior fertilizer in terms of nutrient content, soil microbiota, and plant growth enhancers over conventional compost and chemical fertilizers, is one possible alternative solution for minimizing the detrimental effects of commercial fertilizer and low-quality organic manure [33–35]. Modified row arrangement, also known as MBILI (Managing Beneficial Interactions in Legume Intercrops), is another cutting-edge technique that has been put forth as a superior and reliable cropping system for increasing yields of both component crops in addition to enhancing farmers' livelihoods, resilience, and food security [36,37]. Hence, we hypothesize that utilizing a high-quality organic fertilizer (vermicompost) and a modified row arrangement could reduce inter- and intra-specific competition, thereby boosting the productivity of sorghum and peanut in the intercropping system by (i) adjusting space, (ii) supplying adequate plant nutrients, and (iii) reducing overshading. In this regard, the objective of this study was to assess the possibility of reducing the peanut yield penalty and determining the appropriate rate of vermicompost in sorghum/peanut intercropping at Babile, Eastern Ethiopia.

2. Materials and methods

2.1. Description of the experimental site

The experiment was conducted during the 2021 and 2022 main cropping seasons at the Haramaya University (HrU) Babile research site under rainfed conditions on deep sandy loam soil [38]. Babile district is situated in a semiarid ecology with a geographical location of 9° 13′ 13.5″ N latitude, 42° 19′ 20.9″ E longitude, and an altitude of 1647 m above sea level. The mean annual maximum and minimum temperatures were 27.1 °C and 11.3 °C, respectively, while the annual average rainfall was 700 mm with an irregular weather pattern [38].

2.2. Description of planting material

The sorghum variety '*Melkam* (WSV387)' was used as a test crop. The variety was released in 2009 by the Melkasa Agricultural Research Center as a high-yielding, drought-tolerant, early-maturing open-pollinated variety with moderate resistance to *Striga* and an average yield ranging between 3.7 and 5.8 t/ha [39]. It is the best-adapted and stable variety for intercropping across the lowlands of Ethiopia and is preferred by farmers since it might be harvested twice a year [40]. Peanut cultivar '*Babile-1* (ICGV-98412)' was used as a component cropand obtained from HrU. It is an upright growing habit, Spanish type with sequential branching, and medium maturing variety [41]. In addition, it is high yielding (1.9–2.42 t/ha), drought-tolerant, moderate resistance to leaf spot, and high oil content, which makes it ideal for profitably and sustainably intercropping in the lowlands of Ethiopia [41].

2.3. Vermicompost preparation and analysis

The vermicompost was made from a combination of *Lantana camara L.*, wheat straw, *Parthenium hysterophorus L.*, and animal dung with red worm (*Eisenia fetida*) as a decomposer. Before being applied to the soil, the composite samples were analyzed in the HrU soil laboratory for specific parameters, such as pH by water extract, electrical conductivity (EC), total N (%) by the Kjeldahl method,

Table 1
Chemical properties of vermicompost.

Parameter	Values	Rating	Parameter	Values	Rating
pH (H_2O)	7.25	Neutral	**Mn (mg/kg)**	194.67	Very high
EC (mS/cm)	5.32	High	**Exch. Ca (cmol (++)/kg)**	32.77	Very high
Total N (%)	1.93	Very high	**Exch. Mg (cmol (++)/kg)**	25.848	Very high
OM (%)	40.72	Very high	**Exch. K (cmol (+)/kg)**	20.14	Very high
Av. P (mg/kg)	20.14	High	**CEC (cmol (+)/Kg)**	43.5	Very high
Zn(mg/kg)	44.42	High	**C: N**	12.24	Optimum
Fe(mg/kg)	54.33	High			

Where N = nitrogen; Av. P = available phosphorus; Exch. (K, Mg, and Ca) = exchangeable cations; Zn = zinc; Fe = iron; OM = total organic matter; EC = electrical conductivity; N = carbon nitrogen; ppm = parts per million.

available P by the Olsen method, cation exchange capacity (CEC), exchangeable bases (Ca, Mg, K, and Na) by ammonium acetate, micronutrients (Zn, Fe, and Mn) by the EDTA method, and total organic carbon by the Walkley and Black method following their standard protocols [42]. The laboratory results in Table 1 reveal that total nutrient levels, pH, and CEC of vermicompost were within the optimal range for most crop production [43].

2.4. *Experimental design and field management*

The treatments consisted of two pure-stands (SM = sole sorghum, GM = sole peanut), three planting geometrys (S1G1 = 1-row sorghum with 1-row peanut, S1G2 = 1-row sorghum with 2-row peanut, MBILI = Managing Beneficial Interactions in Legume Intercrops via Modifying 2-row sorghum Alternately with 2-row peanut), and four rates of vermicompost (V) (0, 1.5, 3, and 4.5 t/ha). These from 20 treatment combinations (SMV0, SMV1.5, SMV3, SMV4.5, GMV0, GMV1.5, GMV3, GMV4.5, S1G1V0, S1G1V1.5, S1G1V3, S1G1V4.5, S1G2V0, S1G2V1.5, S1G2V3, S1G2V4.5, MBILIV0, MBILI V1.5, MBILI V3, and MBILI V4.5) that were replicated three times in a factorial arrangement using a randomized complete block design. The intercropping system was combined according to additive series, which is more suited to agronomic objectives for maximizing production per unit area due to land constrained and no need to sacrifice the yield of staple crops [23,44].

The land was plowed and harrowed by a tractor to bring a fine tilth in 2021 and 2022 consecutive years under rainfed conditions. The sorghum seeds were dribbled in prepared rows on July 8, 2021 and June 29, 2022 in the same location and thinned to one seedling per hole by maintaining 25 cm intra-row spacing two weeks after sowing in both consecutive years. At the same time and site, a peanut seed was sown between rows of sorghum by keeping 60 × 10 cm row spacing for sole cropping and 20 cm intra-row spacing for intercropped peanut (Fig. 1). For the MBILI row configuration, 50 cm of spacing were kept between two consecutive rows of sorghum, but in all intercropping systems, 37.5 cm of row spacing were maintained between each peanut as well as peanut-sorghum (Fig. 1). The field has a gross area of 16.88 m^2 (3.75 m × 4.5 m) and the space between each plot and block (replications) remaining 1 m and 1.5 m, respectively. According to specified treatments, vermicompost was incorporated a week before planting. There was no other fertilizer applied besides vermicompost to prevent confusing impacts on the intercropping system's production. The hoeing and weeding were done as required following standard procedure to keep the field free from any weeds, insect pests, and diseases for both consecutive years. Irrigation was not applied as the trail was conducted under rainfed conditions. All necessary data were taken from the 3 m × 4 m (12 m^2) net plot area to avoid border effect.

2.5. *Data collection*

2.5.1. *Sorghum yield parameters*

Sorghum plant height (cm) and head length (cm) were measured at physiological maturity from ten randomly selected plants per plot. Yield parameters such as thousand kernel weights (g), grain yield (kg), and above-groundnut biomass (kg) were taken after harvest from the net plot area. Head weight (g) was measured on five randomly selected plants per plot. After adjusting the moisture content to 12.5 %, the sorghum kernel weight and grain yield were measured and converted to tons per hectare (t/ha). Leaf area index (LAI) is an important agronomic parameter that reflects crop growth and predicts crop yield [79]. The leaf area (LA) of an individual fully expanded flag leaf of ten plants was manually measured from each plot at 50 % physiological maturity by following the formula: LA = maximum leaf length × maximum leaf width × 0.75; (0.75 is correction factor for sorghum). LAI was calculated as the ratio of LA to the ground area occupied by the respective plants.

2.5.2. *Yield and yield components of peanut*

The number of primary branches per plant (N^o), the height of the main axis (cm), the number of seeds per pod (N^o), the number of pods per plant (N^o), and the hundred seed weight (g) were determined from 10 randomly selected plants in each plot. After the moisture content was adjusted to 13 %, the dry pod yield (kg) was measured from each net plot and converted to tons per hectare (t/ha). The shelling percentage was determined as the proportion of shelled seed weight to the unshelled pods multiplied by 100.

2.5.3. *Biological, ecological, and economic efficiency of the systems*

The biological efficiency was accessed using the land equivalent coefficient (LEC), area time equivalent ratio (ATER), and system

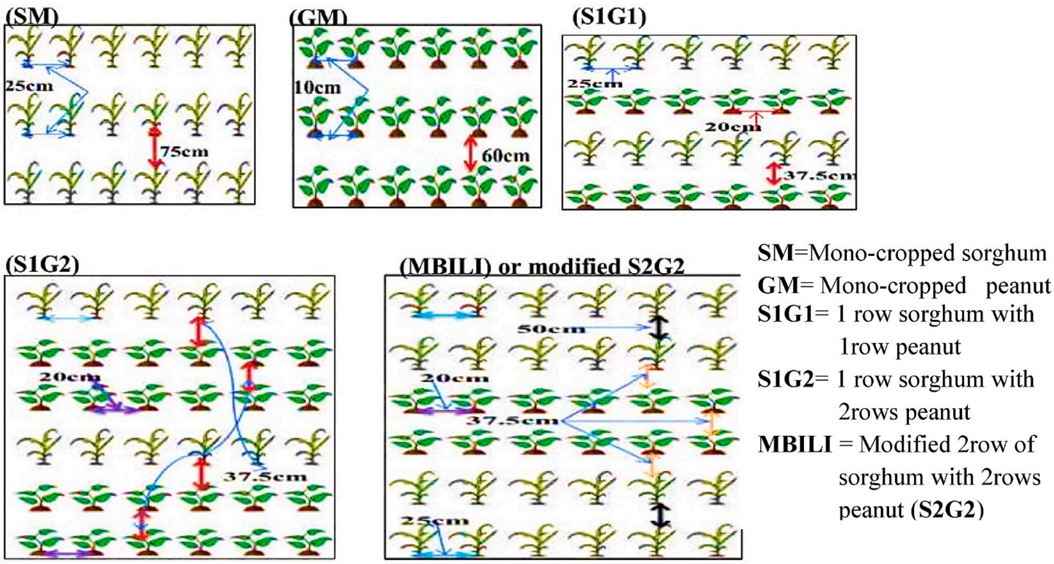

Fig. 1. Field layout for sorghum-groundnut cropping system at Babile Site.

productivity index (SPI), while economic efficiency was computed using the sorghum equivalent yield (SEY) and monetary advantage index (MAI) [16,32]. Aggressivity (A) and competitive ratio (CR) indices were also used for assessing interspecific competition [45,46] (Table 2).

✓ For calculating SEY and MAI, the average prevailing market prices (P) of each component crop in Ethiopian Birr (**ETB**[1]**)** perkg during 2022 were used since there is a high market price fluctuation. The 2022 price for sorghum grain was 65 ETB/kg and the Dry seed yield of peanut was 85 ETB/kg.

2.6. *Statistical analysis*

A combined analysis of variance was performed to determine the yield stability and profitability of sorghum-peanut combinations. In all the comparisons, the level of significance was set at $\alpha = 0.05$. The mean comparison for the treatments was computed using least significant difference (LSD) for parameters found to be significantly different at a given level of significance using R software version 4.3.1.

3. Results

3.1. *Groundnut yield and yield components*

3.1.1. *Number of primary branches and plant height*

Peanut plant height was significantly ($P < 0.05$) affected due to the single and interaction effects of vermicompost and row arrangements (Table 3). However, the number of primary branches was only influenced by the main effects of vermicompost and planting geometry. The number of branches increased by 17 % and 16 % in the 2021 and 2022 years, respectively, as the rate of vermicompost increased from 0 to 4.5 t/ha (Fig. 2A and C). On the other hand, Fig. 2 B & D shows that intercropping peanut in S1G1 and S1G2 significantly reduced the number of primary branches by 10-4% as compared with sole cropping.

Similarly, the tallest plant height (55 cm) was observed in the plot receiving 4.5 t/ha vermicompost in the S1G1 row configuration, which was statistically at par with the plot receiving nil fertilizer (Fig. 3A). The shortest plants were attained in untreated pure-stand peanut, which was around 37 % lower than the plot that received the maximum fertilizer dose (Fig. 3B). Fig. 3 clearly shows that the height of peanuts linearly increased as the rate of vermicompost increased in both years. Increasing the rate of vermicompost from 0 to 4.5 t/ha increased plant heights by 30, 21, and 25 % in S1G1, S1G2, and MBILI row arrangements, respectively (Fig. 3).

3.1.2. *Total number of pods per plant (NPP) and seeds per pod (NSP)*

The main effect of vermicompost and planting geometry significantly ($P < 0.05$) influenced pod yields during both cropping seasons (Table 3). However, their interaction effects on both parameters were statistically insignificant. The highest NPP in sole groundnut was measured at 4.5 t/ha, and it was statistically similar to the NPP in intercropped groundnut in MBILI row configuration (Fig. 4A and B). When compared to intercropped peanut in an S1G1 row arrangement with no fertilizer, this was almost 31 % higher (Fig. 4). Both in the 2021 and 2022 years, increasing the rates of vermicompost resulted in a 21 % increase in NPP. However,

Table 2
Formula and description of indices for assessing biological, competitive, and economic efficiency of sorghum/peanut intercropping system.

Name of indices	Formula	Description	Reference
Land equivalent Coefficient (LEC)	$LEC = \left[\frac{Ysi}{Ysm}\right] * \left[\frac{Ygi}{Ygm}\right]$	**'Y' indicates the economic** Yields of each crop	[47]; [48]
System productivity index (SPI)	$SPI = Ysi + \frac{YSm}{Ygm} * Ygi$	Assess productivity and stability in intercropping	Odo [49]; Oseni [50], Agegnehu & Ghizaw [51]; Lithourgidis et al. [52]
Area-time equivalent ratio (ATER)	$ATER = \left(\frac{Ysi}{Ysm} * \frac{tsi}{T}\right) + \left(\frac{Ygi}{Ygm} * \frac{tgi}{T}\right)$	T = duration (day) of species with the longest growing period t = duration in intercropping system	Hiebsch & McCollum [53]; Doubi et al. [54]
Competitive Ratio (CR)	$CRs = \frac{\left(\frac{Ysi}{Ysm * Zsi}\right)}{\left(\frac{Ygi}{Ygm * Zgi}\right)}$	Z = sowing proportion of component crops Quantify the exact degrees of competition	Willey & Rao [55]; Zhang et al. [56]
Aggressivity (A)	$Asg = \left(\frac{Ysi}{(Ysm\ x\ Zsi)}\right) - \left(\frac{Ygi}{(Ygm\ x\ Zgi)}\right)$ A_{sg}=sorghum aggressivity relative to peanut	Measure of the interspecies competition	Dhima et al. [57]; Doubi et al. [54] Lithourgidis et al. [52]
Sorghum equivalent yield (SEY)	$SEY = Ysi + \frac{Ygi * Pg}{Ps}$	P = market price of each crop	[51] [32]
Monetary Advantage Index (MAI)	$MAI = \frac{(LER - 1)}{LER} * ((Ysi\ x\ Ps) + (Ygi\ x\ Pg))$		Ghosh [16].

NB: Where Y_{si} and Y_{gi} depict the corresponding economic yield of sorghum and peanut under the intercropping systems. Whereas Y_{sm} and Y_{gm} represent the respective yields under pure stands.[1]

[1] At the time of harvest, 1 USA Dollar = 55.190 Ethiopian Birr (1$ = 55.190 ETB).

Table 3
Mean squares of ANOVA for yield and yield components of peanut at Babile in the 2021 and 2022 years.

Source of Variation	Df	Primary Branches per plant	Plant Height (cm)	Number of Pods per Plant	Number of Seeds per Pod	Shelling Percentage (%)	Hundred Seed Weight (g)	Dry Seed Yield (t/ha)
2021								
RA	**3**	1.015**	127.416**	31.419**	0.059*	42.76^{ns}	18.27^{ns}	0.457**
VC	**3**	5.597**	856.862**	118.161**	0.591**	650.23**	862.26**	0.752**
RA*VC	**9**	0.054^{ns}	20.275*	1.367^{ns}	0.019^{ns}	10.33^{ns}	8.00^{ns}	0.032**
Error	**32**	0.06	6.723	0.81	0.01	15.10	15.65	0.009
CV (%)		**5.16**	**6.48**	**5.48**	**5.49**	**5.40**	**5.63**	**5.35**
2022								
RA	**3**	0.74**	39.068**	32.746**	0.05*	34.98^{ns}	35.54^{ns}	0.286**
VC	**3**	4.78**	873.708**	109.195**	0.687**	715.69**	427.22**	0.763**
RA*VC	**9**	0.022^{ns}	18.773*	0.997^{ns}	0.009^{ns}	4.25^{ns}	29.80^{ns}	0.025*
Error	**32**	0.064	5.432	0.894	0.008	15.13	14.54	0.001
CV (%)		**5.33**	**6.67**	**5.8**	**5.01**	**5.29**	**5.63**	**5.34**

NB: ns = not significant; *and ** = significant at 5 % and 1 % probability levels, respectively; df = degree of freedom; CV=Coefficient of variation; VC=Vermicompost; RA = Row arrangement (row configuration).

intercropping in S1G1 and S_1G_2 row arrangements caused NPP to decline by roughly 6 % and 7 %, respectively (Fig. 4C and D).

Correspondingly, increasing the rate of vermicompost boosted NSP by 14 and 17 percent in the years 2021 and 2022, respectively (Fig. 5 A & C). The highest NSP (2.2) was obtained in an intercropped plot in the MBILI row arrangement at 4.5 t/ha, which was statistically at par with mono-crop groundnut. On the contrary, the lowest number of seeds per pod was recorded in intercropped peanut in the S1G1 row arrangement, which was 16 % and 19 % lower than its maximum in 2021 and 2022 years, respectively. The NSP was decreased by 4–7% in the S1G1 and S1G2 row arrangements when compared to the crop grown in the MBILI and mono-cropping systems (Fig. 5 B & D).

3.1.3. Shelling percentage (SH %) and hundred seed weight (HSW)

The ANOVA result in Table 3 depicts the presence of a single effect on SH% and HSW, although the main effect of row arrangement and its interaction with vermicompost was insignificant (Table 3). Regardless of row arrangements, increasing the rate of vermicompost from 0 to 4.5 t/ha raised SH% by 11.4 % and 12 % during the 2021 and 2022 years, respectively (Fig. 6C and D). Even if there

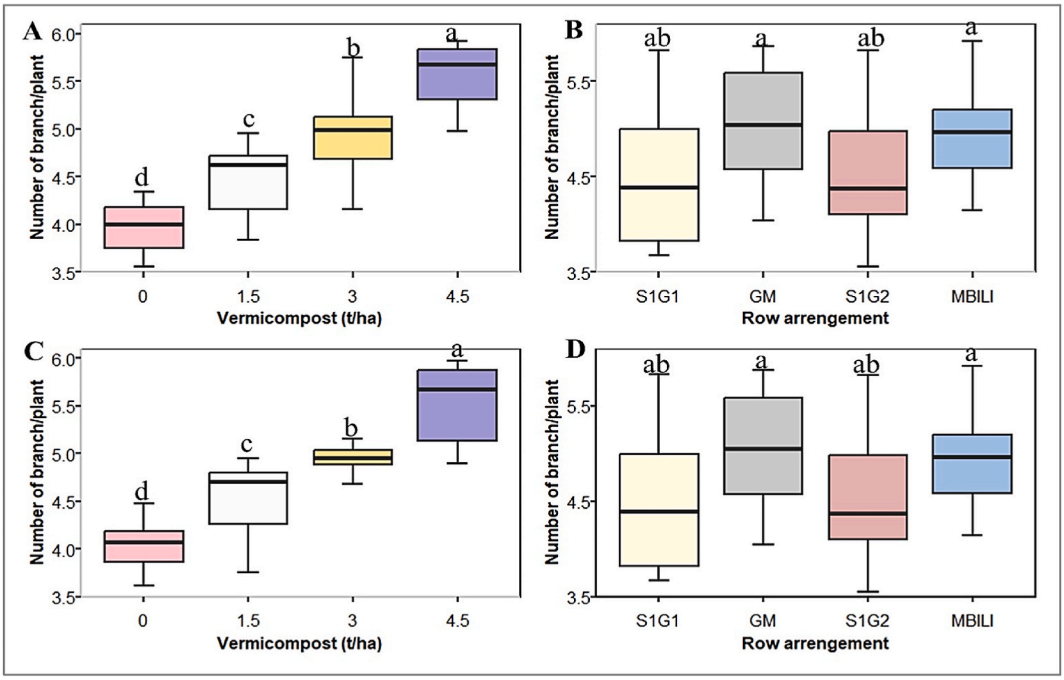

Fig. 2. Main effect of vermicompost and row-configuration on number of branches per plant during 2021(a & b) & 2022 (c & d) cropping season; GM = sole peanut, S1G1 = 1:1 row ratio; S1G2 = 1:2 row ratio; MBILI = modified 2:2 row ratio; Values with the same letter in each figure panel insignificantly.

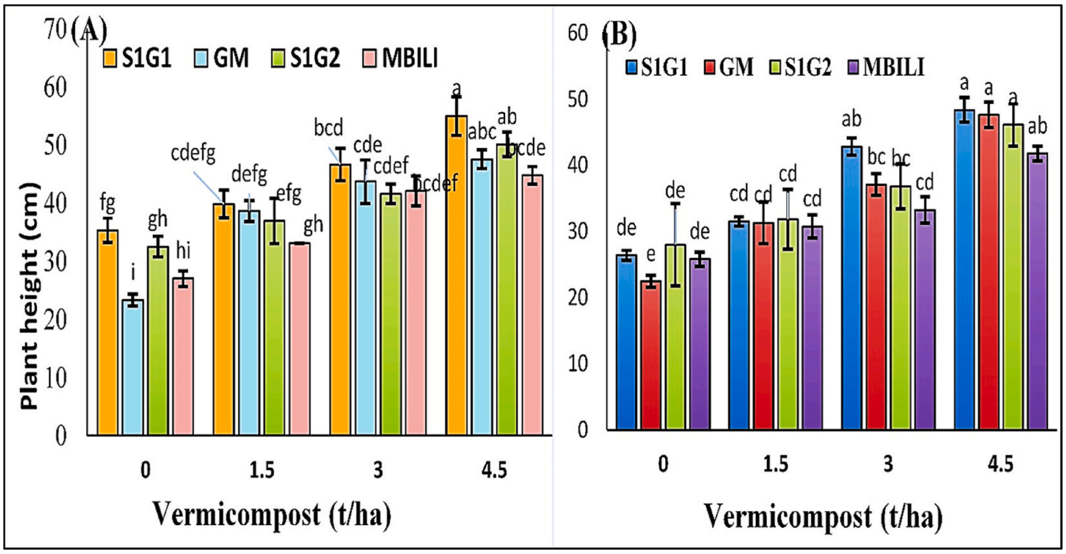

Fig. 3. Interaction effect of vermicompost and row-configuration on peanut plant height during 2021 (A) & 2022 (B) cropping season; GM = mono-cropped peanut, S1G1 = 1:1 row ratio; S1G2 = 1:2 row ratio; MBILI = modified 2:2 row ratio; Bar sharing the same letter are insignificant.

was no statistical significance under interaction effects, application of 4.5 t/ha in MBILI gave relatively better shelling percentage and hundred seed weight than other treatment combinations. Accordingly, the lowest HSW (60 g) was measured in S1G1 without fertilizer, whereas the maximum HSW (84 and 83 g) was measured at 4.5 t/ha vermicompost under MBILI during 2021 and 2022 years, respectively. When the rates of vermicompost were increased from 0 to 4.5 t/ha, the HSW rose by 15 % (Fig. 6A and B).

3.1.4. Dry seed yield

The main effects of planting geometry and vermicompost treatment resulted in significant ($P < 0.05$) variations in groundnut seed

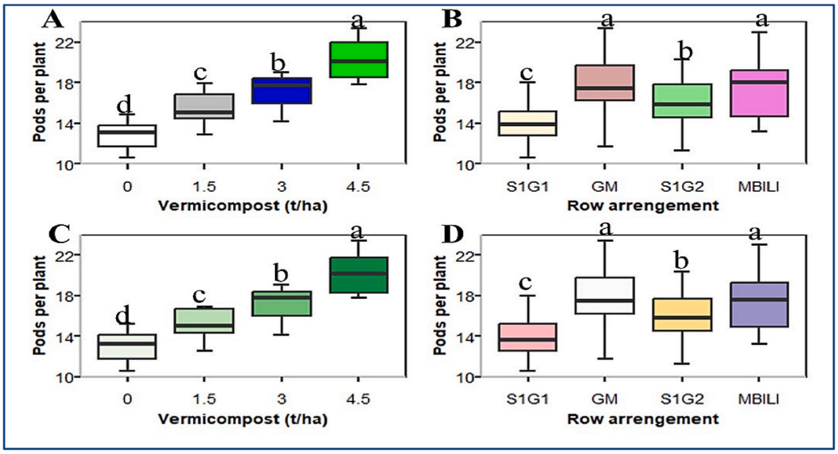

Fig. 4. Main effect of vermicompost and row-configuration on the number of pods per plant during 2021 (a & b) & 2022 (c & d) cropping season; S1G1 = 1:1 row ration; S1G2 = 1:2 row ratio; MBILI = modified 2:2 row ratio; Values with the same letter in each figure panel insignificantly.

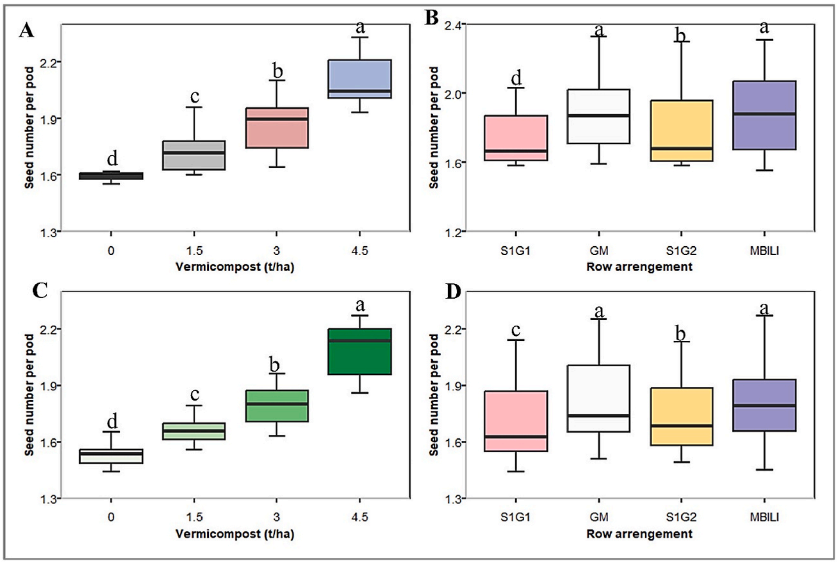

Fig. 5. Main effect of vermicompost and row-configuration on the number of seeds per plant (NSP) during 2021 (a & b) & 2022 (c & d) cropping season; S1G1 = 1:1 row ration; S1G2 = 1:2 row ratio; MBILI = modified 2:2 row ratio; Values with the same letter in each figure panel insignificantly.

yield in both years (Table 3). At 4.5 t/ha vermicompost, the MBILI row arrangement produced the highest value. This value was statistically similar to solo groundnut at the same fertilizer rate, and nearly twice as high as in the S1G1. The lowest yield (1.4 t/ha) was attained in the S1G1 row arrangement without fertilizer, which was statistically similar to the yields in S1G2 at nil and S1G1 at 1.5 t/ha rate of vermicompost (Table 4). In pure-stand groundnut, increasing rates of vermicompost from 0 t/ha to 4.5 t/ha result in yield increases of 23 and 17 percent in 2021 and 2022, respectively (Table 4). In comparison to the MBILI row arrangement, groundnut intercropping in the S1G1 row configuration considerably reduced seed yield by 13 and 20 % in both growing seasons (Table 4).

3.2. Sorghum yield and yield attributes

3.2.1. Plant height, head length, and leaf area index (LAI)

Analysis of variance revealed that the interaction effect of vermicompost with row configuration does not significantly affect sorghum plant height and panicle length. In contrast, the main effect of vermicompost had a significant ($P < 0.05$) effect on both parameters in both years and row arrangement for head length (Table 6). The tallest plant (137.95 cm) was attained at 4.5 t/ha of vermicompost (Table 5), while the shortest sorghum was recorded under MBILI and S1G2 row configuration in 2021 and 2021 years, respectively (Fig. 7). Increasing rates of vermicompost from 0 to 4.5 t/ha raised plant height by about 25 % in both years. The trend

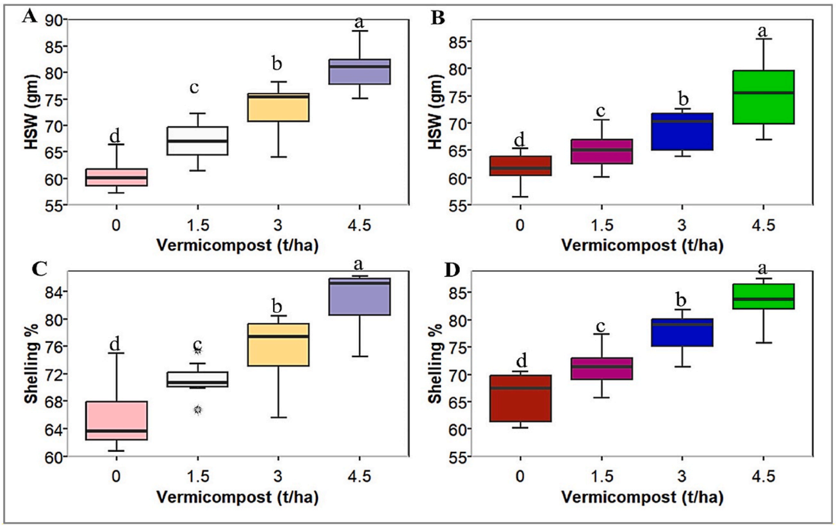

Fig. 6. Main effect of vermicompost on hundred seed weight (HSW) during 2021 (A) & 2022 (B) and shelling percentage (SH %) during 2021 (C) & 2022 (D) cropping season; Values with the same letter in each figure panel insignificantly**.**

Table 4
Interaction effect of row arrangements and vermicompost on groundnut seed yield in 2021 and 2022 years.

Cropping Pattern	Vermicompost-fertilizer (t/ha)							
	Dry seed yield (t/ha) 2021				Dry seed yield (t/ha) 2022			
	0	1.5	3	4.5	0	1.5	3	4.5
S1G1	**1.336^{j}**	**1.433^{ij}**	1.680^{fg}	1.792^{ef}	**1.449^{j}**	**1.514^{ij}**	1.728^{efgh}	1.921^{bcd}
S1G2	**1.427^{ij}**	1.638^{fgh}	1.752^{efg}	1.884^{de}	**1.584^{hij}**	1.796^{defg}	1.937^{bcd}	2.041^{b}
MBILI	1.633^{gh}	1.908^{de}	2.069^{bc}	2.152^{b}	1.657^{ghi}	1.830^{def}	2.039^{b}	**2.342^{a}**
GM	1.511^{hi}	1.862^{de}	1.989^{cd}	**2.441^{a}**	1.667^{fghi}	1.858^{cde}	1.996^{bc}	**2.437^{a}**
LSD	0.16					**0.17**		
CV (%)	5.35					**5.34**		

NB: GM = sole groundnut; S1G1 (1:1) = 1 row of sorghum with 1 row of groundnut; S1G2 (1:2) = 1 row of sorghum with 2 rows of groundnut; MBILI (2:2) = 2 row of sorghum with 2 rows of groundnut; LSD = Least Significant Difference, CV=Coefficient of variation.

was the same for the head length of sorghum (Table 5).

LAI was significantly ($P \leq 0.05$) affected by the main effect of vermicompost, but there was no variation among the main and interaction effect row arrangement with vermicompost (Table 5). Plots receiving 4.5 t/ha of vermicompost gave higher LAI compared to the treatments, followed by 3 t/ha fertilizer in both years, while the lowest LAI was recorded in control plots. Increasing rates of vermicompost from 0 to 4.5 t/ha increased LAI by 17 % and 16 % in 2021 and 2022 years, respectively.

3.2.2. Thousand kernel weight (TKW)

Although the main effect of row configurations and vermicompost levels had a significant effect on TKW, their interaction effect was insignificant (Table 6). The findings showed that intercropped sorghum had a lower TKW than mono-crop sorghum. The increase

Table 5
Main effect of vermicompost on sorghum plant height (PH), leaf area index (LAI), head length (HDL), and thousand kernel weight (TKW) in 2021 & 2022 years.

Vermicompost (t/ha)	2021				2022			
	PH (cm)	LAI (cm^2/cm^2)	HDL(cm)	TKW (g)	PH(cm)	LAI (cm^2/cm^2)	HDL (cm)	TKW (g)
0	83.55^{d}	2.32^{d}	19.19^{d}	27.77^{d}	83.88^{d}	2.35^{d}	19.59^{d}	27.55^{d}
1.5	99.08^{c}	2.64^{c}	23.91^{c}	31.42^{c}	102.91^{c}	2.89^{c}	24.14^{c}	31.52^{c}
3	113.28^{b}	2.96^{b}	27.34^{b}	3578^{b}	124.78^{b}	3.0^{b}	26.64^{b}	35.38^{b}
4.5	137.95^{a}	3.24^{a}	32.24^{a}	41.82^{a}	142.62^{a}	3.27^{a}	31.95^{a}	41.82^{a}
CV	**6.47**	**5.16**	**7.73**	**5.78**	**6.02**	**5.38**	**7.67**	**5.86**
LSD	**7.87**	**0.16**	**2.23**	**1.64**	**7.68**	**0.17**	**2.20**	**1.66**

NB: Values with the same letter under each parameter are insignificantly at $P < 0.05$). LSD = Least Significant Difference, CV=Coefficient of variation.

Table 6
Mean squares of ANOVA for sorghum yield attributes in the 2021 and 2022 cropping seasons.

Source of Variation		2021						2022					
	df	PH (cm)	HDL(cm)	LAI	TKW (g)	ABM (t/ha)	GY (t/ha)	PH (cm)	HDL (cm)	LAI	TKW (g)	ABM (t/ha)	GY (t/ha)
RA	3	448.5*	7.36*	0.02*	22.89*	2.55*	0.11^{ns}	392.76*	9.32*	0.03*	20.05*	2.47*	0.12^{ns}
VC	3	6407**	1093*	1.92**	438**	57.98**	43.38**	7858.77**	318.69**	1.83**	443.03**	63.50**	42.19**
RA*VC	9	21.27^{ns}	0.96^{ns}	0.02^{ns}	5.25^{ns}	0.263^{ns}	0.20*	21.27^{ns}	4.42^{ns}	0.02^{ns}	6.17^{ns}	0.47^{ns}	0.15**
Error	32	49.23	3.93	0.02	3.91	0.232	0.075	46.79	3.850	0.02	3.99	0.341	0.05
CV (%)		**6.47**	**7.73**	**5.16**	**5.78**	**6.986**	**8.27**	**6.02**	**7.67**	**5.38**	**5.86**	**8.233**	**6.62**

NB: PH=Plant height; HDL=Head length; LAI= Laef area index, ABM = Above ground biomass; GY = Grain yield; ns = not significant; * and ** = significant at 5 % and 1 % probability levels, respectively; df = degree of freedom; CV=Coefficient of variation; VC=Vermicompost; RA=Row arrangement (row configuration).

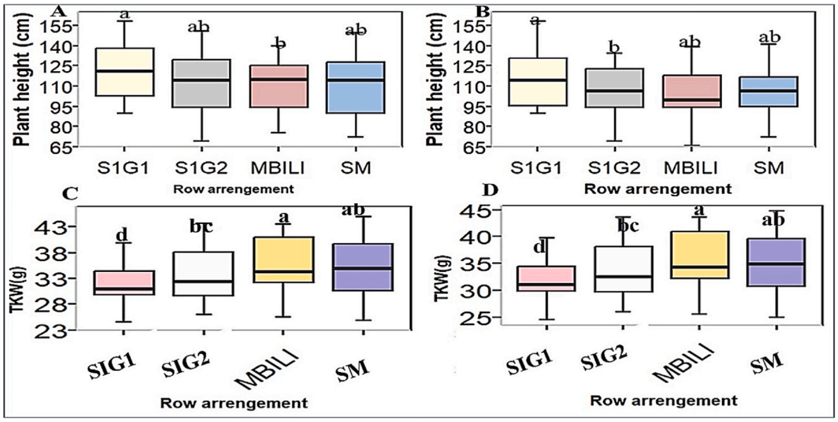

Fig. 7. Main effect of row arrangement on sorghum plant height during 2021 (A) & 2022 (B) and thousand seed weight during 2021 (C) & 2022 (D) years, respectively; S1G1 = 1:1 row ratio; S1G2 = 1:2 row ratio; MBILI = modified 2:2 row ratio; Values with the same letter in each figure panel insignificantly.

in vermicompost rate from zero to 4.5 t/ha increased sorghum TKW by 20 % (Table 5). Compared to mono-crop sorghum, intercropping in S1G1 and S1G2 decreased sorghum TKW by 3 and 1.5 percent, respectively. However, intercropping sorghum with peanut in the MBILI row arrangement boosts sorghum TKW by 1 % (Fig. 7 B & D).

3.2.3. Above-ground dry biomass (ABM) and grain yield

Vermicompost and planting geometry each had a substantial ($P < 0.05$) impact on the above-ground dry biomass of sorghum, but their combined effect was not statistically significant (Table 6). Application of vermicompost at 4.5 t/ha kg significantly increased the ABM by about 59 % over the control in 2021 years (Fig. 8A and B). When compared to mono-crop sorghum, intercropping reduces ABM by 5.5 and 2 percent in S1G1 and S1G2 row arrangements, respectively (Fig. 8 B & D).

Likewise, sorghum grain yield was significantly ($P < 0.05$) affected by the main effect of vermicompost and its interaction with planting geometry, but the main effect of row configuration had no significant effect in either year (Table 6). Even though the sole and intercropped sorghum under nil fertilizer was statistically insignificant, the MBILI row arrangement gave the highest grain yield in both years (Table 7). A significant improvement in grain yield (5.95 t/ha) was noticed in the MBILI row arrangement at 4.5 t/ha vermicompost application, which was statistically comparable to pure-stand sorghum at the same fertilizer rates. The yield of sorghum increased by about 65 and 64 percent in pure-stand and intercropping sorghum, respectively, when vermicompost was applied at a rate of 4.5 t/ha (Table 7).

3.3. Biological, ecological, and economic efficiency of sorghum/groundnut intercropping

The main effect of different row configurations and levels of vermicompost significantly ($P \leq 0.05$) affecting land equivalent coefficient (LEC), area time equivalent ratio (ATER), system productivity index (SPI), aggressivity of sorghum relative to groundnut (A_{sg}), rate of competitiveness (CRs), sorghum equivalent yield (SEY), and monetary advantage index (MAI) (Table 8). However, unlike the A_{sg}, SEY, SPI, and MAI indices, their interaction was insignificant for LEC, CRs, and ATER indices (Table 8). As the rate of vermicompost increased, the values of LEC, CRs, and ATER decreased, whereas the values of S1G1, S1G2, and MBILI increased (Table 9). The highest LEC (1.06) was found in sorghum/groundnut at MBILI row proportion owing to better spatial complementarity. CRs and ATER values followed a trend similar to that of LEC, where their values were above 1.00 (Table 9). Similarly, the highest A_{sg} (0.35) was recorded in nil vermicompost, which illustrates the dominance of sorghum. Similarly, maximum CRs (>2.54) recorded in low vermicompost and in a MBILI row proportion more pronounced dominance of sorghum (Table 9). The highest values of SPI (10.91), SEY (8.89), and MAI (281.05 ETB) were recorded in the MBILI row arrangement at 4.5 t/ha vermicompost (Table 9). The lowest SPI (2.2), SEY (3.09), and MAI (98.69 ETB) were attained in the S1G1 row ratio with fertilizer application (Table 9).

4. Discussion

4.1. Effect of planting geometry and vermicompost on yield and yield traits of peanut

The highest yield advantages of intercropping peanut attained in the MBILI row configuration are possibly related to enough space and sufficient light to reach the understory that stimulated the photosynthetic and metabolic activities of the plant, thereby resulting in the formation of a healthy and well-structured plant [7,15,58]. These support our hypothesis that adjusting planting geometry with proper nutrient management could alleviate interspecific competition, thereby minimizing the negative effect of over-competing sorghum on groundnuts. Under the 4.5 t/ha dose, GM shows a slight decline in grain yield with time. In contrast, intercropping shows a significant increase in grain yield with time, which means that intercropping, especially MBILI, is a more sustainable and

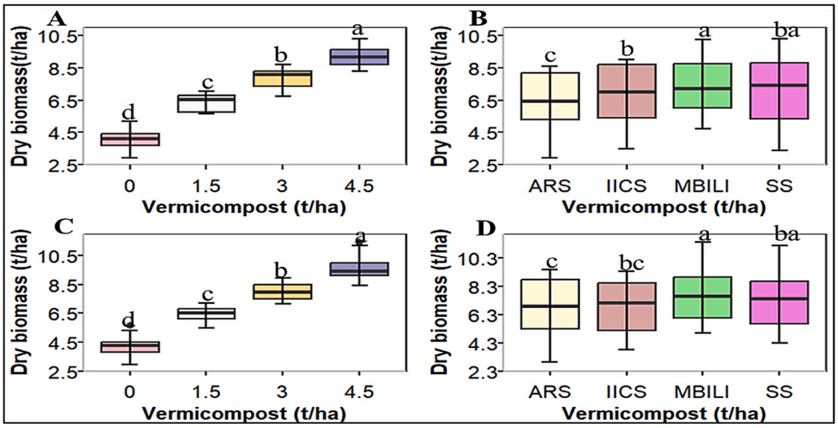

Fig. 8. Main effect of vermicompost and Row arrangement on above-ground biomass (ABM) during 2021 (A & B) & 2022 (C & D) years, respectively; S1G1 = 1:1 row ratio; S1G2 = 1:2 row ratio; MBILI = modified 2:2 row ratio; Values with the same letter in each figure panel insignificantly.

Table 7
Interaction effect of row arrangements and levels of vermicompost on sorghum grain yield in 2021 and 2022 years.

Cropping Pattern	Vermicompost-fertilizer (t/ha)							
	Sorghum grain yield (t/ha) 2021				Sorghum grain yield (t/ha) 2022			
	0	1.5	3	4.5	0	1.5	3	4.5
S1G1	**1.219^{g}**	2.638^{ef}	3.54^{d}	5.434^{b}	**1.234^{h}**	2.82^{f}	3.82^{e}	5.298^{c}
S1G2	**1.18^{g}**	2.642^{ef}	3.701^{d}	5.468^{b}	**1.227^{h}**	2.656^{fg}	4.075^{de}	5.416^{bc}
MBILI	**1.199^{g}**	2.975e	3.62^{d}	**5.9467^{a}**	**1.296^{h}**	2.795^{f}	4.068^{de}	**5.946^{a}**
SM	**1.189^{g}**	2.266^{f}	4.197^{c}	5.81^{ab}	**1.18^{h}**	2.297^{g}	4.1340^{d}	**5.711^{ab}**
LSD	0.456				0. 365			
CV (%)	8.27				6.49			

NB: SM = sole sorghum; S1G1 (1:1) = 1 row of sorghum with 1 row of groundnut; S1G2 (1:2) = 1 row of sorghum with 2 rows of groundnut; MBILI (2:2) = 2 row of sorghum with 2 rows of groundnut; LSD = Least Significant Difference, CV=Coefficient of variation.

Table 8
Mean squares of ANOVA for land equivalent coefficient (LEC), system productivity index (SPI), area time equivalent ratio (ATER), competitive ratio of sorghum (CRs), monetary advantage (MAI), aggressivity of sorghum, and sorghum equivalent yield (SEY).

Source of Variation	Df	LEC	ATER	Asg	CRs	SPI	SEY	MAI (ETB)
RA	**2**	0.21**	0.19**	0.06**	0.32**	18.27^{ns}	2.14**	9160**
VC	**3**	0.1**	0.1**	0.05**	0.39**	862.3**	42.09**	27773**
RA*VC	**6**	0.001^{ns}	0.01^{ns}	0.01**	0.06^{ns}	8.00^{ns}	0.12*	605.3*
Error	**22**	0.01	0.81	0.01	0.08	15.65	0.06	256.7
CV (%)		**11.81**	**5.75**	**15.49**	**11.65**	**6.05**	**4.23**	**9.29**

NB: RA = Row arrangement, VC=Vermicompost (0, 1.5, 3, 4.5 t/ha), CV = coefficient of variation.

stable yield for groundnut production than monocropping. This result follows the findings of Mucheru-muna et al. [36] and Kinyua et al. [37], who proved that MBILI with optimum fertilizer substantially enhances crop yield and monetary advantages over the conventional intercropping method. El-Aref et al. [59] also reported similar results in sorghum/peanut intercropping. The lowest yield of peanut recorded in S1G1 row arrangement and in pure-stand at nil fertilizer were associated with intensive inter- and intra-species competition that led to substantial nutritional stress [60]. However, S1G1 gave the tallest plant height, which might be linked to the overshadowing effect of sorghum [58,61]. Similarly, Almaz et al. [62] and Xiao et al. [63] observed significant yield reductions of intercropped legumes with cereal crops.

We observed a linear increment of peanut yield attributes with vermicompost, which is in agreement with the findings of Xiao et al. [63], who proposed that increasing nutrient availability in the soil could moderate the competitive effect existing in the intercropping system. The enhanced yield parameters in high fertilizer doses are most probable due to the release of sufficient nutrients from vermicompost as needed by the crop [33,34]. Recent studies suggested that the application of microbial fertilizer prepared from organic substrate increased available water, hydraulic properties, and readily available water, thereby mitigating the adverse effects of salinity on plants [64]. Furthermore, microbial inoculants further enhance organic matter biodegradation and stabilization of P during biowastes composting [65], thereby increasing the grain yield of crops. It is also related to the role of intercropping in increasing the

Table 9
Main effect of row configuration and vermicompost on LEC, CRs, ATER, MAI and their interaction effect on Asg, SPI, SEY, MAI indices.

Factors	LEC	CRs	ATER	Treatments	Asg		SPI	SEY	MAI
VC_0	1.02^{a}	2.54^{a}	1.91^{a}	S1G1	VC_0	0.35^{a}	2.2^{g}	3.09^{g}	98.69^{i}
$VC_{1.5}$	0.99^{a}	2.52^{a}	1.89^{a}		$VC_{1.5}$	0.34^{a}	4.33^{f}	4.46^{f}	134.83^{gh}
VC_3	0.86^{b}	2.36^{a}	1.76^{b}		VC_3	0.13^{efg}	7.34^{d}	6.01^{d}	163.13^{ef}
$VC_{4.5}$	0.79^{b}	2.09^{b}	1.69^{b}		$VC_{4.5}$	0.23^{bcd}	9.47^{b}	7.79^{b}	205.64^{cd}
LSD	**0.11**	**0.27**	**0.1**	**S1G2**	**VC_0**	0.19^{bcde}	2.23^{g}	3.17^{g}	102.79^{i}
Row configuration					**$VC_{1.5}$**	0.17^{cdef}	4.51^{ef}	4.65^{f}	146.78^{fg}
MBILI	**1.06^{a}**	**2.57^{a}**	**1.96^{a}**		**VC_3**	0.1^{fg}	7.73^{d}	6.3^{d}	183.14^{de}
S1G2	0.88^{b}	2.3^{b}	1.77^{b}		**$VC_{4.5}$**	0.24^{bc}	9.78^{b}	8.01^{b}	221.16^{bc}
S1G1	0.81^{b}	2.27^{b}	1.71^{b}	**MBILI**	**VC_0**	0.06^{gh}	2.34^{g}	3.37^{g}	114.84^{hi}
LSD	**0.09**	**0.23**	**0.09**		**$VC_{1.5}$**	0.25^{b}	5.07^{e}	5.23^{e}	184.27^{de}
					VC_3	0.02^{h}	8.68^{c}	7.09^{c}	234.05^{b}
					$VC_{4.5}$	0.16^{def}	**10.91^{a}**	**8.89^{a}**	**281.05^{a}**
				LSD		**0.08**	**0.6**	**0.4**	**27**

NB: S1G1 = 1:1 row ratio; S1G2 = 1:12 row ratio; MBILI = modified 2:2 row ratio; VC = vermicompost (0, 1.5, 3, 4.5 t/ha); CV = coefficient of variation; LSD = least significant difference.

phyto-availability of limited resources by modifying soil physicochemical properties [35,66] thus resulting in a high economic yield. Increases in pod yield may be boosted by maximum pod/plant and seeds/pod. Ghosh et al. [18], Surya et al. [67], and Bekele et al. [3] found similar results.

4.2. Effect of row arrangement and vermicompost on yield attributes of sorghum

The presented result revealed that MBILI (modified S2G2) at 4.5 t/ha of vermicompost gave the highest yield attribute, followed by S1G2. This result in harmonies with the findings of Suleman et al. [15] and El-Aref et al. [59], who stated that the highest sorghum grain yield was found in an intercropped 2:2 row proportion. Intercropped sorghum under S1G1 row proportions reduced sorghum yield by 2–5% compared to other treatment combinations, probably due to increased competition for sunlight, space, water, and nutrients [68]. High rates of vermicompost show a slight reduction in head length with time; however, plant height shows a significant increase with time, which indicates more sustainability of plant height than head length, probably due to the role of N released from vermicompost.

The improvement in sorghum yield under MBILI row configuration with the application of high vermicompost is conceivably linked to a balanced supply of plant-available nutrients from the decomposition of vermicompost [33,35] throughout the crop growth period. This is not only because of improved nutrient availability but also owing to its beneficial effects on the soil's physicochemical properties. Furthermore, the highest grain yield in the sole and MBILI with high fertilizer dose during both years may also be related to increased canopy size (LAI) due to low inter-specific competition [69], which is key for growth and grain yield accumulation. The results were in harmony with the result of Chhetri and Sinha [70], who observed higher maize yield at a 2:2 ratio intercropped with cowpea. Likewise, Annadurai et al. [22] stated favorable plant geometry permits adequate interception of sunlight and optimal absorption of nutrients and water. On the contrary, the lowest grain yields observed in sole-cropped sorghum under nil fertilizer justify the usually proposed low soil fertility of the study area [71].

4.3. Biological, ecological, and economic efficiency of sorghum/groundnut intercropping

The assessment of intercropping systems using multiple indices such as LEC, ATER, and CRs shows that intercropping sorghum with groundnut under MBILI row arrangement gives high yield stability and greater land use efficiency. This demonstrates the superiority of intercropping over either species' sole crop, thereby higher overall production per unit area [32,38,46,72]. In this study, the value of LEC, ATER, and CRs declined as the rates of vermicompost increased, which implies high fertilizer dose encouraged the competitive ability of cereal over legumes in the mixture [73]. Similarly, the result shows that all intercrop combinations had LEC values above 0.79 and Asg values greater than zero, which implies these cropping systems have high yield advantages, stability, and profitability. CRs and ATER values followed a trend similar to that of LEC, where their values were above 1.00, which further indicated intercrop benefits. This is coinciding with the outcomes of Oseni [50] in a sorghum/cowpea mixture and Hauggaard-Nielsen et al. [74] in legume-barley. Yilmaz et al. [68] found positive and high-value Ag and CR maize, showing that maize was the predominant crop in all mixes and planting patterns. These results are consistent with Brahimi et al. [75], who found that intercropping considerably increased grain yield and resource usage efficiency compared to sole cropping systems.

In addition, compared to other treatment combinations, intercropped sorghum/groundnut with MBILI planting geometry provided higher values of SPI, SEY, and MAI, most likely due to enhanced yield and groundnut component values. These findings align with those of Kinyua et al. [37], who demonstrated that applying the MBILI-MBILI intercropping system resulted in not only higher net revenue but also more stability than other maize-pigeon pea intercropping systems. Similarly, Muyayabantu et al. [76] observed increased yield and economic advantages in maize/soybean combinations under integrated nutrient management. The same results have been reported in an intercropped maize/mung bean mixture [77]. One possible explanation for this could be enhanced complementarity among component crops and improved use of supplied nutrients [12,70]. Similarly, intercropped sorghum with groundnuts is more profitable, as indicated by the highest SEY and MAI, which generally implies that growing peanut under MBILI row arrangement is more beneficial and efficient than other row configurations.

5. Conclusion

The current results suggest that intercropped peanut provided a larger yield advantage over other treatment combinations at 4.5 t/ha of vermicompost in MBILI row configuration. Compared to S1G1 row configurations, the above treatment combination significantly increased the number of pods, seed production, and groundnut shelling percentage. Furthermore, MBILI intercropping resulted in higher LEC, ATER, SPI, and MAI than other intercropping strategies. Using 4.5 t/ha of vermicompost in conjunction with an MBILI row arrangement could lessen sorghum's negative effects on intercropped peanuts, resulting in a more profitable crop output. Intercropping at higher fertilizer doses shows a substantial increase in peanut yield with time, which suggests intercropping, especially MBILI, is a more sustainable and stable yield for peanut production than monocropping. Furthermore, by offering yield stability and some ecological benefits, this system could create a sustainable and resilient agricultural system. Therefore, farmers were advised to use a modified S2G2 row arrangement (MBILI) with a 4.5 t/ha vermicompost to maximize the productivity of the sorghum and peanut under current climate change. However, the current yield is still far less than the potential yield obtained elsewhere, indicating further investigation to reduce other yield-limiting factors at research sites.

Data availability statement

Data will be made available on request.

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Ethics approval and consent to participate

Not applicable for this section.

Consent for publication

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CRediT authorship contribution statement

Addisu F. Ebbisa: Fufa, Writing – review & editing, Writing – original draft, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Nigussie Dechassa:** Supervision. **Zelalem Bekeko:** Visualization, Validation, Supervision. **Fayera Liben:** Visualization, Validation, Supervision, Project administration.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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