PLANT SCIENCE TODAY
ISSN 2348-1900 (online)
Vol 10(4): 238–246
https://doi.org/10.14719/pst.2627

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RESEARCH ARTICLE

Effect of the summer pearl millet-groundnut intercropping system on the growth, productivity, and competitive ability of crops under south Odisha conditions

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OPEN ACCESS

ARTICLE HISTORY

Received: 27 April 2023
Accepted: 25 August 2023

Available online
Version 1.0 : 30 September 2023
Version 2.0 : 06 October 2023

Check for updates

Additional information

Peer review: Publisher thanks Sectional Editor and the other anonymous reviewers for their contribution to the peer review of this work.

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Indexing: Plant Science Today, published by Horizon e-Publishing Group, is covered by Scopus, Web of Science, BIOSIS Previews, Clarivate Analytics, NAAS,UGC Care etc. See https://horizonepublishing.com/journals/index.php/PST/indexing_abstracting

CITE THIS ARTICLE

Priya G S, Maitra S, Shankar T, Sairam M. Effect of the summer pearl millet-groundnut intercropping system on the growth, productivity, and competitive ability of crops under south Odisha conditions. Plant Science Today. 2023; 10(4): 238–246. https://doi.org/10.14719/pst.2627

Abstract

A millet-based intercropping system is common in dryland and rainfed conditions. Pearl millet (*Pennisetum glaucum* L.) exhibits wide adaptability to different agroclimatic conditions and seasons, making it suitable for an intercropping system. Groundnut (*Arachis hypogea* L.) is a leguminous oil-seed crop that can be cultivated as an intercrop in various cereals and millets to enhance productivity and resource efficiency. Based on these facts, the present study was conducted at the Research Farm of Centurion University of Technology and Management during the summer season of 2022 to assess the effect of the summer pearl millet + groundnut intercropping system on the growth, productivity, and competitive ability of crops under the conditions of south Odisha. The experiment consisted of nine treatments. In case of pearl millet, the highest plant height at harvest was achieved in pearl millet (30 cm × 10 cm) + groundnut (1:1) (186 cm), while the maximum plant height of groundnut at harvest was observed in pearl millet (45 cm × 10 cm) + groundnut (1:2) (70 cm). Dry matter production at harvest and leaf area index (LAI) at 60 days after sowing (DAS) of pearl millet were highest in pearl millet sole (857 g m^{-2} and 2.19, respectively). The maximum dry matter production at harvest was found in groundnut sole. The highest yield of individual crops was observed in their pure stands, with 2677 kg ha^{-1} and 2633 kg ha^{-1} of pearl millet grain and groundnut pod, respectively. Among mixed stands, pearl millet (30 cm × 10 cm) + groundnut (1:1) and pearl millet (45 cm × 10 cm) + groundnut (1:1) showed superior values of different competition functions, such as aggressivity, relative crowding coefficient, monetary advantage, land equivalent ratio, and area time equivalent ratio. The results concluded that pearl millet and groundnut could be intercropped with a 1:1 row proportion with pearl millet spacing of either 30 cm × 10 cm or 45 cm × 10 cm in south Odisha conditions.

Keywords

Pearl millet; legume; intercropping; yield attributes; competition functions

Introduction

Pearl millet (*Pennisetum glaucum* L.), also known as bajra, is the sixth most widely grown crop in the world, following wheat, rice, corn, barley, and sorghum. Its ability to withstand drought and extreme weather conditions on unproductive soils makes the crop more suitable for dryland farming. Pearl millet is also known as a nutri-cereal due to its nutritional value, containing approximately 13-14% protein, 5-6% fat, 74% carbohydrate, and 1-2% minerals. It also contains a higher amount of carotene, riboflavin (Vitamin B2), and niacin (Vitamin B4) (1). In India, pearl millet occupies an area of 6.93

million ha with an average production of 8.61 million tonnes and a productivity of 1243 kg ha^{-1} during 2018-19. In Odisha, pearl millet occupies an area of 1870 ha with a production of 1160 tonnes and a productivity of 620 kg ha^{-1} (2).

Groundnut (*Arachis hypogea* L.) is a leguminous crop that is highly suitable for intercropping under various agroclimatic conditions. It ranks as the fourth most important edible oil in the world and is also one of the most prominent oilseeds in India as well as in Odisha. Additionally, groundnut is a good source of protein, fat, and other beneficial nutrients, containing approximately 50% oil, 25-30% protein, 20% carbohydrate, and 5% fibre, making it a valuable contributor to human nutrition (3). Groundnut can fix atmospheric nitrogen in the soil and share excess nitrogen with non-legumes, and thereby enhancing the yield of cereals (4).

Due to the limited supply of land resources and declining soil fertility, both globally and locally, there is a growing concern about agriculture's capacity to meet the future demand of a growing population (5,6). Intercropping is an effective approach that boosts total production per unit area (7, 8). Intercropping is the practise of cultivating two or more crops simultaneously on the same piece of land in different row proportion with an emphasis to maximise the use of available natural resources, stabilising crop yields, and enhancing economic returns, thus contributing to agricultural sustainability (9, 10). Intercropping systems enhance the better utilization of available land, light, soil moisture, and nutrients. The complementarity effect and productivity increases are highest when the component crops have diverse growing habitat to meet their significant resource demands at different times (11–13). However, research evidence on this aspect is scarce for south Odisha conditions. Considering the above facts, a study was conducted to assess the potential of pearl millet + legume intercropping system.

Materials and Methods

A field experiment was conducted at the Experimental Research Farm of Centurion University of Technology and Management (23˚39' N latitude and 87˚42' E longitude) during the summer season of 2022. The experimental farm is located in Paralakhemundi, Gajapati district, Odisha (23˚39' N latitude and 87˚42' E longitude). During the crop -growing season, weather data were collected from the meteorological observatory at the M. S. Swaminathan School of Agriculture, Centurion University of Technology and Management, from March 3, 2022 to June 27, 2022, as presented in Fig.1. During the crop period, the average weekly maximum and minimum temperatures were 41.0°C and 33°C, and 28°C and 18°C, respectively. The weekly mean relative humidity ranged between 87% and 92% over the crop-growing season, with a mean rainfall of 1.6 mm occurring during the cropping period. The sunshine hours per day varied between 11 hrs and 8.7 hrs during the experimentation period.

Prior to cultivation, soil samples were collected from the experiment site at a depth of 0–30 cm. Standard

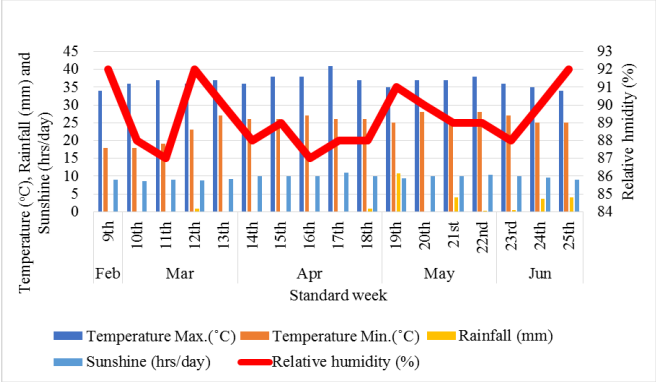

Figure 1. Meteorological conditions during the period of experimentation.
Data source: Meteorological Observatory, Centurion University of Technology and Management, Odisha

techniques were followed to estimate the physical and chemical properties of the research plot. The experimental soil has a sandy loam texture with a pH of 6.1 and organic carbon of 0.34%. The nitrogen, phosphorus, and potassium content were found to be 226, 13.8, and 125.4 kg ha^{-1}, respectively. The trial was designed in a Randomized Block Design (RBD) comprising nine treatments and replicated thrice. The treatments and proportions of crops are detailed in Table 1. Each experimental plot had a size of 4.5 m × 3.6 m. In the study, the pearl millet hybrid 'PA 9285' and groundnut variety 'K6' were considered with crop durations of 90 and 120 days, respectively. Sole pearl millet was sown with a spacing of 45 cm × 10 cm, while sole groundnut was sown with a spacing of 30 cm × 10 cm. Groundnut was seeded between pearl millet rows in intercropped treatments, with 1, 2, or 3 rows, depending on the treatment details. The recommended fertilizer dose for pearl millet sole and intercropped treatments were 60-30-30 kg ha^{-1} of N:P_2O_5:K_2O and that of groundnut sole was 20-40-20 kg ha^{-1}. To keep the plots weed-free, two hand weedings were done at 20 and 40 DAS for all the treatments. The data at harvest, such as plant height, leaf area index, dry matter accumulation, yield attributes, and yield, were collected from each treatment and analysed statistically by using analysis of variance (ANOVA), the standard error of means (S. Em ±), and the critical difference at the 5% probability level of significance (14). Further, the Excel software (Microsoft Office Home and Student version 2019-en-us, Microsoft Inc., Redmond, Washington, USA) was used for statistical analysis. Additionally, some competitive functions, including land equivalent ratio (LER), area-time equivalent ratio (ATER), aggressivity, relative crowding coefficient (RCC), competitive ratio (CR), and monetary advantage (MA), were computed using the formulas provided by (15–20), respectively.

Results and Discussion

Effect of pearl millet-groundnut intercropping on growth attributes

The data on plant height, dry matter accumulation, and leaf area index of pearl millet and groundnut were statistically analysed and presented in Table 2. The plant height of pearl millet at harvest was highest in pearl millet (30 cm × 10 cm) +

Table 1. Treatment details and proportion of plant stand.

Treatments	Percentage of crop stand
Pearl millet sole (45 cm × 10 cm)	100% Pearl millet
Groundnut sole (30 cm × 10 cm)	100% Groundnut
Pearl millet (45 cm × 10 cm) + groundnut (1:1)	100% Pearl millet + 66% groundnut
Pearl millet (45 cm × 10 cm) + groundnut (1:2)	100% Pearl millet + 133% groundnut
Pearl millet (30 cm × 10 cm) + groundnut (1:1)	150% Pearl millet + 100% groundnut
Pearl millet (30 cm × 10 cm) + groundnut (2:2)	75% Pearl millet + 50% groundnut
Pearl millet (60 cm × 10 cm) + groundnut (1:1)	75% Pearl millet + 50% groundnut
Pearl millet (60 cm × 10 cm) + groundnut (1:2)	75% Pearl millet + 100% groundnut
Pearl millet (60 cm × 10 cm) + groundnut (1:3)	75% Pearl millet + 150% groundnut

groundnut (1:1) (186 cm) and it was statistically at par with pearl millet (45 cm × 10 cm)+ groundnut (1:1) and pearl millet (45 cm × 10 cm) + groundnut (1:2). This increase in plant height in mixed stands was likely due to the accommodation of more plants per unit area, resulting in interspecies competition and stem elongation in pearl millet. These results are consistent with previous studies (21, 22). Similarly, the plant height of groundnut at harvest was highest with pearl millet (45 cm × 10 cm) + groundnut (1:2) (70 cm). In such case, mixed stand might be favorable for the creation of microclimate that enhances the height of groundnuts. These results are consistent with the previous research (23). Dry matter production of pearl millet at harvest was found to be highest in pearl millet sole (45 cm × 10 cm)(857g m^{-2}) followed by pearl millet (45 cm × 10 cm) + groundnut (1:1) (816g m^{-2}); however, both the treatments remained on par with each other (Table 2). These findings are consistent with previous research (22). Sole groundnut production resulted in the highest dry matter, but it was statistically similar to pearl millet (30 cm × 10 cm) + groundnut (1:1), which produced significantly more dry matter than other mixed stands. A previous study (24) also reported similar results. The highest LAI of pearl millet at 60 DAS was observed in the pearl millet sole cropping (2.19). This treatment was statistically similar to both pearl millet (45 cm × 10 cm) + groundnut (1:1) and pearl millet (30 cm × 10 cm) + groundnut (1:1), which remained significantly superior to other mixed stands (Table 2). These results align with the findings of previous studies (21, 25). LAI of groundnut at 60 DAS was highest in the pearl millet (30 cm × 10 cm) + groundnut (1:1) (2.40), closely followed by groundnut sole (2.12), and both treatments remained statistically at par. These results are in accordance with the previous finding (26).

Effect of pearl millet-groundnut intercropping on yield attributes of crops

The effective tiller per plant of pearl millet was recorded highest (1.31) in the intercropping system of pearl millet (60 cm × 10 cm) + groundnut (1:1). It was followed by pearl millet (60 cm × 10 cm) + groundnut (1:2) (1.29), pearl millet sole (45 cm × 10 cm) (1.27), and pearl millet (45 cm × 10 cm) + groundnut (1:1) (1.22); however, they were also statistically at par with pearl millet (60 cm × 10 cm) + groundnut (1:1). Previous research supports these findings in the same direction (25, 27). Among all the treatments, pearl millet (60 cm × 10 cm) + groundnut (1:1) recorded the highest panicle length (24.31 cm) and panicle diameter (4.85 cm), as well as the highest weight of grains per plant (13.12 g) (Table 3). These results may be attributed to the lower plant population of pearl millet due to wider spacing and comparatively less intra- and inter-species competition for available resources (25, 28–30).

Table 2. Plant height, dry matter accumulation and leaf area index of pearl millet and groundnut as influenced by intercropping.

Treatments	Plant height at harvest (cm)		Dry matter production at harvest (g m^{-2})		Leaf area index at 60 DAS	
	PM	GN	PM	GN	PM	GN
Pearl millet sole (45 cm × 10 cm)	167 ^{bcd}	--	857 ^{a}	--	2.19 ^{a}	--
Groundnut sole (30 cm × 10 cm)	--	65 ^{abcd}	--	733 ^{a}	--	2.12 ^{ab}
Pearl millet (45 cm × 10 cm) + groundnut (1:1)	177 ^{abc}	63 ^{cde}	816 ^{a}	603 ^{bc}	2.09 ^{ab}	1.56 ^{d}
Pearl millet (45 cm × 10 cm) + groundnut (1:2)	179 ^{ab}	70 ^{a}	649 ^{c}	615 ^{b}	2.04 ^{bc}	1.97 ^{bc}
Pearl millet (30 cm × 10 cm) + groundnut (1:1)	186 ^{a}	67 ^{abc}	748 ^{b}	715 ^{a}	2.08 ^{abc}	2.40 ^{a}
Pearl millet (30 cm × 10 cm) + groundnut (2:2)	167 ^{bcd}	59 ^{e}	632 ^{c}	391 ^{e}	2.00 ^{bcd}	1.50 ^{d}
Pearl millet (60 cm × 10 cm) + groundnut (1:1)	163 ^{d}	62 ^{de}	637 ^{c}	443 ^{d}	1.94 ^{cde}	1.51 ^{d}
Pearl millet (60 cm × 10 cm) + groundnut (1:2)	165 ^{cd}	65 ^{bcd}	554 ^{d}	567 ^{bc}	1.87 ^{de}	1.60 ^{d}
Pearl millet (60 cm × 10 cm) + groundnut (1:3)	170 ^{bcd}	69 ^{ab}	508 ^{d}	559 ^{c}	1.84 ^{e}	1.76 ^{cd}
S.Em. ±	5.31	2.17	24.50	23.92	0.05	0.10
C.D. (p=0.05)	16.09	6.59	74.30	72.54	0.14	0.31
C.V. (%)	5.34	5.78	6.29	7.17	7.45	9.86

PM=Pearl millet; GN=Groundnut

Table 3. Yield attributes of pearl millet as influenced by pearl millet-groundnut intercropping.

Treatments	Number of effective tillers plant^{-1}	Panicle length (cm)	Panicle diameter (cm)	1000-grain weight (g)	Weight of grains plant^{-1}	Number of grains panicle^{-1}
Pearl millet sole (45 cm ×10 cm)	1.27 ^{ab}	23.9 ^{ab}	4.3 ^{b}	7.9	12.0 ^{ab}	1200 ^{a}
Pearl millet (45 cm × 10 cm) + groundnut (1:1)	1.22 ^{abc}	23.7 ^{ab}	4.1 ^{b}	7.8	11.3 ^{bc}	1193 ^{a}
Pearl millet (45 cm × 10 cm) + groundnut (1:2)	1.09 ^{d}	22.2 ^{bc}	4.0 ^{b}	7.5	8.4 ^{d}	1080 ^{b}
Pearl millet (30 cm × 10 cm) + groundnut (1:1)	1.11 ^{cd}	20.7 ^{c}	3.9^{b}	7.3	6.5 ^{e}	768 ^{e}
Pearl millet (30 cm × 10 cm) + groundnut (2:2)	1.16 ^{bcd}	23.6 ^{ab}	4.1 ^{b}	7.8	11.1 ^{bc}	1118 ^{ab}
Pearl millet (60 cm ×10 cm) + groundnut (1:1)	1.31 ^{a}	24.3 ^{a}	4.8 ^{a}	8.3	13.1 ^{a}	943 ^{d}
Pearl millet (60 cm × 10 cm) + groundnut (1:2)	1.29 ^{ab}	24.1 ^{a}	4.3 ^{b}	7.9	12.5 ^{ab}	1052 ^{bc}
Pearl millet (60 cm × 10 cm) + groundnut (1:3)	1.11 ^{cd}	22.5 ^{ab}	4.0 ^{b}	7.7	10.2 ^{c}	988 ^{cd}
S.Em. ±	0.04	0.71	0.16	0.27	0.48	36.71
C.D. (p=0.05)	0.13	2.16	0.50	NS	1.45	111.36
C.V. (%)	6.37	5.34	6.72	6.11	7.75	6.10

NS= Non-significant

There was no significant difference among sole and intercropped treatments in case of 1000-grain weight. The highest number of grains per panicle was recorded in pearl millet sole, which remained statistically at par with pearl millet (45 cm × 10 cm) + groundnut (1:1) and pearl millet (30 cm × 10 cm)+ groundnut (2:2). However, other intercropped treatments were significantly inferior to sole pearl millet. These results align with earlier findings (30, 31).

Effect of pearl millet groundnut intercropping on yield attributes of groundnut

In groundnut, the highest number of branches per plant (9.50) was recorded in pearl millet (30 cm × 10 cm) + groundnut (1:1), which was on par with groundnut sole (9.11) and pearl millet (45 cm × 10 cm) + groundnut (1:2) (8.84) (Table 4). The pearl millet (30 cm × 10 cm) + groundnut (1:1) treatment recorded a significantly higher number of branches per plant compared to the other intercropping systems. The highest number of pods per plant in groundnut was recorded in pearl millet (60 cm × 10 cm)+ groundnut (1:1) (11.4), which was statistically at par with pearl millet (45 cm × 10 cm) + groundnut (1:1) (11.0) and groundnut sole (30 cm × 10 cm) (10.5). These results are consistent with previous research (23, 32, 33). The number of kernels per podwas recorded maximum in pearl millet (60 cm × 10 cm) + groundnut (1:1) (1.71) treatment, possibly due to wider row spacing and less competition (34, 35). There were no significant differences in the 100-kernel weight of groundnut among the treatments. Regarding the weight of pods per plant, groundnut sole (30 cm × 10 cm) (12.21g) exhibited superiority (12.21 g) over all intercropped treatments. Among the intercropped treatments, the highest weight of pods per plant was obtained in pearl millet (45 cm × 10 cm) + groundnut (1:1) (8.90 g), followed by pearl millet (60 cm × 10 cm) + groundnut (1:2) (8.53 g) and pearl millet (30 cm × 10 cm) + groundnut (1:1) (7.86 g). These findings align with previous research (36, 37).

Effect of pearl millet groundnut intercropping on yield of crops

The highest grain yield of pearl millet was obtained with sole pearl millet (2677 kg ha^{-1}), remaining significantly superior to all intercropping treatments (Table 5). Among the intercropped treatments, pearl millet (45 cm × 10 cm) + groundnut (1:1) yielded significantly higher results compared to other intercropped treatments. The plant population of pearl millet remained same (100%) in pearl millet sole (45cm×10cm) and pearl millet (45 cm × 10 cm) + groundnut (1:1). This is probably the reason for the enhanced yield of pearl millet in its pure

Table 4. Yield attributes of groundnut as influenced by pearl millet-groundnut intercropping.

Treatments	**Number of branches plant^{-1}**	**No of pods plant^{-1}**	**No of kernels pod^{-1}**	**100-kernel weight (g)**	**Weight of pods plant^{-1} (g)**
Groundnut sole (30 cm × 10 cm)	9.11 ^{ab}	10.5 ^{ab}	1.6 ^{ab}	40.0	12.21 ^{a}
Pearl millet (45 cm × 10 cm) + groundnut (1:1)	7.91 ^{c}	11.0 ^{a}	1.6 ^{ab}	40.0	8.90 ^{b}
Pearl millet (45 cm × 10 cm) + groundnut (1:2)	8.84 ^{ab}	9.0 ^{c}	1.4 ^{b}	34.4	5.54 ^{d}
Pearl millet (30 cm × 10 cm) + groundnut (1:1)	9.50 ^{a}	9.4 ^{c}	1.4 ^{b}	35.0	7.86 ^{c}
Pearl millet (30 cm ×10 cm) + groundnut (2:2)	7.63 ^{c}	9.8 ^{bc}	1.6 ^{ab}	38.0	2.76 ^{f}
Pearl millet (60 cm × 10 cm) + groundnut (1:1)	7.82 ^{c}	11.4 ^{a}	1.7 ^{a}	41.0	5.53 ^{d}
Pearl millet (60 cm × 10 cm) + groundnut (1:2)	8.32 ^{bc}	9.6 ^{bc}	1.5 ^{ab}	37.5	8.53 ^{bc}
Pearl millet (60 cm × 10 cm) + groundnut (1:3)	8.47 ^{bc}	8.0 ^{d}	1.0 ^{c}	33.5	4.08 ^{e}
S.Em. ±	0.3	0.36	0.06	2.07	0.31
C.D. (p=0.05)	0.92	1.08	0.19	NS	0.93
C.V(%)	6.19	6.27	7.31	9.58	7.66

NS= Non-significant

stand. Similar findings were noted by earlier researchers (27,38,39). Stover yield of pearl millet varied among the treatments, with the highest stover yield recorded in pearl millet sole (5289 kg ha^{-1}) which was statistically at par with pearl millet (45 cm × 10 cm) + groundnut (1:1) (5037 kg ha^{-1}) and pearl millet (30 cm × 10 cm) + groundnut (1:1) (4892 kg ha^{-1}). Pearl millet sole recorded a higher stover yield due to 100% plant density and its pure stand, which did not face any interspecies competition. These results are consistent with the previous research (40).

Significant differences were observed among all the treatments regarding the pod yield of groundnut (Table 5). The highest pod yield of groundnut was recorded in groundnut sole (30 cm × 10 cm) (2633 kg ha^{-1}) and was significantly superior to all other treatments due to the presence of 100% population in sole groundnut. Among intercropped treatments, the highest pod yield was registered in pearl millet (60 cm × 10 cm) + groundnut (1:2) (2048 kg ha^{-1}) followed by pearl millet (45 cm × 10 cm)+ groundnut (1:1) (1945 kg ha^{-1}) and pearl millet (45 cm × 10 cm) + groundnut (1:1) (1945 kg ha^{-1}). The highest pod yield was noted in groundnut sole (30 cm × 10 cm), as expected, due to 100% plant density, whereas in the mixed stands, plant density decreased as per row proportions and planting geometry. These results are in tune with the findings of the earlier research (32,33).

The data revealed that the maximum stover yield of groundnut was obtained with pearl millet (30 cm × 10 cm) + groundnut (1:1) (4987 kg ha^{-1}), remaining significantly superior to all other treatments. The highest stover yield of groundnut observed in pearl millet (30 cm × 10 cm) + groundnut (1:1) might be due to higher plant stand and complementary effects. Previous research works also suggested similar findings (36, 33). The treatment pearl millet (45 cm × 10 cm) + groundnut (1:1) recorded the highest HI (47.13) closely followed by groundnut sole (30 cm × 10 cm) (44.04). However, the lowest HI was produced by pearl millet (60 cm × 10 cm) + groundnut (1:3) (26.42). Related findings were earlier recorded by researchers (33).

Effect of intercropping system on competitive functions

The competitive functions, derived using various equations, are presented in Table 6 and Table 7. The maximum LER value was obtained in treatment pearl millet (30 cm × 10 cm) + groundnut (1:1) (1.75), surpassing all other treatments. This was followed by pearl millet (45 cm × 10 cm)+ groundnut (1:2) (1.59), pearl millet (45 cm × 10 cm) + groundnut (1:1) (1.33), pearl millet (60 cm × 10 cm)+ groundnut (1:2) (1.28), and pearl millet (60 cm × 10 cm)+ groundnut (1:3) (1.19). Since the LER values of these intercropping treatments are greater than one, they are considered advantageous over sole cropping. These results align with previous research works conducted (41, 42).

Regarding ATER, pearl millet (30 cm × 10 cm)+ groundnut (1:1) exhibited the highest ATER value (1.49), indicating an advantage over time and space compared to other treatments. Additionally, treatments such as pearl millet (45 cm × 10 cm) + groundnut (1:2), pearl millet (45 cm × 10 cm) + groundnut (1:1), pearl millet (60 cm × 10 cm) + groundnut (1:2) and pearl millet (60 cm × 10 cm) + groundnut (1:3) also yielded ATER values greater than one, signifying their benefits. These results are in line with the previous findings (43, 44).

In terms of aggressivity, the treatments, namely, pearl millet (45 cm × 10 cm) + groundnut (1:1) (0.35), pearl millet (30 cm × 10 cm) + groundnut (2:2) (0.22) and pearl millet (60 cm × 10 cm) + groundnut (1:1) (0.21) showed that pearl millet was more aggressive than groundnut. This implies that pearl millet was the dominant crop, and groundnut was dominated within the mentioned combinations. However, in pearl millet (30 cm × 10 cm) + groundnut (1:1), pearl millet (45 cm × 10 cm) + groundnut (1:2) (0.24), pearl millet (60 cm × 10 cm) + groundnut (1:2) (0.28) and pearl millet (60 cm × 10 cm) + groundnut (1:3) (0.39) treatments, groundnut was more aggressive than pearl millet. There is equal competition between pearl millet and groundnut; however, the proportion and planting geometry made the difference. These findings are consistent with previous research results (6, 41, 45).

Table 5. Yield and harvesting index of pearl millet and groundnut as influenced by intercropping.

Treatments	Grain/pod yield (kg ha^{-1})		Stover/haulm yield (kg ha^{-1})		Harvest index (%)	
	PM	GN	PM	GN	PM	GN
Pearl millet sole (45 cm × 10 cm)	2677 ^{a}	--	5289 ^{a}	--	33.6 ^{ab}	--
Groundnut sole (30 cm × 10 cm)	--	2633 ^{a}	--	4102 ^{b}	--	44.0 ^{a}
Pearl millet (45 cm × 10 cm) + groundnut (1:1)	2255 ^{b}	1945 ^{bc}	5037 ^{ab}	3238 ^{c}	33.4 ^{ab}	47.1 ^{a}
Pearl millet (45 cm x 10 cm) + groundnut (1:2)	1804 ^{cd}	1811 ^{c}	4126 ^{c}	3975 ^{b}	30.4 ^{bcd}	31.3 ^{cd}
Pearl millet (30 cm × 10 cm) + groundnut (1:1)	1875 ^{c}	1842 ^{c}	4892 ^{b}	4987 ^{a}	27.7 ^{d}	27.0 ^{de}
Pearl millet (30 cm x 10 cm) + groundnut (2:2)	1690 ^{d}	1310 ^{d}	4065 ^{c}	2241 ^{e}	29.4 ^{cd}	37.0 ^{b}
Pearl millet (60 cm × 10 cm) + groundnut (1:1)	1710 ^{d}	1422 ^{d}	3874 ^{c}	2662 ^{d}	30.6 ^{bcd}	34.8 ^{bc}
Pearl millet (60 cm × 10 cm) + groundnut (1:2)	1794 ^{cd}	2048 ^{b}	3219 ^{d}	3460 ^{c}	35.8 ^{a}	33.6 ^{bc}
Pearl millet (60 cm × 10 cm) + groundnut (1:3)	1424 ^{e}	1380 ^{d}	2984 ^{d}	3842 ^{b}	32.3 ^{bc}	26.4 ^{e}
S.Em. ±	68.28	67.42	169.01	132.32	1.16	1.54
C.D. (p=0.05)	207.09	204.50	512.63	401.36	3.50	4.67
C.V. (%)	6.21	6.49	6.99	6.43	6.32	7.59

PM=Pearl millet; GN=Groundnut

The highest combined K value was registered in pearl millet (30 cm × 10 cm)+ groundnut (1:1) (12.23), indicating greater yield advantage over other treatments. It was followed by pearl millet (45 cm × 10 cm) + groundnut (1:2) (8.04) and pearl millet (45 cm × 10 cm)+ Groundnut (1:1) (6.57), both of which were greater than unity, indicating the benefits of the mixed stand. Similar results were reported in earlier research (35, 41, 45).

The data on competitive ratio (CR) found that among all the intercropping systems, the CR of pearl millet was greater than unity for some treatments, namely, pearl millet (45 cm × 10 cm) + groundnut (1:1) (1.14), pearl millet (60 cm × 10 cm) + groundnut (1:1) (1.18), pearl millet (60 cm × 10 cm) + groundnut (1:3) (1.01) and (30 cm × 10 cm)+ groundnut (1:1) (1.0) indicated that pearl millet was more competitive than groundnut. In the experiment, both crops exhibited competitiveness based on their proportions and planting geometry. Earlier, (35, 41, 46–48) reported similar findings in their research.

The highest monetary advantage was registered in the treatment pearl millet (30 cm × 10 cm) + groundnut (1:1) (Rs. 58741 ha^{-1}), followed by pearl millet (45 cm × 10 cm)+ groundnut (1:2) (Rs. 49579 ha^{-1}), pearl millet (45 cm × 10 cm) + groundnut (1:1) (Rs. 38086 ha^{-1}), pearl millet (60 cm × 10 cm) + groundnut (1:2) (Rs.31847 ha^{-1}) and pearl millet (60 cm × 10 cm) + groundnut (1:3) (Rs. 16122 ha^{-1}). These treatments were found to be advantageous, while two intercropped treatments recorded negative values, indicating they were disadvantageous. The results confirm the findings of the previous research (47).

Regression analysis for correlation of growth attributes on yield of pearl millet and groundnut

The regression analysis for the correlation between dry matter accumulation and leaf area index over the grain yield of pearl millet and pod yield of groundnut are depicted in Fig. 2A and B and Fig. 3A and B, respectively. The regression analysis of dry matter accumulation and leaf area index of pearl millet showed a strong correlation with grain yield, with mean R^2 value of 0.81 and 0.72, respectively. However, the dry matter accumulation and leaf area index of groundnut were found to be moderately to weekly correlated, with mean R^2 value of 0.62 and 0.28, respectively. The weak correlation in groundnut with mentioned yield attributes was likely due to differences in plant population among the treatments, which might have influenced the yield (13).

Conclusion

The study revealed that intercropping pearl millet with groundnut can significantly increase productivity per unit area, even though yield of sole cropping of pearl millet and groundnut yielded more as individual crops. The calculation of different competitive functions clearly indicates the superiority of intercropping system over pure stands. In conclusion, under the conditions of South Odisha, it is recommended to intercrop pearl millet and groundnut with a 1:1 row proportion, using a pearl millet spacing of 30 cm × 10 cm, to optimize resource utilization and achieve higher total productivity.

Table 6. Land equivalent ratio, area time equivalent ratio and aggressivity of pearl millet-groundnut intercropping system.

Treatments	Land equivalent ratio (LER)			Area time equivalent ratio (ATER)	Aggressively	
	PM	GN	Total		PM	GN
Pearl millet (45 cm × 10 cm) + groundnut (1:1)	0.84	0.49	1.33	1.12	0.35	-0.35
Pearl millet (45 cm × 10 cm) + groundnut (1:2)	0.67	0.91	1.59	1.42	-0.24	0.24
Pearl millet (30 cm ×10 cm) + groundnut (1:1)	1.05	0.7	1.75	1.49	0.35	0.35
Pearl millet (30 cm × 10 cm) + groundnut (2:2)	0.63	0.5	0.99	0.97	0.22	-0.22
Pearl millet (60 cm × 10 cm) + groundnut (1:1)	0.48	0.27	0.96	0.63	0.21	-0.21
Pearl millet (60 cm × 10 cm) + groundnut (1:2)	0.5	0.78	1.28	1.15	-0.28	0.28
Pearl millet (60 cm × 10 cm) + groundnut (1:3)	0.4	0.79	1.19	1.09	-0.39	0.39

PM=Pearl millet; GN=Groundnut

Table 6. Land equivalent ratio, area time equivalent ratio and aggressivity of pearl millet-groundnut intercropping system.

Treatments	Aggressivity		Relative crowding coefficient			Competitive ratio		Monetary advantage (Rs ha^{-1})
	PM	GN	PM	GN	Product (K)	PM	GN	
Pearl millet (45 cm × 10 cm) + groundnut (1:1)	0.35	-0.35	3.52	1.87	6.57	1.14	0.88	38086
Pearl millet (45 cm × 10 cm) + groundnut (1:2)	-0.24	0.24	2.74	2.93	8.04	0.98	1.02	49579
Pearl millet (30 cm × 10 cm) + groundnut (1:1)	0.35	0.35	3.5	3.49	12.23	1.00	1.00	58741
Pearl millet (30 cm × 10 cm) + groundnut (2:2)	0.22	-0.22	0.64	0.37	0.24	0.85	1.18	-1071
Pearl millet (60 cm × 10 cm) + groundnut (1:1)	0.21	-0.21	0.66	0.44	0.29	1.18	0.85	-4496
Pearl millet (60 cm × 10 cm) + groundnut (1:2)	-0.28	0.28	1.52	2.63	4	0.86	1.16	31847
Pearl millet (60 cm ×10 cm) + groundnut (1:3)	-0.39	0.39	1.28	1.24	1.58	1.01	0.99	16122

PM=Pearl millet; GN=Groundnut

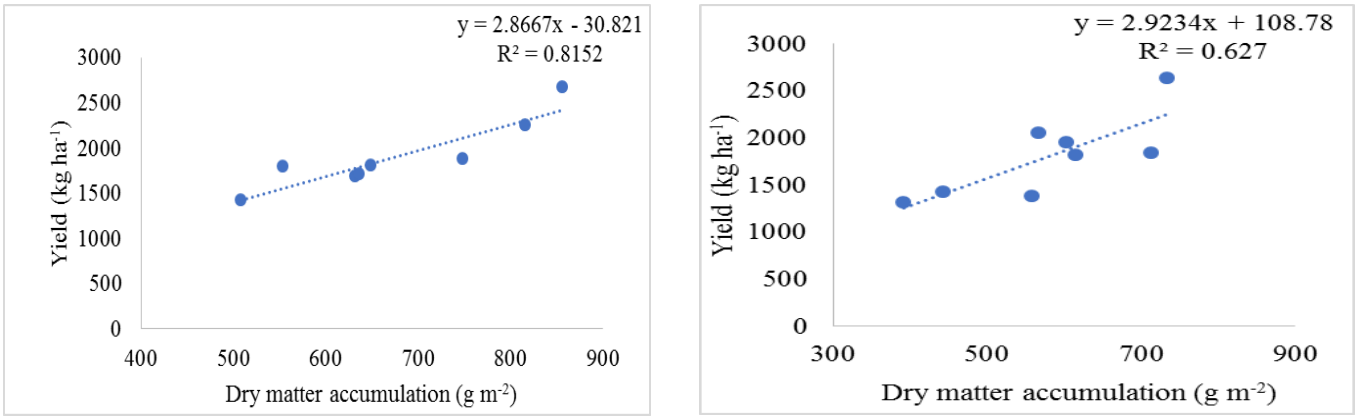

Figure 2. Regression analysis of (A) dry matter accumulation and (B) leaf area index over yield of pearl millet.

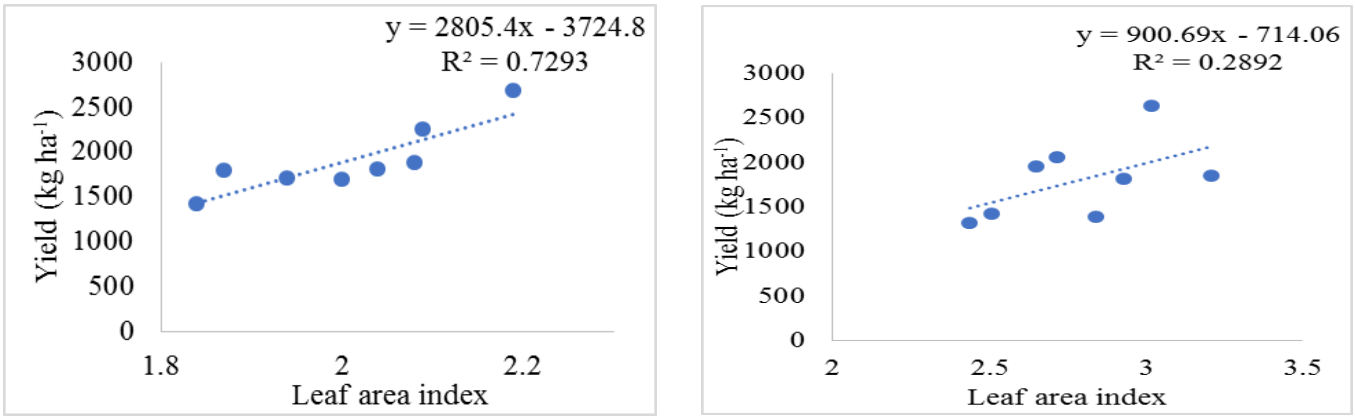

Figure 3. Regression analysis of (A) dry matter accumulation and (B) leaf area index over yield of groundnut.

Acknowledgements

The authors would like to express their gratitude to the authorities of Centurion University of Technology and Management for providing the necessary facilities and support for conducting this research.

Authors' contributions

SP and SM carried out the field experiment and manuscript writing, TS contributed in manuscript making, and MS performed the statistical analysis and sequence analysis. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest.

Ethical issues : None

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