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RESEARCH PAPER

Optimizing growth and yield of pigeonpea under late-sown conditions through land configuration and foliar nutrition

ANILA ALEX[1], S. B. PATIL[1*], R. A. NANDAGAVI[1] AND M. S. SHIRAHTTI[2]

[1]Department of Agronomy, [2]Department of Agril. Engineering, College of Agriculture, Vijayapura
University of Agricultural Sciences, Dharwad - 580 005, India
*E-mail: patilsb13617@uasd.in

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Abstract: A field experiment was conducted during *kharif* 2023 at the AICRP for Dryland Agriculture, Regional Agriculture Research Station, Vijayapura, Karnataka, to study the influence of land configuration and foliar nutrition on the growth, yield and economics of pigeonpea under late-sown conditions. The experiment was laid out in a split-plot design, with three land configurations assigned to the main plot: broad bed and furrow (BBF), conservation furrow (CF) and flatbed (FB) and five foliar spray treatments to subplots: 2% urea, 1% KNO_3, 1% 19:19:19, 0.4% nano-DAP, and control (water spray). Foliar sprays were applied during the P_4 (flowering initiation) and P_5 (50% podding) stages. Among the treatments, BBF in combination with 1% KNO_3 sprays consistently recorded superior performance, resulting in 15-20% higher grain yield over the control. This treatment also produced the highest stalk yield (3833 kg ha^{-1}), biological yield (5129 kg ha^{-1}), grain weight per plant (52.7 g $plant^{-1}$), and number of pods per plant (111). Improved growth attributes, such as taller plants, more primary and secondary branches, contributed to enhanced yield components. The benefits of BBF were attributed to improved soil moisture conservation,while potassium (K) through KNO_3 sprays enhanced stomatal regulation and prevention of water loss, enabling efficient dry matter partitioning to leaves, stems and reproductive parts under late-sown moisture-stressed conditions. Correlation studies between growth and yield revealed that plant height (r=0.58*) and the number of secondary branches (r=0.86**) had significant positive associations with seed yield. Economic analysis indicated that BBF with 1% KNO_3foliar sprayresulted inthe highest net returns (₹ 67,376 ha^{-1}) and benefit-cost ratio (2.21). The study highlights the importance of adopting BBF coupled with foliar sprays of KNO_3 as an effective drought-proofing strategy to enhance productivity and profitability of late-sown pigeonpea in dryland regions.

Key words: Broad bed furrow, Conservation furrow, Foliar spray, Moisture conservation, Potassium nitrate

Introduction

Drought, representing a water shortage relative to normal conditions, is among the natural disasters that cause heavy agricultural losses. Water, an essential element of cell protoplasm, plays a crucial role in sustaining all life on Earth. However, periodic climatic shifts limit water accessibility, adversely deteriorating plant growth and crop yields by affecting physiological processes such as osmotic adjustment, photosynthesis, transpiration and carbon metabolism. Legume crops are commonly grown in rainfed regions, are particularly susceptible to drought.Various climate models predict an increase in the frequency and intensity of drought, indicating a growing threat of water scarcity.

Pigeonpea [*Cajanus cajan* (L.) Millsp.], also known as red gram / arhar / tur, originated in Africa and is a highly drought-tolerant, deep-rooted crop belonging to the Leguminaceae family. One hundred grams of dry pigeonpea seeds contain 343 calories, 21.70g, 15g of fiber and 0.58mg of isoflavone. Additionally, they contain 456 µg folate, 1392 mg of potassium, along with copper, iron, manganese, phosphorus, selenium, calcium and zinc. India has done well over the years in achieving food security. Given the nutritional value of pigeonpea, it should form a larger portion of our diet to ensure both food and nutritional security.

Soil-related constraints that exacerbate drought stress include crusting, compaction, low water infiltration, low water retention capacity, high surface runoff and high losses due to soil evaporation (Lal, 2008). To sustain crop production in a rainfed system, conserving rainwater and promoting its efficient recycling is imperative. The monsoon season is often marked by high rainfall intensity and erosivity, combined with faulty cultural practices leading to high soil and water losses and hence, loss of productivity. Therefore, there is an urgent need to manage the water resources of Vertisols through the adoption of improved land management practices,such asbroad bed and furrow (Kamdi *et al.,*2023), conservation furrow which can help to reduce runoff and concurrently improve crop yields. Previous studies have consistently demonstrated the advantages of adopting improved land configurations such as the broad bed and furrow (BBF) system in pigeonpea cultivation. Rathore *et al.* (2010) reported that BBF improves soil physical conditions by enhancing aeration, reducing surface compaction, and thereby facilitating greater water infiltration and retention. Similarly, Kantwa *et al.* (2005) observed that BBF significantly improved yield attributes such as the number of pods and seeds per plant compared to flatbed planting. Supporting these findings, Sutar *et al.* (2020) also emphasized that BBF produced markedly higher seed yields over flatbed planting, and its performance was comparable with the ridges and furrow system. They further noted that the ridges and furrow method was superior to flatbed planting but slightly less effective than BBF. Collectively, these studies highlight that the choice of land configuration plays a crucial role in improving soil moisture availability, crop growth and yield, particularly in rainfed and moisture-stressed environments. Foliar spraying facilitates quick and efficient nutrient absorption through the stomata or leaf cuticle, allowing nutrients to enter the plant cells directly (Latha and Nadanassababady, 2003). Foliar application is most effective when root absorption is limited due to some reasons like the high degree of fixation, lack of soil moisture, losses from leaching and low soil temperature (Singh *et al.,* 1970). Pigeonpea, being a photo-thermosensitive crop, tends to shorten its vegetative growth period when sown late, which may lead toinsufficient biomass accumulation to support reproductive growth. Foliar sprays of micronutrients such as KNO_3 (Asewar *et al.,* 2017), DAP (Venkatesh *et al.,* 2023), 19:19:19 (Manjunatha *et al.,* 2022) and urea (Dewangan *et al.,* 2017) have been shown to aid in nutrient translocation and reduce plant stress under late-sown conditions.

Pigeonpea's phenological plasticity, favourable minimum support price (MSP) and ability to perform well under delayed sowing make it a reliable contingent crop, especially under challenging climatic conditions. Optimizing land configuration along with appropriate nutrient management can significantly improve input use efficiency, soil moisture, maximum rainfall in filtration, minimum erosion, minimum total run off, good drainage, timely harvest and value addition. Considering these aspects, the present experiment was conducted at the Regional Agriculture research station, Vijayapura, to evaluate the effects of land configuration and foliar nutrient application on growth, yield, and economics of pigeonpea under late conditions.

Material and methods

A field experiment was conducted during *kharif* 2023-24 at the AICRP for Dryland Agriculture, Regional Agriculture Research Station, Vijayapura, Karnataka, to evaluate the influence of land configuration and foliar nutrient sprays on pigeonpea under rainfed conditions. The experiment was carried out on medium-deep black soil (Vertisol) with apH of 8.03 and EC of 0.36 dSm^{-1}. The soil was medium in organic carbon content (0.51%), low in available nitrogen (180.50 kg ha^{-1}), medium in available phosphorus (32.26 kg P_2O_5 ha^{-1}) and high in available potassium (403.70 kg K_2O ha^{-1}). During the cropping period (July 2023 to February 2024), a rainfall of 245 mm was received in 21 rainy days. The highest maximum air temperature was recorded in May (38.2°C), while the lowest maximum temperature occurred in December (29.5°C). The lower minimum temperature ranged from a low of 12.4°C in January to a high of 21.7°C in May.

The experiment was laid out in a split-plot design with three replications. The main plot treatments consisted of three land configurations: broad bed and furrow (BBF), conservation furrow (CF), and flat bed (FB) and five foliar sprays to subplots: 2% Urea, 1% KNO_3, 0.4% nano-DAP, 1% 19:19:19 and a control treatment (water spray). The BBF system was established at the time of sowing with a bed width of 1.8 m and a furrow width of 45 cm. CF were created 30 days after sowing, after every two rows of the crop. Foliar sprays were applied at two critical phenological stages: P_4 (Initiation of flowering) and P_6 (50% podding). Phenological events,*viz.,* P_3 (Initiation of secondary branch), P_5 (50% flowering), P_6 (50% podding) and P_7 (Physiological maturity) were recorded by visual observation on tagged five plants per replication from each plot. One intercultural operation was carried out at 45 DAS to conserve soil moisture and provide favourable conditions for plant growth.

Five plants were randomly tagged in each net plot to record biometric observations at various growth stages. Data on plant height (in cm), number of branches arising from the main stem (primary branches) and from the primary branches (secondary branches) were measured at fourstages: Initiation of secondary branches (P_3), 50 per cent flowering (P_5), 50 per cent podding (P_6) and Physiological maturity (P_7).

At harvest, all plants within the net plot area were cut atground level and collected. The harvested biomass was sun-dried completely and the total produce from the respective plot was weighed just before threshing to record pod weight and biological yield. Thereafter, threshing was done manually by beating with wooden sticks to take the seed yield. The harvest index (HI) was calculated using the formula suggested by Donald (1962).

$$HI= \frac{\text{Economic yield (Kg ha}^{-1})}{\text{Biological yield (Kg ha}^{-1})} \times 100$$

The economics of each treatment were calculated based on prevailing market prices of the corresponding year. The yield was further computed for gross and net returns as well as the benefit-cost ratio (BCR) to assess the profitability. The BCR was worked out by dividing the gross returns by the total cost of cultivation of the respective treatments.

The data was subjected to statistical analysis as per the analysis of various (ANOVA) techniques described by Gomez and Gomez (1984). Summary tables for treatment effect have been prepared and furnished with standard error of means (S.Em±) and critical difference (C.D.) at a 5 percent level of probability (p=0.05) and whether the treatment differences were significant or not. The statistical analysis tool, R-studio, was used for correlation coefficient (r) calculation. The significance (probability) of the correlation coefficient was determined from the t-statistic at 5% and 1% probability.

Results and discussion

Growth attributes in pigeonpea

A significant increase in plant height and the number of branches in pigeonpea was observed when sown on the broad bed and furrow (BBF) system (Table 1). Plant height is largely a turgor-driven process and cell elongation is one of the first physiological processes affected by moisture stress. Therefore, BBF, owing to the better moisture conservation, has assured moisture availability for this process to take place and hence, plants grown on BBF had significantly longer plant height (106.15 cm) at the physiological maturity stage in comparison to conservation furrow (L_2, 98.25 cm) and flatbed (95.44 cm).

Table 1. Growth and yield attributes of pigeonpea as influenced by land configuration and foliar nutrition.

Treatments	Growth attributes			Yield attributes	
	Plant height (cm)	Primary branches per plant	Secondary branches per plant	Total number of pods	Grain weight per plant (g)
Land configuration (L)					
L_1: Broad bed and furrow	106.15	13.35	18.51	104.59	44.4
L_2: Conservation furrow	98.25	12.48	17.11	99.97	41.4
L_3: Flatbed	95.44	11.57	14.60	92.90	40.3
S.Em±	1.90	0.2	0.42	1.60	0.8
C.D. (p=0.05)	7.47	0.78	1.66	6.27	3.0
Foliar spray (F)					
F_1: Control	95.08	12.43	14.53	93.22	37.9
F_2: 2% Urea	98.32	12.91	15.72	98.72	40.8
F_3: 1% KNO_3	104.14	13.22	20.06	104.67	46.9
F_4: 1% 19:19:19	99.43	11.82	17.29	99.61	43.4
F_5: 0.4% nano-DAP	102.76	11.94	16.09	99.53	41.3
S.Em±	1.67	0.65	0.40	1.70	0.7
C.D. (p=0.05)	4.88	NS	1.17	4.96	2.1
Interactions (L x F)					
L_1F_1	95.00	14.33	17.03	101.67	39.0
L_1F_2	102.13	14.33	16.90	102.83	41.2
L_1F_3	116.10	15.33	23.67	111.00	52.7
L_1F_4	103.83	12.07	17.80	103.33	45.0
L_1F_5	113.67	10.67	17.13	104.10	44.2
L_2F_1	95.50	13.67	13.90	98.00	36.7
L_2F_2	97.67	12.23	16.20	102.67	40.8
L_2F_3	99.67	11.67	19.87	100.67	45.3
L_2F_4	99.17	12.13	18.53	97.17	43.0
L_2F_5	99.27	12.7	17.03	101.33	41.3
L_3F_1	94.73	9.3	12.67	80.00	38.0
L_3F_2	95.17	12.17	14.07	90.67	40.2
L_3F_3	96.67	12.67	16.63	102.33	42.7
L_3F_4	95.30	11.27	15.53	98.33	42.3
L_3F_5	95.33	12.47	14.10	93.17	38.3
S.Em±	3.21	1.03	0.75	3.08	1.4
C.D. (p=0.05)	8.45	NS	2.03	8.59	3.7

Likewise, a significantly greater number of primary branches per plant (7.87, 11.69, 12.31, and 13.35) and secondary branches (4.90, 15.71, 16.96 and 18.51) were exhibited by broad bed and furrow (BBF) sown pigeonpea at all the recorded stages.

Among the foliar sprays, 1% KNO_3 produced the tallest plants at 50% flowering, 50% podding and physiological maturity (100.40, 102.01 and 104.14 cm, respectively), which was statistically on par with the treatment 0.4% nano-DAP (99.39, 101.42 and 102.76 cm, respectively) and 1% 19:19:19 (96.02, 97.99 and 99.43 cm, respectively). However, 2% urea (94.94, 97.00, and 98.32 cm, respectively) and control (91.83, 94.11, and 95.08 cm, respectively) treatments noted shorter plant heights in all three stages and were at par. Foliar sprays failed to give any significant difference in the number of primary branches per plant, but the largest number of primaries was recorded in 2% urea treatment (11.53) at 50% flowering and by 1% KNO_3 at 50% podding (12.50) and physiological maturity (13.22). Whereas, the number of secondary branches per plant differed significantly with respect to different foliar nutrition, with 1% KNO_3 recording a statistically higher number of secondary branches per plant (17.50, 18.01 and 20.06, respectively) at 50% flowering, 50% podding and physiological maturity phenophases.

The interaction between land configuration and foliar sprays had a significant impact on plant height through all phenological stages. Pigeonpea on a broad bed furrow with foliar sprays of 1% KNO_3 and 0.4% nano-DAP recorded more plant height. Although foliar sprays did not significantly influence the number of primary branches, the number of secondary branches was higher in BBF with 1% KNO_3 treatment combination (23.67). A higher number of primary and secondary in BBF with 1% KNO_3treatment over control (8.80, 12.67, respectively) has increased the photosynthetic capacity of the plant, contributing to adequate sources, which provided the sink with enough assimilates under late sown conditions.These findings are in line with the results of Krishnaprabu (2019) in pigeonpea. Foliar application of micronutrients and water-soluble fertilizers is encouraged to boost the vegetative growth under stress and help the plant supply photosynthates to the reproductive part and compensate for the possible yield losses. Potassium (K) supplied through 1% KNO_3 mitigates the adverse consequences of drought stress by regulating the physio-biochemical characteristics, such as activating enzymes, osmoregulation, and membrane transport in cotton (Zahoor

Table 2. Yield and yield related attributes of pigeonpea as influenced by land configuration and foliar nutrition.

Treatments	Yield (kg ha^{-1})			
	Seed	Stalk yield	Biological	Harvest Index (%)
Land configuration (L)				
L_1: Broad bed and furrow	1150	3122	4272	27.15
L_2: Conservation furrow	1031	2641	3672	28.02
L_3: Flatbed	929	2256	3184	30.2
S.Em±	30	85	106	0.59
C.D. (p=0.05)	117	334	417	2.31
Foliar spray (F)				
F_1: Control	876	1890	2765	31.93
F_2: 2% Urea	976	2461	3437	28.87
F_3: 1% KNO_3	1208	3323	4531	26.83
F_4: 1% 19:19:19	1108	3027	4135	27.8
F_5: 0.4% nano-DAP	1015	2664	3679	26.86
S.Em±	31	95	106	0.87
C.D. (p=0.05)	91	276	310	2.54
Interactions (L x F)				
L_1F_1	1100	2391	3491	31.39
L_1F_2	1135	3123	4258	26.71
L_1F_3	1296	3833	5129	25.27
L_1F_4	1137	3133	4270	25.76
L_1F_5	1083	3130	4213	26.62
L_2F_1	837	2112	2948	27.05
L_2F_2	1027	2325	3352	30.83
L_2F_3	1165	3103	4268	27.5
L_2F_4	1100	3015	4115	27.94
L_2F_5	1025	2652	3677	26.79
L_3F_1	690	1167	1857	37.34
L_3F_2	767	1933	2700	29.06
L_3F_3	1163	3033	4197	27.71
L_3F_4	1087	2933	4020	29.7
L_3F_5	937	2212	3148	27.17
S.Em±	57	169	196	1.47
C.D. (p=0.05)	158	478	536	4.4

Table 3. Economics of pigeonpea as influenced by land configuration and foliar nutrition.

Treatments	Cost of cultivation (₹ ha^{-1})	Gross returns (₹ ha^{-1})	Net returns (₹ ha^{-1})	Benefit -cost ratio
Landconfiguration (L)				
L_1: Broadbedandfurrow	30,176	86,840	56,663	1.88
L_2: Conservationfurrow	30,096	77,820	47,724	1.58
L_3: Flatbed	29,696	70,119	40,423	1.36
S.Em±	-	2,254	2,254	0.08
C.D. (p=0.05)	-	8,848	8,848	0.30
Foliar spray(F)				
F_1: Control	29,367	66,104	36,737	1.25
F_2: 2% Urea	29,408	73,705	44,296	1.50
F_3: 1% KNO3	30,285	91,212	60,927	2.01
F_4: 1% 19:19:19	29,877	83,645	53,767	1.80
F_5: 0.4%nano-DAP	31,011	76,633	45,621	1.47
S.Em±	-	2,364	2,364	0.08
C.D. (p=0.05)	-	6,901	6,901	0.23
Interactions(LxF)				
L_1F_1	29,554	83,050	53,496	1.81
L_1F_2	29,595	85,693	56,097	1.90
L_1F_3	30,472	97,848	67,376	2.21
L_1F_4	30,064	85,816	55,752	1.85
L_1F_5	31,198	81,792	50,594	1.62
L_2F_1	29,474	63,168	33,694	1.14
L_2F_2	29,515	77,539	48,023	1.63
L_2F_3	30,392	87,958	57,566	1.89
L_2F_4	29,984	83,050	53,066	1.77
L_2F_5	31,118	77,388	46,270	1.49
L_3F_1	29,074	52,095	23,021	0.79
L_3F_2	29,115	57,883	28,768	0.99
L_3F_3	29,992	87,832	57,840	1.93
L_3F_4	29,584	82,069	52,485	1.77
L_3F_5	30,718	70,718	40,000	1.30
S.Em±	-	4,301	4,301	0.14
C.D. (p=0.05)	-	11,953	11,953	0.40

et al., 2017), corn (Matok *et al.,* 2022), rice (Weng *et al.,* 2007), and oilseed (Farahani *et al.,* 2019). The balance of source production and sink utilization of carbon is tightly coordinated through an integrated signal network in which hormones, sugar, and environmental cues converge to regulate developmental and stress adaptive processes (Ruan, 2014). The photosynthetic capacity of leaves and stems during vegetative growth determines plant productivity through its translocation to the reproductive parts. Similar findings were confirmed by Pandey *et al.*(2018) in blackgram.

Yield attributes of pigeonpea

Among the land configurations, BBF out performed other land configurations in the number of pods per plant (104.59), seed weight per plant (44.4 g), straw yield (3122 kg ha^{-1}), biological yield (4272 kg ha^{-1}) and seed yield (1150 kg ha^{-1}). Likewise, 1% KNO_3 gave a higher value in the yield and associated parameters, which was on par with 1% 19:19:19 (Table 2).Growth parameters, *viz.,* plant height, number of primary and secondary branches, total dry matter production, and its distribution in the different plant parts, might have contributed to the higher biological yield value.

There was a notable and statistically significant increase in yield and yield-related parameters, like the number of pods per plant (111), seed weight per plant (52.7 g), straw yield (3833 kg ha^{-1}), biological yield (5129 kg ha^{-1}) and seed yield (1296 kg ha^{-1}) in 1% $KNO_3$with the BBF treatment combination. Potassium nitrate (KNO_3) is a powerful growth stimulant for plants, enhancing photosynthetic pigments and lowering oxidative stress and sodium (Na^+) uptake in plants under water deficit and salt stress (Fayez and Baizaid, 2014). Potassium as an ideal participant in mitigating stress was confirmed in the works of Kumawat *et al.*(2025) in mungbean and Khalequzzaman *et al.*(2024) in cotton. Delaying leaf senescence increases seed yield due to the maintenance of carbon assimilation. This was the major principle behind the use of land configuration and foliar sprays that helped to extend the life of the crop under drought stress. Potassium triggers the closing of stomata and preserves the water inside the cells. These factors ensured the crop was supplied with KNO_3 and 19:19:19 to produce enough photosynthates and a stronger sink, thus enabling the plant to survive under stress and give better seed yield and yield

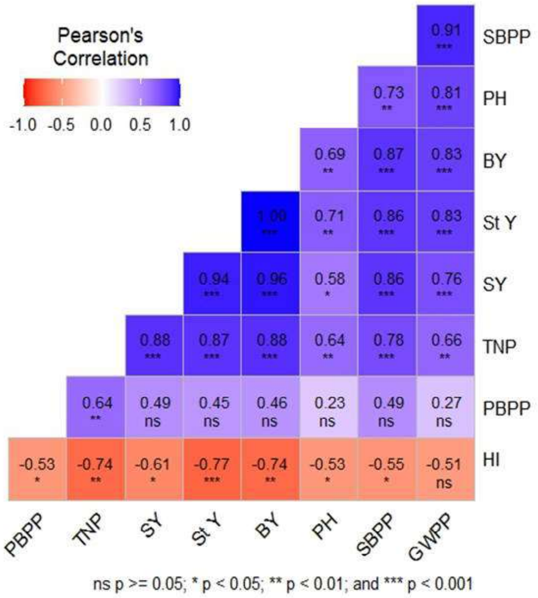

Fig 1. Correlogram between growth and yield parameters of pigeonpea

parameters.These findings align with a prior study by Devaranavadagi *et al.*(2023) and Tripathi *et al.* (2017) in pigeonpea.

Economics of pigeonpea production systems

In the present study, the cost of cultivation was higher in the case of broad bed and furrow (₹ 30176 ha^{-1}), followed by conservation furrow (₹ 30096 ha^{-1}) and flatbed (₹ 29696 ha^{-1}). There was a significant difference in gross returns, net returns, and BC ratio among the cultivars. KNO_3 @1% recorded a higher gross returns (₹ 91212 ha^{-1}), net returns (₹ 60927 ha^{-1}) and BC ratio (2.01). This was significantly followed by 1% 19:19:19 (₹ 83645 ha^{-1}, ₹ 53767 ha$^{-1,}$ and 1.80) in gross, net returns and BCR. Drought proofing through broad bed and furrow (BBF) with 1% KNO_3 spray at 2 stages of pigeonpea, namely, initiation of flowering (P_4) and 50% podding (P_6) stages, has procured a higher gross return (₹ 97848 ha^{-1}) and net return (₹ 67376 ha^{-1}). Economic analysis also confirms a higher BCR under BBF with 1% KNO_3 spray (2.33), followed by BBF with 1% 19:19:19 (1.92), which was on par with BBF with 2% urea spray (1.92). As per the current package of practices (POP) recommendation, it is 2% urea. Our experiment clearly denotes that making a broad bed and furrow instead of a flat bed with a 1% KNO_3 spray at the initiation of flowering and 50% podding stages can procure an additional yield of 12-13%. Optimum moisture conservation and quick utilization of the foliar nutrients at the critical growth stages have ensured higher net returns and BCR with the BBF and 1% KNO_3 treatment combination.

Correlation studies

The correlation coefficient obtained for growth parameters (plant height, primary branch, secondary branch) and yield and yield related parameters (total number of pods, grain weight per plant, seed yield, stalk yield, biological yield and harvest index) of pigeonpea are represented in the correlogram (Fig. 1). Plant height exhibits a highly significant and positive correlation with grain weight per plant (r=0.81**) and seed yield (r=0.58*), indicating taller plants tend to produce more and heavier seeds.Total number of pods per plant shows a strong positive correlation with the seed yield (r=0.88**), stalk yield (0.87**), and seed weight per plant (r=0.66*),suggesting a crucial relationship between pod production and seed characteristics and overall yield. The strong correlation between stalk yield and seed yield (r=1.000**) emphasizes the direct influence of stalk (source) on overall seed yield (sink). The positive correlations identified between various traits provide valuable insights for targeted breeding programs aimed at improving yield and seed traits in pigeonpea. These findings are consistent with a prior study by Pundalik (2022) on pigeonpea.

Conclusion

From the present investigation, it can be concluded that crop sown on BBF significantly improved the growth of pigeonpea, particularly in terms of plant height and branching, compared to conservation furrow and flat bed and it decreased significantly in flatbed sowing, respectively, at physiological maturity during the period of experimentation. The important yield attributes *viz.,* number of pods per plant and seed weight per plant was recorded highest in 1% spray, followed by 1% 19:19:19 and 0.4% nano-DAP, respectively. Among the interactions, sowing on BBF with 1% KNO_3 at critical stages recorded significantly higher seed yield, stalk yield and biological yield. Even though late sowing of pigeonpea fetched very low yield and economics in comparison to the normal-sown crop, drought-proofing technologies such as those used in this study could ensure a yield improvement of 10-20%.

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