LR-5365
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RESEARCH ARTICLE

Legume Research- An International Journal

Transforming Rainfed Pigeonpea Cultivation in India: The Impact of Complete Mechanization on Growth, Productivity and Energy Indices

A.V. Ramanjaneyulu[1], D. Sravanthi[2], D. Swetha[3],
N. Sainath[4], D. Srinivasa Chary[5], P. Rajaiah[6]

10.18805/LR-5365

ABSTRACT

Background: Pigeonpea is a leguminous, long duration and wide spaced crop. Performing labour intensive, agronomic operations timely from land preparation to post harvest is expensive since rural to urban migration has become a major problem. There is a dire need to evaluate the effects of complete mechanization and suggest options for reducing cost of production, augment the productivity, profitability and energy use efficiency in pigeonpea.

Methods: A large plot experiment was conducted in pigeonpea for two years (*kharif* 2019-20 and 2020-21) under rainfed conditions in an alfisol with two treatments *viz.,* Conventional practices (CPs) and Mechanization practices (MPs). The recorded data was analysed through a two sample t-test for statistical significance. It was carried out at Agricultural Research Station, Tornala, Professor Jayashankar Telangana State Agricultural University, Hyderabad, India.

Result: Mechanization practices (1362 kg ha^{-1}) have increased the pigeonpea seed yield by 16.51% over conventional practices (1169 kg ha^{-1}) besides saving 42.5 man-days and 67.5 hours ha^{-1}. MPs have not only reduced the total cost by Rs. 6,745 ha^{-1}, but also enhanced the net returns by Rs. 18,225 ha^{-1}. Higher infiltration rate, net energy and energy output efficiency over CPs helped substantiate the results.

Key words: Energy, Man days, Mechanization, Pigeonpea, Yield.

INTRODUCTION

Pigeon pea {*Cajanus cajan* (L.)} is an important multipurpose pulse and food legume crop grown in tropical and sub tropical regions of Asia, Latin America, Eastern and Southern Africa. India is the world leader with an area of 4.90 M ha and production of 4.22 MT accounting for 81% and 90% of global area and production, but with low productivity of 861 kg ha^{-1} (FAO, 2022). Pigeonpea is an unique jewel in rainfed environments due to it's propensity to thrive in fragile environments. Approximately 90% of it's growing area is under rainfed conditions in India. Timely execution of agronomic operations is very crucial in rainfed environments to overcome the problems of short sowing window, extremities of monsoon and quantitative and qualitative harvest time losses. Analogous to any other crop, the pigeonpea production in India is threatened by scarcity and escalating labour cost especially during critical agronomic operations. Among many practices influencing yield (Sajjan, 2018), lack of mechanization is one of the main limitations for obtaining higher productivity of pigeonpea in India. Additionally, the proportion of agricultural labour to the total workforce in the country is anticipated to come down from 55% in 2011 to 25.7% by 2050 (FAO, 2022). Low mechanization index (MI) in pigeonpea (12.78%) as compared to that of wheat (40.77%), chickpea, mustard and soybean (26.4-32.5%) and pearlmillet (23.4%), low and wide variation in MI from 6.0% in Assam to 45.0% in Punjab (Chouhan and Singh, 2014) in India is a matter of concern. Traditional way of pigeonpea cultivation demands

[1]AICRP on Agroforestry, Professor Jayashankar Telangana State Agricultural University, Hyderabad-500 030, Telangana, India.
[2]Agricultural College, Professor Jayashankar Telangana State Agricultural University, Aswaraopet, Khammam-507 301, Telangana, India.
[3]Agricultural Research Station, Professor Jayashankar Telangana State Agricultural University, Tornala, Siddipet-502 114, Telangana, India.
[4]Regional Agricultural Research Station, Professor Jayashankar Telangana State Agricultural University, Jagtial-505 529, Telangana, India.
[5]College of Agriculture, Professor Jayashankar Telangana State Agricultural University, Rajendranagar, Hyderabad-500 030, Telangana India.
[6]AICRP on Farm Implements and Machinery, Professor Jayashankar Telangana State Agricultural University, Hyderabad-500 030, Telangana, India.

Corresponding Author: A.V. Ramanjaneyulu, AICRP on Agroforestry, Professor Jayashankar Telangana State Agricultural University, Hyderabad-500 030, Telangana, India.
Email: anumularaman2022@gmail.com
Orcid: https://orcid.org/0000-0001-5567-6639

How to cite this article: Ramanjaneyulu, A.V., Sravanthi, D., Swetha, D., Sainath, N., Chary, D.S. and Rajaiah, P. (2024). Transforming Rainfed Pigeonpea Cultivation in India: The Impact of Complete Mechanization on Growth, Productivity and Energy Indices. Legume Research. 1-6. doi: 10.18805/LR-5365.

Submitted: 16-06-2024 **Accepted:** 13-11-2024 **Online**: 11-12-2024

maximum human resources requiring ample time. Under rainfed situation, 10-15% yield reduction is observed if the sowing is delayed by one week and harvesting/threshing are not taken up timely. This situation necessitated the farmers to move slowly towards mechanization. In India, improved agricultural tools and equipment are estimated to contribute food production by saving in seeds (15-20%), fertilizers (15-20%), time (20-30%) and labour (20-30%) besides reducing planting cost (42-44%), increasing the cropping intensity (5-20%) and productivity (10-15%) in various crops (Singh *et al.,* 2012; Korwar *et al.,* 2012). Despite multiple benefits of mechanization, the agronomic package for complete mechanization in pigeonpea is under-researched. Hence, the present study in alfisols was executed to evaluate the complete mechanization and it's impact on yield, profitability and energy use pattern, in pigeonpea under rainfed conditions in alfisols.

MATERIALS AND METHODS

Site characterization

An experiment was conducted during *kharif* season of 2019-20 and 2020-21, at Agricultural Research Station, Tornala, Professor Jayashankar Telangana State Agricultural University (PJTSAU), Telangana state, India, to quantify the impact of complete mechanization on productivity, profitability and energy indices of rainfed pigeonpea. The experimental site was sandy clay loam in texture, near neutral in pH (6.6) with EC of 0.33 dS m^{-1} (non-saline), low in organic carbon (0.42%) and available N (235.6 kg ha^{-1}), medium in available phosphorus (24.2 kg ha^{-1}) and potash (210 kg ha^{-1}).

Experimental details

The experiment was laid out with two treatments *viz.,* M1: conventional practices (CPs) and M2: mechanization practices (MPs) each in 0.2 ha area. Each treatment block (100 m×20 m) was divided into ten equal sub plots *i.e.* replicates after leaving the border rows on either side, for ease of replicated sampling and data recording.

The farmer preferred and adopted practices included under CPs were sowing by manual dibbling, line weeding with *khurpi*, harvesting, threshing, stubble collection, heaping and burning manually, while intercultivation with cattle drawn blade and spraying of plant protection chemicals with battery operated knapsack sprayer. Similarly, machine tested and proven practices included under MPs were sowing with seed cum ferti drill, intercultivation with tractor drawn twin cultivator in the initial stages (45 DAS) and power tiller (7 HP) in the later stage depending on the need, intra row line weeding with hand held weed scraper, spraying with motorized power sprayer for plant protection, ridge and furrow formation with tractor drawn ridger for overcoming low or excess moisture stress, harvesting with paddy combiner (Kubota) and stubble incorporation with rotary mulcher (Machio company).

Agronomic practices and data management

The pigeonpea seeds (7.5 kg ha^{-1}) were sown at a spacing of 120 cm×15 cm on 21-7-2019 during the first year and 02-07-2020 in the second year. WRGE-97, a mid early, moderately resistant to fusarium wilt, drought tolerant and high yielding (12-15 q ha^{-1}) variety released in 2019 from PJTSAU, Telangana was used in the experiment. The seeds were treated with *Trichoderma viride* (10 g kg^{-1}), followed by carbendazim (1.0 g kg^{-1}), before sowing. Further, gap filling and thinning were carried out at 15 days after sowing (DAS). The crop was raised completely rainfed during both the years. The entire recommended fertilizer dose of 20-50-0 kg N:P_2O_5:K_2O ha^{-1} was applied as basal. A pre-emergence herbicide Pendimethalin (1.0 kg a.i. ha^{-1}) was sprayed a day after sowing in the presence of moisture. Further, chlorantraniliprole 18.5% W/W (0.3 ml lit^{-1}) against *Maruca vitrata* during flowering to pod formation stage and spinosad 45% SC (0.3 ml lit^{-1}) against *Helicoverpa armigera* and *Spodoptera litura* during pod development stage, were sprayed once. An amount of 771.1 mm and 1156.9 mm in 50 rainy days each (an average of 964.0 mm) against 614.1 mm and 613.6 mm (an average of 613.85) was received during crop growth period in 2019 and 2020, respectively.

The data on growth and yield traits were recorded duly following standard procedures. The seed yield recorded from each replicate was converted into kg ha^{-1}. The infiltration rate from each treatment was worked out using a double ring infiltrometer. The operation wise time and labour requirements were computed from time to time during the crop growth period. The energy indices were computed using the formulae given below (Rafiee *et al*., 2010) and energy was expressed in MJ ha^{-1}.

Energy input

Summation of energy equivalents for all agronomic operations starting from land preparation to marketing in pigeonpea .

Energy output

Summation of energy equivalents for seed and stalks of pigeonpea.

$$\text{Net energy} = \text{Energy output} - \text{Energy input}$$

$$\text{Energy productivity} = \frac{\text{Seed cotton yield}}{\text{Energy input}}$$

$$\text{Energy ratio (energy use efficiency)} = \frac{\text{Energy output}}{\text{Energy input}}$$

$$\text{Energy profitability (PE)} = \frac{\text{Net energy return}}{\text{Input energy}}$$

$$\text{Energy output efficiency (EOE)} = \frac{\text{Energy output}}{\text{Duration of the system}}$$

$$\text{Specific energy (energy intensity)} = \frac{\text{Energy input}}{\text{Seed cotton yield}}$$

Finally, the replicated data were analyzed through two-sample t-test using SPSS 20.0 software. Further, the significance at 1% level and 5% level was considered when t-calculated value was more than or equal to t-table value and otherwise it was considered as non-significant.

RESULTS AND DISCUSSION

Growth and yield traits and yield

The plant height and no. of branches plant^{-1} were significantly affected by conventional and mechanization practices at 1% level of significance (Table 1). Significantly taller plants (1.95 m) with more no. of branches plant^{-1} (20.6) were registered with CPs than MPs (1.73 m, 18.6).

The MPs and CPs showed significant effect on seed index and yield of pigeonpea at 1% level of significance (Table 1). Pigeonpea under MPs has produced significantly higher seed yield (1362 kg ha^{-1}), stalk yield (1664 kg ha^{-1}) and biological yield (3023 kg ha^{-1}) than that of CPs (1169, 1465 and 2634 kg ha^{-1}), respectively. This could be ascribed to relatively more no. of pods and significantly higher seed index under MPs over CPs. Further, placement of seed at optimal depth in moist zone in the soil when sown with seed cum ferti drill might have facilitated better germination, establishment and production of better yield traits in mechanization. In the current study, mechanical intercultivation has helped in loosening the soil, uprooting and exposing the weeds finally leading to their death. Additionally, it has provided better soil physical conditions for better aeration, increased infiltration (Fig 1) and moisture storage due to breakage of soil crust. Further, intra row weeding with hand held weed scraper is faster, beneficial, less tedious and economical than traditional methods. Furthermore, use of paddy combiner facilitated in faster and simultaneous mechanical harvesting/threshing. The results of this study were found to be in line with that of Patil and Basavaraja (2018) who reported 52.5% higher yield in pigeonpea in mechanized farms than non-mechanized farms. Korwar *et al.* (2012) reported 24% saving in seed and 30% less fertilizer with the use of mechanized sowing operation using precision planter in pigeonpea.

Man-days and time requirement

MPs consumed only 52.5 man-days and 102.5 hours ha^{-1} against 95 man-days and 170 hours ha^{-1} in conventional practices indicating a saving of 42.5 man-days and 67.5 hours ha^{-1} with mechanization (Table 2). More man-days were required for harvesting and threshing followed by weed management and plant protection measures. Use of seed cum ferti drill helped in reducing the man days by 75%

Table 1: Effect of mechanization on growth, yield traits, yield and economics of rainfed pigeonpea (Pooled data of *kharif* 2019-20 and 2020-21).

Treatment	Plant height (m)	No. of branches Plant^{-1}	No. of pods Plant^{-1}	Seed index (g)	Seed yield (kg ha^{-1})	Stalk yield (kg ha^{-1})	Biological yield (kg ha^{-1})	Cost of cultivation (Rs ha^{-1})	Gross returns (Rs ha^{-1})	Net returns (ha^{-1})	B:C ratio
CPs	1.95	20.6	265.5	11.9	1169	1465	2634	53947	69047	15100	1.32
MPs	1.73	18.6	286.5	12.2	1362	1664	3023	47202	80524	33325	1.73
t-cal value	6.174**	3.045**	-1.275$^{¥}$	-2.133*	-4.760**	-4.193**	-5.144**	2.633*	-4.904**	-5.006**	-4.411**
Probability	0.000	0.004	0.211	0.040	0.000	0.000	0.000	0.013	0.000	0.000	0.000

Market price: Rs. 58 kg^{-1} (2019); Rs. 60 kg^{-1} (2020); Average: Rs. 59 kg^{-1}.

**indicates significant at 1%; * indicates significant at 5%; $^{¥}$ indicates non-significant.

Note: t-table value at 5% level is 2.0322 and 1% level 2.7284.

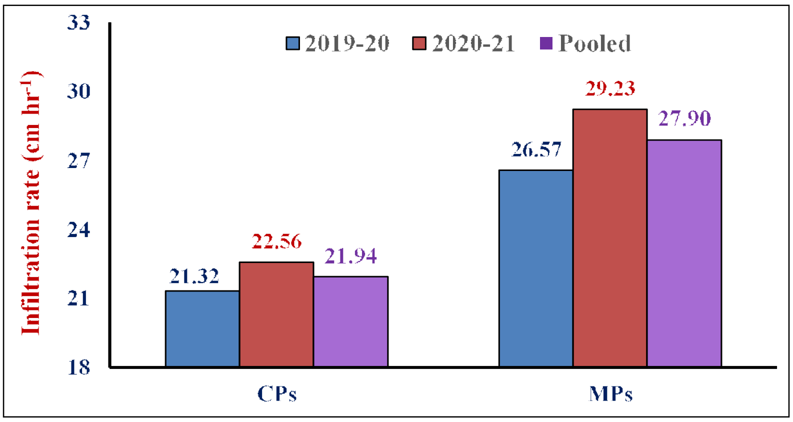

Fig 1: Impact of CPs and MPs on soil water infiltration in pigeonpea (*kharif* 2019-20 and 2020-21).

besides placing the seeds at optimum soil depth than the traditional approach. Singh *et al.* (2012) suggested use of either bed planter or 6-row inclined plate planter for planting pigeonpea for promising results. Korwar *et al.* (2012) recommended precision planter cum herbicide applicator for various rainfed crops for precise and simultaneous sowing cum fertilizer and herbicide application. Further, this approach also helps in completion of sowing over a larger area during a short sowing window, before the soil moisture is exhausted in rainfed crop ecosystem (Kumar *et al.,* 2020).

In manual method, application of fertilizers followed by seed sowing were done 'behind the plough' duly involving cattle pair and 10 labour which took 15 hours ha^{-1} to complete the operation. But, in mechanized sowing with seed cum ferti drill, seeding and fertilizer application were done in a single operation with minimal man-days (2.5 ha^{-1}) and time (5.0 hours ha^{-1}) thus reducing the man days and workforce by 75% and 66.7%, respectively over CPs.

In addition to exhausting the soil moisture, nutrients and aeration, weeds hinder the harvesting process and lower the quality of the seed (Kumar *et al.,* 2023). Hence, timely weed control especially during critical period of crop weed competition (45-60 DAS) is utmost important. Machine aided interculture and intra row weeding helped to save 10 man-days (44.4%) and 12.5 hours time ha^{-1} (27.8%) in the present study (Table 2). Further, the plant protection with motorized power sprayer reduced the time requirement by 37.5% over that of knapsack sprayers. Tractor operated boom sprayers will be of great use in large pigeonpea fields for expedite coverage. Now a days, the use of drones is becoming popular for plant protection in view of their quick, precise and uniform coverage, in relatively larger areas. It takes only 0.83 hours ha^{-1} with drone against 7.5 hours ha^{-1} with battery sprayer and 4.25 hours ha^{-1} with motorized power sprayer, besides saving 90% water requirement (Ramanjaneyulu *et al.,* 2021).

The pigeonpea is a tall growing thick woody stem plant with multiple branches. Traditional way of harvesting with sickle by human labour is laborious, risky, tedious and sometimes injurious to the labour. Harvesting early at high moisture content increases the drying cost and delaying the harvesting leads to yield loss due to shattering, birds/ rodents damage, pests and diseases. Further, threshing is again a laborious process requiring beating the sticks against hard surface followed by drying in the sun. Prolonged storage of harvested material may be affected by high humidity, frost or untimely rains leading to impairment of seed quality (Benaseer *et al.,* 2018). In the current investigation, use of paddy combiner which does both the harvesting and threshing in single operation could reduce the man-days by 25.0 (90.9%) and time by 26.25 hours ha^{-1} (87.5%). Kumar *et al.* (2019) suggested 26.61 m s^{-1} and 2.0 kmph as optimum values for peripheral velocity and forward speed for running the paddy combiner to reduce damage to the seed, less processing and shattering losses besides higher threshing efficiency in pigeonpea. Further, Lohan *et al*. (2007) suggested for use of lower cylinder speed and high concave clearance in rasp bar and spike tooth threshing cylinders due to less seed damage. Wallis *et al.* (1981) in Australia and Fiji and Gupta (1990) in India have successfully demonstrated paddy combiner and wheat combiner for mechanized harvesting and threshing of short and extra early short duration varieties of pigeonpea, respectively.

Regarding residue management, the stalks were heaped and burnt as a part of CPs. On the contrary, in MPs, rotary mulcher was run over the remaining stalks in the field which resulted in tiny pieces followed by incorporation during subsequent tillage operations. This technique has the potential to improve the soil fertility, porosity and regulating other physical soil properties like hydraulic conductivity and bulk density (Senthil Kumar and Thilagam, 2015). Additionally, residue recycling of N fixing leguminous

Table 2: Effect of mechanization on man days and time requirement of rainfed pigeonpea (Pooled data of *kharif* 2019-20 and 2020-21).

Particulars	Man-days				Time			
	CPs		MPs		CPs		MPs	
	No. ha^{-1}	%	No. ha^{-1}	%	Hours ha^{-1}	%	Hours ha^{-1}	%
Land preparation	2.5	2.63	2.5	4.76	12.5	7.35	12.5	12.20
Layout and land configuration	5.0	5.26	5.0	9.52	15.0	8.82	7.5.0	7.32
Sowing, seed treatment and fertilizer application	10.0	10.53	2.5	4.76	15.0	8.82	5.0	4.88
Thinning/gap filling	5.0	5.26	5.0	9.52	7.5	4.41	7.5	7.32
Weed management	22.5	23.68	12.5	23.81	45.0	26.47	32.5	31.71
Plant protection	17.5	18.42	17.5	33.33	30.0	17.65	18.75	18.29
Harvesting and threshing	27.5	28.95	2.5	4.76	30.0	17.65	3.75	3.66
Post harvest management	5.0	5.26	5.0	9.52	15.0	8.82	15.0	14.63
Total	95		52.5		170		102.5	
Saving due to MPs	42.5				67.5			

CPs: Conventional practices; MPs: Mechanization practices crop like pigeonpea not only supports soil conservation but also sustains long term crop productivity and subsequently lowers the reliance on synthetic inputs (Devaraj and Isaac, 2023).

Economics

The economic returns were found to be significant at 1% and cost of cultivation at 5% level of significance (Table 1). Adoption of MPs (Rs. 47,202 ha^{-1}) have not only reduced the cost of cultivation by 12.5%, but also accrued higher gross returns (Rs. 80,524 ha^{-1}) by 16.6% and net returns (Rs. 33,325 ha^{-1}) by 120.7% besides higher B:C ratio (1.73) over CPs (Rs. 53,947, 69,047, 15,100 ha^{-1}, 1.32). It was mainly owing to reduced cost of about Rs. 6,750 ha^{-1} (Table 1) due to saving of 45 man-days ha^{-1} under MPs (Table 2). Further, the conventional methods require more no. of workers for performing same operations, higher wage rate and less operational efficiency than mechanical methods. Earlier, Patil and Basavaraja (2018) reported significant reduction in man-days but higher net returns in mechanized farms than non-mechanized in pigeon pea.

Energy indices

All the energy indices were influenced at 1% level but net energy at 5% level of significance (Table 3). MPs have significantly dominated the CPs for energy input, energy output, net energy and energy output efficiency. Conversely, significantly higher energy productivity, energy ratio and energy profitability with CPs over MPs. This was because MPs required 50.7% higher energy but produced only 16.3% higher energy output following less significant improvement in yield *i.e.* 16.5% higher seed yield only over CPs. It means less seed yield per unit energy consumed in MPs.

Table 3: Effect of mechanization on energy indices of rainfed pigeonpea (Pooled data of *kharif* 2019-20 and 2020-21).

Treatment	Energy input (MJ ha^{-1})	Energy output (Seed) (MJ ha^{-1})	Energy output (Stalks) (MJ ha^{-1})	Energy output total (MJ ha^{-1})	Net energy (MJ ha^{-1})	Energy productivity (MJ ha^{-1})	Energy ratio (MJ ha^{-1})	Energy profitability (MJ ha^{-1})	Specific energy (MJ ha^{-1})	Energy output efficiency (MJ day^{-1})
CPs	9487	17185	15983	33168	23682	0.2817	3.573	2.573	4.785	207.3
MPs	14300	20025	18540	38565	24267	0.2132	2.721	1.721	6.387	241.0
t-cal value	-13.478**	-4.760**	-2.977**	-3.917**	-0.362*	5.645**	3.969**	3.969**	-3.580**	-3.915**
Probability	0.000	0.000	0.005	0.000	0.720	0.000	0.000	0.000	0.001	0.000

**indicates significant at 1%.

* indicates significant at 5%* indicates non-significant.

Note: t-table value at 5% level is 2.0322 and 1% level 2.7284.

CONCLUSION

According to the findings of this research study, mechanization can be recommended in pigeonpea for timely completion of various agronomic operations and also realization of enhanced soil water infiltration. The seed yield increase by 16.5%, greater saving in man-days and time, besides reducing the total cost of cultivation by 12.5% and enhancing the net income by 120.7% over conventional approach substantiate the experimental hypothesis.

ACKNOWLEDGEMENT

The present study was supported by Professor Jayashankar Telangana State Agricultural University, Hyderabad, Telangana, India.

Disclaimers

The views and conclusions expressed in this article are solely those of the authors and do not necessarily represent the views of their affiliated institutions. The authors are responsible for the accuracy and completeness of the information provided, but do not accept any liability for any direct or indirect losses resulting from the use of this content.

Informed consent

All animal procedures for experiments were approved by the Committee of Experimental Animal care and handling techniques were approved by the University of Animal Care Committee.

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this article. No funding or sponsorship influenced the design of the study, data collection, analysis, decision to publish, or preparation of the manuscript.

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