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Research Paper

Agronomic interventions for enhanced light interception and radiation use efficiency in hybrid pigeon pea

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ABSTRACT

To find out the best agronomic management options for realising optimum plant expression and yield of hybrid pigeon pea. The field investigation was conducted at International Crops Research Institute For Semiarid tropics, Hyderabad during the *kharif* 2021 and 2022. The objective was to analyze the impact of various establishment methods, plant geometries, and nutrient management techniques on hybrid pigeon pea, using a split-split plot design. The study employed a line quantum sensor to measure amount of light interception, photosynthetically active radiation at the stage of maximum leaf area development, and subsequently calculated radiation use efficiency. Heat maps showed that transplanted plot recorded 13.9% higher mean photosynthetically active radiation (PAR) over dibbling. Whereas, in plant geometry factor 120 cm × 120 cm recorded 10.6% higher mean PAR over 150 cm × 60 cm but which was on par with 100 cm × 100 cm. However, square transplanting at 100 cm × 100 cm combined with an integrated nutrient management approach (Vermicompost 5 t/ha, 100% (or) 150% soil test based NPK, PSB, and seed treatment with *Rhizobium*) resulted in the higher mean seed radiation use efficiency which was (44.2% and 31.5%) higher respectively than with inorganic nutrient management alone (100% and 150% soil test based NPK). The optimal agronomic technique for increased pigeon pea yield was determined to be transplanting of pigeon pea at 100 cm × 100 cm and implementing integrated nutrient management, which includes seed treatment with *Rhizobium*, soil test-based NPK, vermicompost @ 5 t/ha, and PSB.

Key words: Heat maps, Nutrient management, % light interception, Pigeon pea, Planting methods, Radiation use efficiency, Square geometry

Pigeon pea, primarily consumed in the form of split pulse (dal) inspite having huge demand the area under cultivation (4.54 M ha) and the average national productivity very low (729 kg/ha) (Directorate of Economics and Statistics, GOI 2022). In recent years, because of changes in monsoon patterns, farmers find it difficult to sow pigeon pea within the optimal planting window (*i.e.* June 01-July 15). Owing to photosensitivity, early flowering occurs regardless of the exact sowing time. Consequently, these plants have restricted source development (Susithra *et al*., 2019; Gowda *et al*., 2022). As a substitute for traditional dibbling techniques, the idea of transplanting emerged to address the problem of source-sink imbalances. Nevertheless, it was found that traditional crop geometry, such as 150 × 30 cm, caused a great deal of interplant competition, which in turn caused low plant expression and increased flower drop because of inadequate air circulation, among other issues (Pradeep *et al*., 2018; Tiwari and Namrata, 2020). Therefore, the plant geometry was taken into consideration as a second factor in order to prevent these difficulties. Higher number of primary, secondary, and tertiary branches may develop when employing the square planting technique, which promotes maximum leaf area development. The spacing between crop rows and inter rows (plants) was equal. A broad leaf area combined with this branching character makes for ideal circumstances for excellent light interception. The production of food materials and their effective distribution to the economically impor-

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tant parts of the plant are facilitated (Mallikarjun and Hulihalli, 2015). The first commercial hybrid pigeon pea (ICPH 2740) in Telangana state on the name of "*Mannem Konda Kandi"* was released in 2015 (Saxena *et al*., 2016).

The intention of this study was to determine how planting technique affects radiation interception, which works in conjunction with ideal plant geometry and appropriate nutrient management techniques to achieve high radiation use efficiency. The investigation's hypothesis was that planting techniques, planting geometry, and nutrient management will have an impact on the hybrid pigeon pea's efficiency in light interception, radiation use efficiency and yield.

MATERIALS AND METHODS

During the rainy season (*kharif*) of 2021 and 2022, a field study was conducted at the ICRISAT, Hyderabad. About 998.4 mm and 1000 mm rainfall was received in 2021 and 2022, respectively which is almost equals to average rainfall (906 mm) of the region. The experimental soil was clay in treatment. Prior to the experimentation, the soil study showed that the amount of available nutrients were 231.1 kg N/ha, 29.8 kg P_2O_5/ha, and 350.5 kg K_2O/ha. A split-split plot design was used to manage the field investigation with following treatments. Main factor consists of dibbling; transplanting, sub factor (planting geometry) contains 100 × 100 cm; 120 × 120 cm; 150 × 60 cm, sub-sub factor (nutrient management) control; 100% STB NPK (25:37.5:8.5 kg/ha); 100% STB NPK + vermicompost + PSB + seed treatment with *Rhizobium*; 150% STB NPK; 150% STB NPK + vermicompost + PSB + seed treatment with *Rhizobium*. Both transplanting and dibbling of the main plot treatments were done on the same day. The seedlings were raised in protrays in advance and dibbling and transplanting was done on same day (20th June and 23th June during *kharif* 2021 and 2022, respectively).

In order to calculate the leaf area, plants from each plot designated for destructive sampling were chosen, and the leaf area of these plants was measured. Using a leaf area meter (Li-COR, Lincoln, Nebraska, USA), the leaf area measurements were taken at 135 days after sowing (DAS), and the results were expressed as cm^2/plant. The same day, a line quantum sensor was used to detect the interception of photosynthetically active radiation (PAR). The sensor was positioned on top to record the entire amount of radiation that entered. The sensor was placed near the base of the plant's surface in order to record both the reflected and diffused radiation from the plant. The following formula was used to determine the percentage of radiation interception based on the data that was gathered (Soujanya *et al*., 2023).

$$Percent\ radiation\ interception = 100 - \frac{(bottom\ PAR\ reading \times 100)}{Top\ PAR\ reading}$$

To calculate the radiation use efficiency (%), the total incoming seasonal radiation data was obtained from the meteorological observatory (Class-B) situated at ICRISAT. From the total radiation approximately 50% of the solar radiation was considered as PAR (Manoj *et al.,* 2019).

$$Radiation\ use\ efficiency\ = \frac{Plant\ dry\ matter\ (or)\ seed\ weight}{Cumulative\ incoming\ PAR\ per\ season} \times 100$$

In order to visualize the link between leaf area, % photosynthetically active radiation (PAR) interception, and radiation use efficiency under various agronomic techniques throughout the *kharif* season of 2021 and 2022, GraphPad Prism Version 9.5.1(733) was used to construct the heat map. The data for leaf area and % PAR interception were adjusted column-wise to guarantee accurate comparability. Setting the minimum value to 0% and the highest value to 100% was part of the normalization process. This made it possible for the data to be represented consistently on the heat map.

RESULTS AND DISCUSSCION

Two heat maps were created for the *kharif* season of 2021 and 2022, as shown in Fig. 1 and Fig. 2, respectively to facilitate easy and comprehensive comparison. Instead of presenting extensive data tables with multiple factors, heat map provides a visual representation of the data using a color gradient as a scale. In these heat maps, the left side column represents different treatment combinations, while the color intensity on the right side serves as a scale. The color gradient ranges from red, indicating higher values to violet, indicating lower values. The bottom of the heat maps represents eight parameters organized into different clusters, each represents by a color gradient illustrating

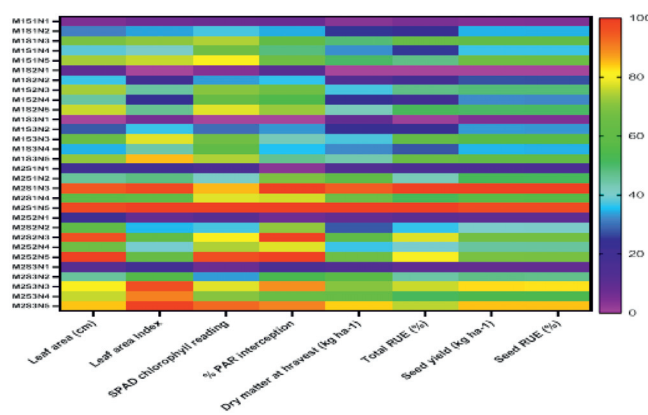

Fig. 1. Representation of leaf area, % PAR interception in relation to seed radiation use efficiency as influenced by agronomic practices by heat map during *kharif* 2021

M_1, Dibbling; M_2, Transplanting; S_1, 100 × 100 cm; S_2, 120 × 120 cm; S_3, 150 × 60 cm; N_1, Control; N_2, 100% STB NPK (25:37.5:8.5 kg/ha); N_3, 100% STB NPK + vermicompost + PSB + seed treatment with *Rhizobium*; N_4, 150% STB NPK; N_5, 150% STB NPK + vermicompost + PSB + seed treatment with *Rhizobium*

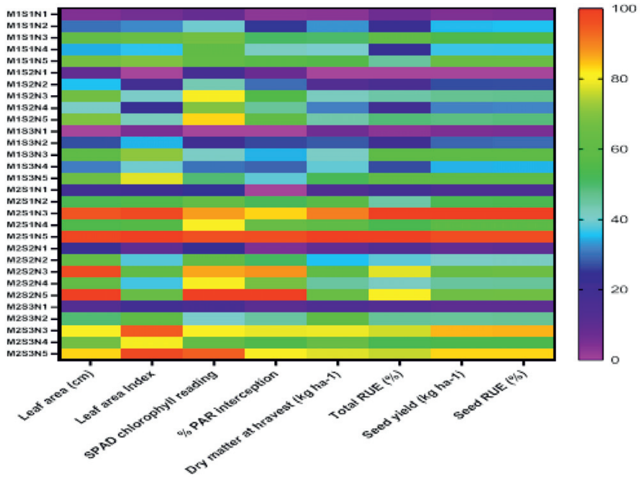

Fig. 2. Representation of leaf area, % PAR interception in relation to seed radiation use efficiency as influenced by agronomic practices by heat map during *kharif*, 2022

M_1, Dibbling; M_2, Transplanting; S_1, 100 × 100 cm; S_2, 120 × 120 cm; S_3, 150 × 60 cm; N_1, Control; N_2, 100% STB NPK (25:37.5: 8.5 kg/ha); N_3, 100% STB NPK + vermicompost + PSB + seed treatment with *Rhizobium*; N_4, 150% STB NPK; N_5, 150% STB NPK + vermicompost + PSB + seed treatment with *Rhizobium*

how these parameters were influenced by various agronomic practices (Stavridou *et al*., 2021). Analysis of the heat map reveals that the combination of transplanting with wider spacing (120 cm × 120 cm plant geometry) in conjunction with the application of 150 % STB NPK + vermicompost @ 5 t/ha + vermicompost enriched with PSB + seed treatment with *Rhizobium* resulted in higher mean leaf area per plant (34.9% higher depicted by the intensive red color) over transplanting with 100 cm × 100 cm in conjunction with organic nutrient approach. With transplanting edge effect from seedling stage makes higher root proliferation and various mineralogical process (Singh *et al*., 2020; Ransing and Tomar, 2022) leads to higher nutrient and minerals uptake accelerate higher photosynthetic leaf area development under organic approach (Mbuthia *et al*., 2015; Kumar *et al*., 2022).

However, when considering the leaf area index, it was observed that transplanting with wider spacing (120 cm × 120 cm plant geometry) in combination with 150 % STB NPK + vermicompost @ 5 t/ha + vermicompost enriched with PSB + seed treatment with *Rhizobium* resulted in a lower LAI compared (100 cm × 100 cm) mentioned earlier. Mani *et al.,* (2022) the increase in plant spacing did not proportionately increase the leaf area index. Leaf area serves as the site for photosynthates production (Yao *et al*., 2016) and a higher leaf area is generally associated with optimal light interception. Crop geometry should be planned to achieve an optimum plant structure with a greater number of primary, secondary and tertiary branches to avoid competition (Sannathimaappa *et al*., 2023). Achieving such plant expression and optimal light interception can be facilitated by implementing an integrated approach to nutrient management to meet the nutrient demands of the crop (Pandey *et al*., 2015; Pradeep *et al*., 2018). The key to increasing light usage efficiency per plant was improved morphology, which affected canopy shape, light interception, and eventually yield (Li and Wang, 2010). As hybrid pigeon pea with suitable plant geometry and nutrient supplement might improve long lasting nutrient, moisture availability and better soil conditions forces the compensate effect on light interception and biomass development despite of lower plant population (Garg *et al*., 2023).

Higher SPAD chlorophyll readings were observed with increased nutrient content and lower population density. However, comparatively lower values were seen with dibbling as opposed to transplanting. This difference can be attributed to the fact that transplanting involves the use of healthy and vigorously growing seedlings (Sannathimaappa *et al*., 2023), which have a greater capacity for nutrient uptake and consequently exhibit higher SPAD values (Karaman, 2023). In contrast, the fourth cluster exhibited higher % photosynthetically active radiation (PAR) interception in the 100 cm × 100 cm plant geometry, indicated by the intense red color. This pattern was also observed with the application of 150 % (or) 100 % STB NPK + vermicompost @ 5 t/ha + vermicompost enriched with PSB + seed treatment with *Rhizobium*. While higher leaf area per plant may contribute to increased light interception is ultimately influenced by the crop geometry (Sannathimaappa *et al*., 2023).

In the case of pigeon pea, being an indeterminate crop, the interception of photosynthetically active radiation depends on the number of secondary and tertiary branches

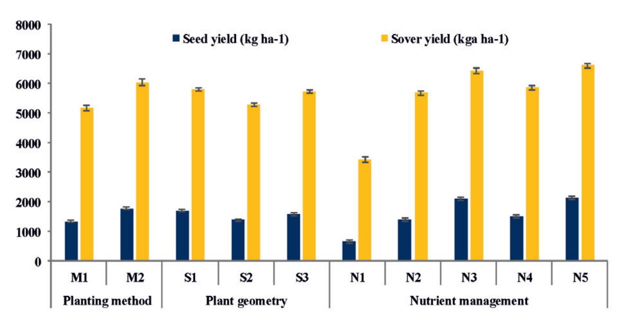

Fig. 3. Mean yield of hybrid pigeonpea influenced by agronomic practices

M_1, Dibbling; M_2, Transplanting; S_1, 100 × 100 cm; S_2, 120 × 120 cm; S_3, 150 × 60 cm N_1, Control; N_2, 100% STB NPK 25:37.5:8.5 kg/ha); N_3, 100% STB NPK + vermicompost + PSB + seed treatment with *Rhizobium*; N_4, 150% STB NPK; N_5, 150% STB NPK + vermicompost + PSB + seed treatment with *Rhizobium* and the leaf area index. The square planting system resulted in maximum leaf area development per plant (Ramanjaneyulu *et al*., 2017; Kaur and Saini, 2020), creating favourable conditions for maximum light interception (Kumar *et al*., 2021). However, although per plant leaf area and % PAR interception were higher with the 120 cm × 120 cm plant geometry, total dry matter production and total radiation use efficiency were higher with the 100 cm × 100 cm geometry when considering the nutrient combination on hectare basis. This indicates that the 100 cm × 100 cm square geometry facilitated optimal plant expression and maximum dry matter production, with effective utilization of plant nutrients and resources. For the vegetative growth, plant needs nitrogen this might supplied by biological nitrogen fixation coupled with vermicompost application ascribed the formation of a greater number of primary, secondary branches and leaf area development.

Fig. 1-3 that, transplanted plot recorded the mean seed yield 25.1% higher over dibbling, (Singh *et al*., 2018 and Dhandapani, 2023). Among the planting geometry treatments on hectare basis, it was found that 100 cm × 100 cm square plant geometry, recorded 18.6 % higher mean seed yield over 120 cm × 120 cm square plant geometry on hacter basis. It was observed that, compared to application of 100 % and 150 % STB NPK alone, integrated approach has recorded 31.5% and 29.5% higher mean seed yield respectively. Higher values were observed with a combination of three agronomic practices i.e., transplanting + 100 cm × 100 cm plant geometry + 100 % or 150% STB NPK + along with integrated approach (39.8% and 36.4% higher mean seed yield respectively over transplanting with 100 cm × 100 cm plant geometry + inorganic nutrient approach (100% and 150% STB NPK). Similarly the seed radiation use efficiency also influenced same manner like seed yield. Recommended dose of fertilizer, vermi-compost enriched with PSB resulted in initial nutrient available through chemical fertilizer, with enhanced fixed phosphorus availability through the action of PSB, from the vermicompost abundant and balanced availability of nutrients might leads positive impact on plant growth. Effective utilization of intercepted radiation is known to increase radiation use efficiency (De Biman *et al*., 2023; Yao *et al*., 2016) and the translocation of photosynthates from source to economic parts play a crucial role in this process (Manoj *et al*., 2012; Mallikarjun and Hulihalli,2015). Additionally, crop geometry provides an opportunity for better conversion of flowers into pods and facilitates effective seed filling through proper ventilation (Barla *et al*., 2018; Varatharajan *et al*., 2019; Kumar *et al*., 2021).

Thus, it can be concluded that the transplanting of hybrid pigeon pea at 100 cm × 100 cm supplemented with integrated nutrient management 100% soil test based NPK + 5 t/ha PSB enriched vermicompost and *Rhizobium* seed treatment is a suitable option for yield in hybrid pigeon pea.

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