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EFFECT OF PLANTING GEOMETRY OF CLONAL EUCALYPTUS (*EUCALYPTUS TERETICORNIS*) ON FODDER PRODUCTIVITY OF COWPEA AND TREE GROWTH DYNAMICS

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SUMMARY

The present study was carried out during the *kharif* season of 2019–20 at the Forestry Research Farm, CCS Haryana Agricultural University, Hisar, Haryana, India. The experimental site is geographically located at 29°092′ N latitude and 75°432′ E longitude, with an elevation of 215.2 m above mean sea level, and falls within the semi-arid agro-climatic zone of north-western India, to evaluate the effect of *Eucalyptus tereticornis* planting geometry on growth and fodder productivity of cowpea. The study included two geometries (4×2 m and 5×2 m) along with a control (without trees) under a randomized block design with seven replications. Forage crop cowpea was sown during *Kharif* season. Results indicated that wider spacing (5×2 m) significantly improved tree growth parameters such as height and DBH. Among tree-based systems, 5×2 m spacing performed better than 4×2 m. The study highlights the importance of optimum spacing in agroforestry systems for balancing tree growth and crop productivity. The standard package and practices as recommended by university were followed for raising of fodder cowpea crop. The fertilizer and irrigation requirements of trees were fulfilled from the irrigation and fertilizers application to the fodder crop. Growth measures of eucalyptus clone P-23 height and diameter at breast height (DBH) at the end of the cropping season. Tree growth increased with wider spacing. Maximum height (9.2 m) and GBH (25.7 cm) were recorded under 5×2 m spacing. The higher growth at wider spacing may be attributed to reduced intra-specific competition for light, water, and nutrients. The data indicates that 5m x 2m spacing is more appropriate spacing of clonal Eucalyptus plantation from productivity and practically fruitful aspect.

Key words: Planting geometry, agroforestry, cowpea, fodder productivity, DBH, semi-arid region

Rapid population growth has significantly increased the demand for timber and other forest-based products. This rising demand, coupled with agricultural expansion, urbanization, and industrial development, has placed tremendous pressure on natural forests. At the same time, sustaining soil productivity under continuous mono-cropping systems has become increasingly difficult. These challenges highlight the need for sustainable land-use practices such as agroforestry. Planting geometry in agroforestry refers to the spatial arrangement and spacing of trees in relation to agricultural crops and/or livestock within a given area of land. Agroforestry is an integrated land management system in which trees are deliberately combined with agricultural crops and/or livestock within the same production unit to enhance resource-use efficiency, productivity, environmental sustainability, and overall farm profitability. It blends traditional farming knowledge with modern management practices to enhance productivity, improve farm income, increase biodiversity, and promote ecological sustainability. In addition to ensuring diversified and continuous food production, agroforestry contributes to carbon sequestration, conservation of biodiversity, protection of soil and water resources, and reduction of deforestation. It also strengthens the resilience of smallholder farming systems against the adverse effects of climate change (Murthy *et al.*, 2013). According to Sobola *et al.* (2015), agroforestry serves as an effective strategy for mitigating deforestation, soil degradation, and other environmental concerns.

Recognizing its importance, India became the first country to introduce a National Agroforestry Policy (NAP) in 2014. A key objective of this policy is to encourage integrated cultivation of trees with crops and livestock to enhance agricultural productivity, generate employment opportunities, and improve farmers' livelihoods. Agroforestry systems currently occupy approximately 25.32 million hectares in India (Kumar *et al*., 2017). These systems vary considerably in their structure and composition across different agro-climatic regions, utilizing multipurpose tree species such as poplar, eucalyptus, teak, sal, and acacias according to regional suitability.

Among these species, eucalyptus has emerged as one of the most widely adopted exotic trees for spatial arrangement of tree because of its rapid growth, straight bole, short rotation period, high wood density, and superior timber yield. It is commonly planted along field boundaries and bunds, where it generally has minimal adverse effects on associated crops while providing substantial economic returns (Luna, 2009). Eucalyptus ranks second only to teak in plantation area under agroforestry systems in India. In states such as Haryana and Punjab, nearly 90% of the annual timber production originates from sustainably managed farm plantations rather than natural forests (Lal, 2010). Eucalyptus belongs to the family Myrtaceae and is native to Australia, Tasmania, and nearby islands. Globally, eucalyptus plantations cover more than 20 million hectares, particularly in tropical and subtropical regions. The introduction of genetically improved clonal planting material since 1992 has substantially enhanced plantation productivity and profitability. Commercial eucalyptus clones generally produce about 20-25 m^3/ha/year, while productivity as high as 50 m^3/ha/year has been achieved under rain fed conditions by progressive farmers (Lal, 2003, 2011). Consequently, clonal eucalyptus plantations have become an economically attractive option for both agroforestry and reforestation programmes. Agroforestry and farm forestry initiatives supported by the private sector have enabled thousands of farmers to establish approximately 8 million hectares of clonal eucalyptus plantations between 1992 and 2007 (Lal, 2015). Under current demand and market conditions, planting Eucalyptus provides a far better return on investment than alternative land uses (crop production and animal keeping) for the smallholder tree cultivators. It has a great role in minimizing the supply and demand gap of wood products and conserving soil and water as well as providing a greener landscape. Thus contributing significantly to the conservation of biodiversity-rich natural forests. Growing of tree is a popular tool to modify the microclimate under field conditions. Trees mainly modify radiations, relative humidity, carbon dioxide concentration, wind velocity and soil environment to crop (Dhillon *et al*., 2016). Growing of fodder crops under clonal eucalyptus an industrial plant will not only meet human being feed demand, but will also increase its availability during lean periods. Therefore, there is a great need to identify suitable fodder crop that can grow well along with tree plantations with limited solar energy available underneath the trees (Ranjan *et al*., 2016) Clonal eucalyptus (Safeda) has become one of the most important tree species in agroforestry because of its rapid growth, high wood productivity, and adaptability to different agro-climatic conditions. Among the commercially available clones, P-23 is recognized as a superior clone due to its fast growth, straight cylindrical stem, high wood volume, and good drought tolerance. It performs well in states such as Haryana and Punjab. The clone develops a deep and extensive root system that provides strong anchorage and efficient absorption of water and nutrients, although it also increases competition with intercrops as the trees mature. The crown of P-23 is moderately compact with fewer branches, allowing relatively better light penetration than many dense-canopy eucalyptus clones, making it suitable for agroforestry systems during the initial years of plantation. Fodder cowpea (*Vigna unguiculata*) is considered one of the most suitable intercrops with clonal eucalyptus during the early years of plantation. Being a leguminous crop, it fixes atmospheric nitrogen through symbiotic association with Rhizobium bacteria, thereby improving soil fertility and contributing to sustainable production systems. Cowpea also provides high-quality green fodder containing about 16-22% crude protein, suppresses weeds, protects the soil surface from erosion, and adds organic matter when crop residues are incorporated after harvest. Its moderate shade tolerance allows satisfactory growth under young eucalyptus plantations before complete canopy closure.

Overall, the combination of Eucalyptus clone P-23 and fodder cowpea represents a promising planting geometry system that integrates timber production with quality fodder, improves soil health through biological nitrogen fixation, and provides additional income to farmers during the early years of tree establishment. Proper spacing, pruning, irrigation, and nutrient management are essential for maximizing both tree growth and fodder productivity while ensuring the long-term sustainability of the production system.

During the lean period, there is a large gap between the demand and supply of fodder cowpea (*Vigna unguiculata*) is one of the better intercrops because it is a legume, fixes nitrogen, and tolerates partial shade better than many fodder crops. However, fodder yield will usually be lower under trees than in an open field due to shade and competition for water. Clonal eucalyptus helps households to become wood self-sufficient and provides considerable cash income. Most of the studies ranked Eucalyptus as the second major source of rural household income Moreover, the selection of more valuable clone to the local community, proper land use planning, extension support, and economic profitability assessment need to be considered for Eucalyptus plantations. In northern India farmers are cultivating different fodder crops under spacing's of different eucalyptus clones but the information on cultivation of cowpea crop under clonal eucalyptus (P-23) based plantation is lacking. Although the growing of inter crops with trees was started about a decade or so ago, no effort has been made so far to evaluate the effect of different spacing of clonal eucalyptus plantation on the performance and production of fodder crops. Plantation of clonal eucalyptus is one of the best options to increase the tree cover outside the forest. The need of growing tree with fodder crop has been necessitated in many parts of the country, which face several agricultural and ecological problems, predominant of which are soil degradation, large scale deforestation, increasing population pressure of human beings and livestock, and decreasing land: man ratio. Identification of suitable fodder crop under different planting geometry of clonal eucalyptus plantations is essential for maximizing fodder yield and enhancing overall system productivity to meet increasing fodder demands. Cowpea are important fast-growing kharif season fodder crop and constitute integral components of planting geometry. Optimizing planting geometry helps minimize competition for light, water, and nutrients, thereby sustaining both tree growth and crop fodder production.

MATERIALS AND METHODS

The present investigation was conducted during the *kharif* season 2019-20 at the Forestry Research Farm, CCS Haryana Agricultural University, Hisar. The experimental site was located at 29°102 N latitude and 75°432 E longitude, at an altitude of 215 m above mean sea level (MSL). The region falls under the semi-arid agro-climatic zone of north-western India and characterized by a subtropical monsoonal climate. The average annual rainfall ranges from 350 to 400 mm, of which nearly 70–80% is received during the southwest monsoon period (July to September). Summers are extremely hot, with maximum temperatures ranging from 40 to 45°C during May and June, whereas December and January are the coldest months of the year. Eucalyptus seedlings of clone P-23 were transplanted at two different planting geometries 4 m × 2 m and 5 m × 2 m, following a randomized block design during July 2018. Planting pits of approximately 30 cm × 30 cm × 30 cm were prepared and filled with a 3:1 mixture of soil and well-decomposed farmyard manure (FYM) before transplanting. Standard silvicultural practices, including replacement planting, irrigation, weed management, and plant protection measures, were carried out uniformly throughout the experimental period to ensure healthy tree establishment and growth.

Tree growth parameters were assessed periodically by recording tree height (m) and diameter at breast height (DBH, cm) using standard forestry measurement techniques. Tree height was measured from the ground level to the apical shoot using appropriate measuring equipment, while DBH was recorded at 1.37 m above ground level using a diameter tape. Fodder crop cowpea was sown during Kharif season. The recommended package of practices prescribed by the university was followed for raising the fodder cowpea crop. Irrigation and fertilizer applications provided to the intercrop also met the nutrient and water requirements of the eucalyptus trees. Growth attributes of cowpea *viz*., Plant height and stem diameter, leaf area, fresh fodder yield and B:C ratio were recorded from each plot by quadrant method (using a quadrant of 1 × 1 m). These measurements were used to evaluate the growth performance of Clone P-23 and fodder production of crop under the two planting geometries to assess their suitability for the growth and fodder productivity of cowpea

RESULTS AND DISCUSSION

Soil chemical properties of the experimental field

As shown in (Fig. 1), the soil chemical properties of the experimental field under clonal

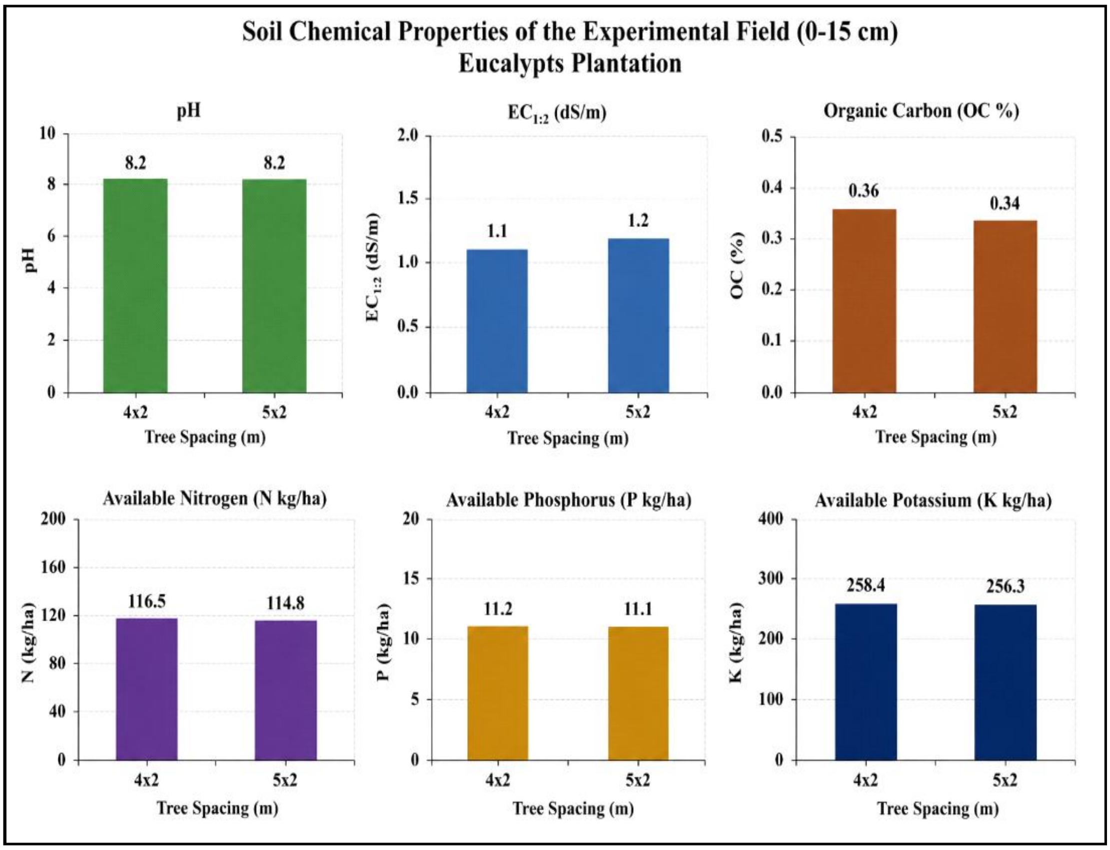


Fig. 1. Soil chemical properties of the experimental field.

Eucalyptus (P-23) plantation at planting geometries (4 m × 2 m and 5 m × 2 m) revealed slight variations in soil characteristics. The soil was alkaline in nature, with a uniform pH of 8.2 under both spacings. Electrical conductivity ($EC_{1:2}$) ranged from 1.1 to 1.2 dS m^{-1}, indicating slightly saline conditions, with marginally higher EC observed under the wider planting geometry (5 m × 2 m).

The organic carbon (OC) content varied from 0.34 to 0.36%, with slightly higher OC recorded under the closer spacing (4 m × 2 m), suggesting relatively greater organic matter accumulation. Available nitrogen content ranged from 114.8 to 116.5 kg ha^{-1}, showing marginally higher was recorded under 4 m × 2 m planting geometry. Similarly, available phosphorus varied narrowly between 11.1 and 11.2 kg ha^{-1}, while available potassium ranged from 256.3 to 258.4 kg ha^{-1} across the two geometries. The soil was slightly saline (pH 8.2), low in organic carbon and nitrogen, and medium in phosphorus and potassium. Planting geometry had minimal effect on soil chemical properties. Overall, the soil under clonal eucalyptus P-23 plantation was characterized as slightly saline, low in organic carbon and available nitrogen, and medium in available phosphorus and potassium. The minor variations observed between spacings indicate that planting geometry had limited immediate influence on soil chemical properties at the surface layer.

Growth Dynamics of clonal eucalyptus (P-23) during the study period

The growth performance of clonal eucalyptus (P-23) under planting geometries (4 m × 2 m and 5 m × 2 m) was evaluated based on plant height and girth at breast height (GBH) recorded during July 2020 and April 2021 (Fig. 2). The results indicated a clear influence of planting geometry on growth parameters. At the initial observation (July 2020), tree height ranged from 6.5 m under 4 m × 2 m spacing to 6.7 m under 5 × 2 m spacing. By April 2021, height increased to 8.7 m and 9.2 m under 4 m × 2 m and 5 m × 2 m spacing, respectively. The current annual increment (CAI) in height was recorded as 2.2 m under closer spacing (4 m × 2 m) and was higher (2.5 m) under wider spacing (5m x 2m), indicating enhanced vertical growth under reduced competition. Similarly, girth at breast height (GBH) showed an increasing trend over time. In July 2020, GBH was 21.9 cm under 4 × 2 m spacing and 23.8 cm under 5 × 2 m spacing. This

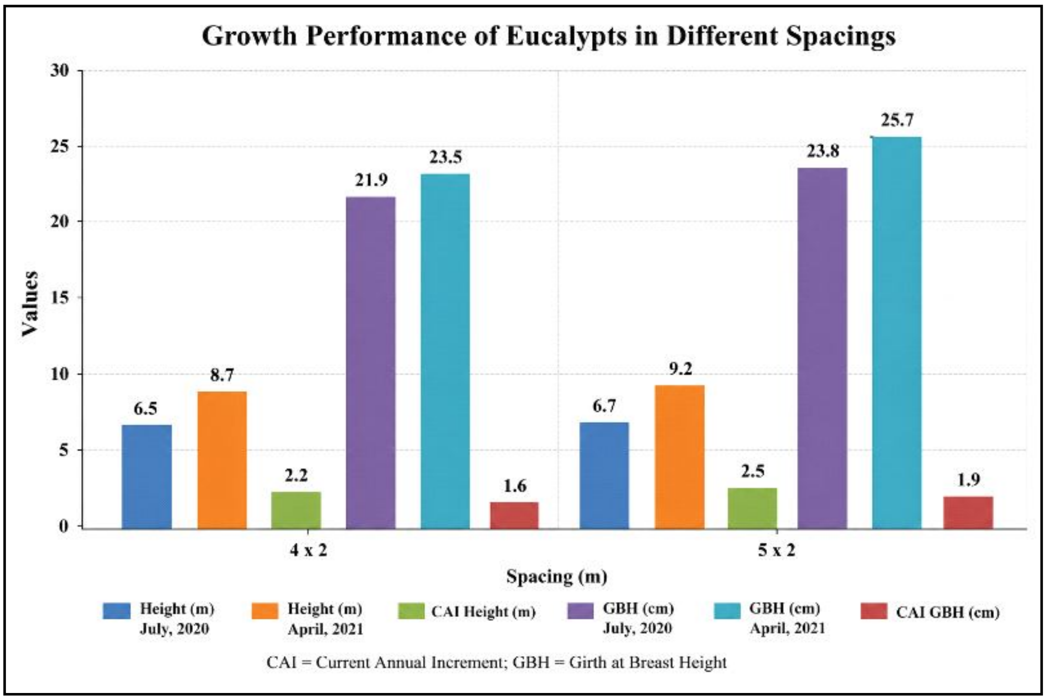


Fig. 2. Growth Dynamics of clonal eucalyptus (P-23) during the study period.

further increased to 23.5 cm and 25.7 cm, respectively, by April 2021. The CAI for GBH was recorded as 1.6 cm under closer spacing and 1.9 cm under wider spacing, suggesting better radial growth in trees planted at wider spacing.

(Silva, 1999) on Eucalyptus also observed that wider spacing performed better for higher growth and higher yield of agricultural crops over other spacings. (Prasad *et al*., 2010 and Yadav *et al*., 2022) reported the spacing of eucalyptus significantly influence the growth parameter of trees in terms of height, dbh and biomass. This may be due to more competition of eucalyptus plants for sunlight and different growth resources. Similar findings have been highlighted by (Ajit *et al*., 2011; Chauhan *et al*. 2011). In Eucalyptus based systems, major impact of planting geometries on eucalyptus growth has been observed under 4x2m planting geometry that the growth in the way of Plant Height and GBH exhibited lowest. This may be presence of saline soil in the experimental area hampered the growth of eucalyptus seedlings in early years of plantation.

Overall, the results demonstrate that wider geometry (5 m × 2 m) significantly improved both height and girth growth, as well as their respective annual increments, in clonal eucalyptus P-23. This may be attributed to reduced inter-tree competition for light, nutrients, and moisture, thereby promoting better overall growth performance.

Influence of planting geometry of *Eucalyptus tereticornis* (Clone P-23) on growth performance and productivity of fodder crop

The data shown in Fig. 3 reveal that the growth and fodder production of cowpea were significantly influenced by planting geometry of *Eucalyptus tereticornis*. The results revealed that all growth parameters and yield attributes of cowpea were affected under planting geometry arrangement as compared to the control (open condition). Among the different geometries, the wider planting geometry (5m x 2m) recorded significantly enhanced plant growth and production than the closer spacing (4 m x 2m). The maximum plant height (82.65 cm), leaf area (162.54 cm^2 per plant), stem diameter (7.15 mm), and fresh yield (14.11 t ha{ ^{1}) were observed under 5 m × 2 m geometry, which were significantly superior to those recorded under 4 × 2 m spacing. The closer planting geometry (4 m × 2 m) resulted in comparatively lower plant height (71.23 cm), leaf area (145.61 cm^2 per plant), stem diameter (6.56 mm), and fresh yield (12.54 t ha{ ^{1}), indicating increased competition for light, moisture, and nutrients. However, the control (without eucalyptus trees) recorded the highest values for all parameters, with plant height of 101.25 cm, leaf area of 205.21 cm^2 per plant, stem diameter of 9.73 mm, and fresh yield (12.54 t ha{ ^{1}), clearly demonstrating the suppressive effect of tree competition on intercrop performance.

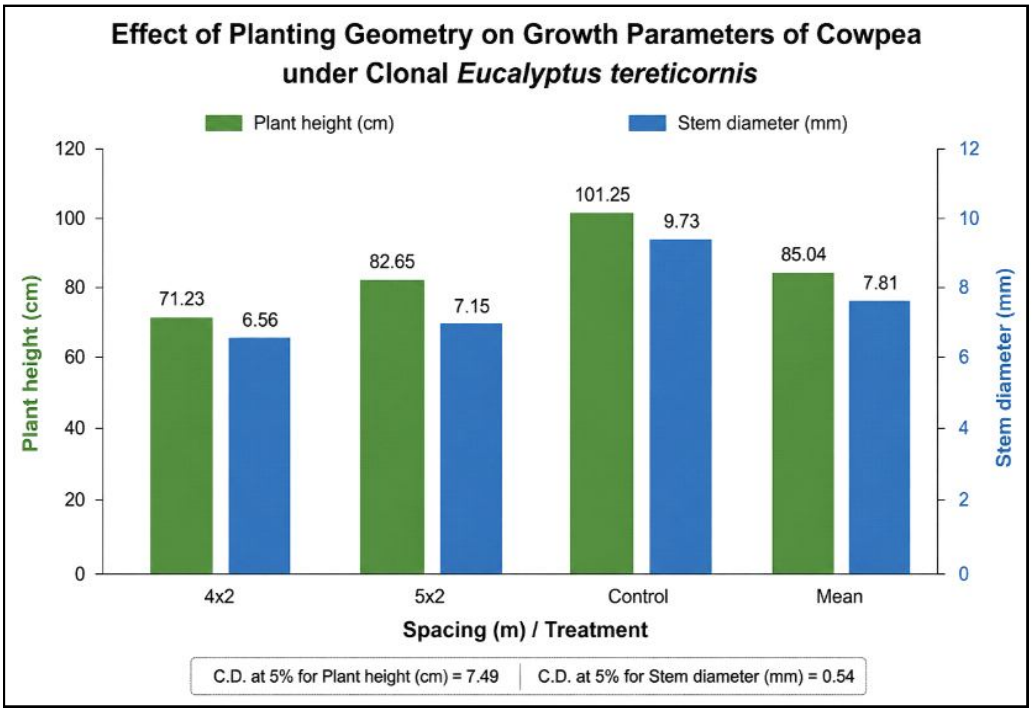


Fig. 3. Effect of planting geometry on growth parameters of cowpea under clonal *Eucalyptus tereticornis.*

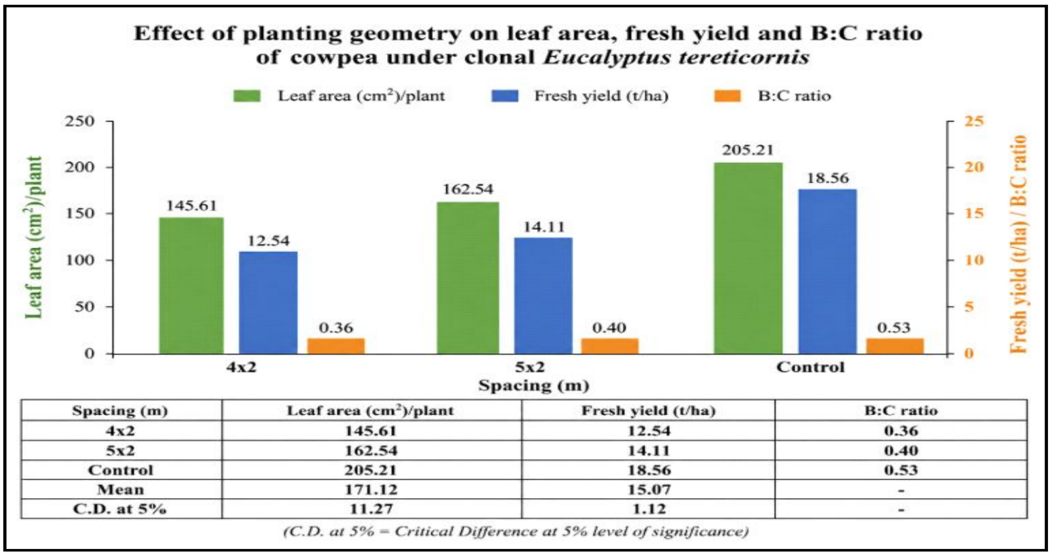
Similar findings were reported by Kumar and Nandal (2004) who observed that all intercrops grown under eucalypts exhibited reduced plant vigour and yield compared to open conditions, with reductions depending on crop type and intensity of competition.

The data presented in (Fig. 4) indicate that the green fodder yield of cowpea was significantly influenced by clonal eucalyptus-based planting geometry. The green fodder yield under the eucalyptus planting geometry of 5 × 2 m was recorded as 12.54 t/ha, whereas a significantly higher yield of 18.56 t/ha was obtained under sole cropping (control).

This shows the per cent fodder yield reduction under 4x2 m and 5x2m planting geometries were 32.44 and 23.98 %, respectively over control. The reduction in green fodder yield under eucalyptus based system can be primarily attributed to interspecific competition for light, soil moisture, and nutrients. The shading effect of eucalyptus canopy reduces light availability, which directly affects photosynthesis and vegetative biomass production, particularly in fodder crops like cowpea that depend on rapid vegetative growth. The results of the present study are in close agreement with the findings of Kombra et al. (2021), who reported significantly higher growth parameters and fodder yield of berseem and oat under sole cropping compared to eucalypts-based systems due to reduced competition for light, moisture, and nutrients. However, despite lower yields under trees. The benefit cost ratio of this experiment was calculated which varied from 0.36 (4x2 m) to 0.53 (control), indicating better economic returns under wider spacing compared to closer spacing. The mean values across treatments were 85.04 cm for plant height, 171.12 cm² per plant for leaf area, 7.81 mm for stem diameter, and 15.07 t ha{ ¹ for fresh yield. Overall, the study indicates that wider planting geometry of eucalyptus (5m x 2m) is more favourable for cowpea growth and fodder production under special arrangement of systems.

CONCLUSION

Research finding suggests that planting geometries of clonal *Eucalyptus tereticornis* (P-23) significantly affects tree growth and fodder productivity of cowpea. planting geometry (5m × 2m) enhanced both tree growth and intercrop performance compared to closer spacing (4m × 2m), although maximum fodder yield was recorded under sole cropping due to absence of competition. Despite reduced yield under tree-based systems, wider planting geometry maintained a better balance between productivity and economic returns. Therefore, adoption of optimum planting geometry, particularly wider geometry, is crucial for improving sustainability and productivity of eucalyptus-based agroforestry systems.



Spacing (m)	Leaf area (cm^2)/plant	Fresh yield (t/ha)	B:C ratio
4x2	145.61	12.54	0.36
5x2	162.54	14.11	0.40
Control	205.21	18.56	0.53
Mean	171.12	15.07	-
C.D. at 5%	11.27	1.12	-

(C.D. at 5% = Critical Difference at 5% level of significance)

Fig. 4. Effect of planting geometry on fodder productivity of cowpea under clonal *Eucalyptus tereticornis.*

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