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EFFECT OF DIFFERENT SPACING'S OF POPLAR (*POPULUS DELTOIDES*) ON GROWTH AND PRODUCTION OF FODDER SORGHUM

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SUMMARY

Performance of fodder sorghum (*Sorghum bicolor*) was investigated with different spacings of poplar (*Populus deltoides*) to evaluate productivity and economics of the silvopastoral agroforestry system at forestry farm, CCS HAU, Hisar (Haryana) during 2018-19. The experiment was laid out by planting fodder sorghum (*var.* HC-171) in between two and half-yr-old poplar at six different spacings, *i.e.* 3×3 m, 4×3 m, 5×3 m, 6×3 m, 7×3 m and 8×3 m in randomized block design (RDB) with three replications. The intercrops sorghum was maintained at 20 cm × 10 cm spacing and supplied with recommended doses of fertilizers. The study revealed that the highest number of plants (29.21) per meter square andthe maximum plant height (177.81 cm) at 20 DAS was recorded in 8×3m spacing followed by 7×3m, 6×3m and least under 3×3m under different spacings of poplar. A similar trend of growth of sorghum was observed after 40 and 60 DAS as it follows the increasing trend with increase in spacing. The number of tillers per meter square and leaf area index was recorded higher (64.26 and 6.40) under control (sole sorghum) over different spacings of poplar. However, maximum number of tillers per m^2 (59.03) and leaf area index (6.00) was found under 8×3m spacing than other spacings. Among the different spacings of poplar, the fodder yield of sorghumwas recorded maximum (38.45 t/ha) under 8×3 m followed by 7×3m (37.98 t/ha), 6×3m (35.85 t/ha), 5×3m (34.38 t/ha), 4×3m (27.78 t/ha) spacings and the minimum (24.27 t/ha) under 3×3 m. The reduction in fresh fodder yield of sorghum under 3×3m, 4×3m, 5×3m, 6×3m, 7×3m and 8×3m spacings of poplar was 44.03, 35.94, 20.72, 17.33, 12.42 and 11.34 per cent, respectively over control (devoid of trees). All the growth and yield attributes of sorghum were recorded lesser under different spacings of poplar as compared to the control (crop in open). While maximum (2.31) benefit to cost ratio was observed under Poplar+ sorghum combination in closer plant geometry of 3×3 m due to more number of trees.

Keywords : Agroforestry, sorghum, poplar, spacing, fodder

With over 37.28 per cent of the world's cattle population, 21.23 per cent of buffalo, 26.40 per cent of goats, and 12.17 per cent of sheep, India is the world's leading producer of livestock (Biswal *et al,* 2020). In addition, the country is the world's largest producer of milk (19 percent of global milk production in 2015), with a goal of producing 300 million tonnes by 2024. This is hoped to be accomplished through increased bovine productivity as a result of genetic improvement, improved disease control, and increased as well as balanced fodder availability. In fact, feed and fodder make up to 50 per cent of the total contribution to livestock productivity and production. The cereal crop residues (wheat, rice, and coarse cereals straws/hay) account for approximately 71 percent of the total feed resources used for animal feeding, with green fodder accounting for 23 percent and concentrated feeds accounting for only 6 percent.For more than 500 million animals in the country, there is currently no feed and fodder security. The availability of fodder is a challenge in the development of animal husbandry (Singh, 2019). A vital role in agriculture is played by fodder crops because a continuous supply of nutritious green fodder in sufficient quantity is a fundamental requirement for livestock in order to meet the demands of milk production while also maintaining the health of the livestock.Close the enormous gap between supply and demand for fodder, particularly for small and marginal farmers who have fewer cows and small ruminants on their property.

Crop improvement has shifted its emphasis away from traditional approaches to ensure long-term fodder availability in order to address this challenge. Even during the summer months, it is critical to ensure that strategies for sustainable green fodder production are implemented at the grass-roots levels (Thangadurai *et al*., 2021). As a result of these obvious challenges, advanced approaches and species selection that minimize production risks under a given environment and season are required to understand and identify cropping patterns in terms of species adaptability and management practices for optimizing resources that enhance climate change adaptation (FAO, 2010). In addition to having great potential for increasing fodder production and conserving biodiversity, agroforestry systems play a critical role in sustainable agriculture through the use of multiple land use systems (George *et al*., 2012). For effective agroforestry land use management, it is necessary to make a careful selection of tree-crop species that will meet the people's socioeconomic as well as environmental needs. (German and colleagues, 2006).Agri-silviculture can be improved by incorporating drought-resistant species such as sorghum into the mix. This can help to meet the needs of both environmental protection as well as the needs of food and fodder supply security (ICRAF, 2000). Due to increasing land pressure and diversification of traditional cropping systems, it is essential to conduct an economic evaluation of various agroforestry systems to determine their viability for adoption.

Sorghum is a crop that has proven to be high yielding and drought resistant in the face of changing weather conditions (FAOSTAT, 2017; Nwogwugwu, 2020). A fail safe crop in semi-arid regions, sorghum is widely grown as a grain crop, particularly in the post-rainy season. Sorghum is grown on an area of 5.7 million hectares in India, with a total annual production of 3 million tonnes. Sorghum is an important fodder crop in India, where it contributes to the health and nutrition of the country's large livestock population (Takkar, 2006). As a result of a lack of available feed and competition for land with other crops, livestock in semi-arid and tropical regions are underweight and underproductive. It is possible that marginal farmers will have limited opportunities to cultivate, particularly during the lean season, and that owning livestock will serve as an alternative source of income. These farmers feed their livestock with crop residues, which have been found to be of poor nutritional quality according to reports. This has an indirect impact on the productivity of livestock, which in turn has an impact on the livelihood and income of farmers. Sorghum [*Sorghum bicolor*] is a multipurpose cereal crop grown in drought-prone areas that provides benefits such as food and feed, shelter, feedstock, and bioenergy (Emendack *et al*., 2018). It is the fifth most important cereal crop grown in the world, according to the United Nations Food and Agriculture Organization. Sorghum is an important forage crop in the kharif season, and it exhibits a wide range of ecological adaptability compared to other forage crops (Iptas *et al*., 1997; Afzal *et al*., 2012).

MATERIALS AND METHODS

The present investigation was carried out at the research farm of Department of Forestry, CCS Haryana Agricultural University, Hisar during the year 2018-19. Geographically, the experimental site is situated at 29° 09' N latitude and 75° 43' E longitude at an altitude of 215.2 m above the mean sea level situated in the semi-arid region of north-western India. The climate is subtropical-monsoonic with an average annual rainfall of 350-400 mm, 70-80 per cent of which occurs during July to September. The summer months are very hot with mean maximum temperature ranging from 40 to 45 °C in May and June whereas; December and January are the coldest months (lowest temperature reaches as low as 0°C).

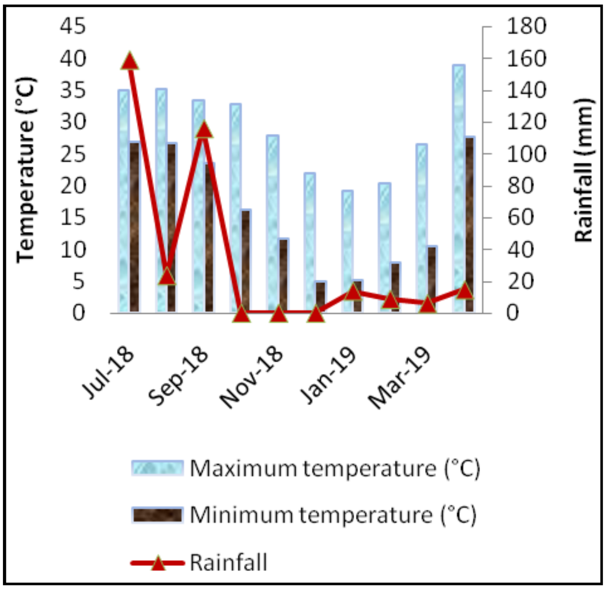

Fig. 1. The monthly mean meteorological data of the experimental site from July, 2018 to April, 2019.

The present study was conducted in an already established two and half-year-old plantation of *Populus deltoides* with six different spacings of 3×3 m, 4×3 m, 5×3m, 6×3m, 7×3m and 8×3. The mean height, basal diameter and diameter at breast height (DBH) of poplar saplings at the time of transplantation were 5.46 m, 3.51 cm and 2.83 cm, respectively. The experiment was laid out in factorial randomized block design with three replications.

During rainy season Sorghum (*var.* HC-171) was sown in all spacings of poplar under study during first week of July and also in control (without tree) with the recommended cultural practices. The Plant population of sorghum was recorded 20 days after sowing (DAS) by counting number of plants per meter square in three replications under different spacings of poplar. Plant height (cm) of sorghum was observed at 20 days interval. Fifteen plants were selected randomly from each plot under different spacings and the height of each plant was measured with measuring scale from soil surface to the tip of last fully opened leaf and then the average was worked out to determine the plant height. Total numbers of tillers were counted in one meter square quadrant used randomly from each plot in three replications at harvesting stage of sorghum and then the average number of tillers per meter square were calculated under different spacings of poplar. Yield attributing parameters like Fresh fodder yield (t/ha) and dry fodder yield (t/ha) were determined at harvest. All plants were harvested from each quadrant of one meter square area in three replications, bundled and labeled. Bundles of each plot were then weighed to record the green fodder yield and converted into ton per hectare. Dry fodder yield was determined by first shade-drying followed by sun drying and then oven drying of harvested samples at 70°C till constant weight was attained.The weight of each sample was measured by weighing balance and converted into ton per hectare. Leaf area was calculated at every 20 days interval with the help of a leaf area meter and then the leaf area index was calculated using the formula;

$$\text{Leaf area index} = \frac{\text{Leaf area}}{\text{Ground area}}$$

The land rent, cost of cultivation and gross income from different spacings of poplar based silvipastoral systems was calculated on the basis of approved market rates of inputs and outputs. The total cost of cultivation and the total income generated from all the components were used for the determination of the net return, B:C ratio, internal rate of return (IRR) and net present worth (NPW). The above parameters were also recorded in control field and data were statistically analyzed.

RESULTS AND DISCUSSION

Plant population/ germination per m²

The results demonstrated in Fig. 2 revealed that sorghum in control (sole crops) exhibited the highest plant population (31.43) followed by 8×3 m (29.21), 7×3 m (26.52), 6×3 m (23.30), 5×3 m (22.13), 4×3 m (19.79) and minimum (17.31) in 3×3 m spacing. The plant population of sorghum fodder crop was recorded lesser under different spacings of poplar as compared to the control (crop in open). The per cent reduction in the plant population was recorded minimum (7.06 per cent) under 8×3m while 15.62, 25.86, 29.58, 37.03 and 44.92 per cent under, 7×3m, 6×3m, 5×3m, 4×3m and 3×3m spacings, respectively over control (sole sorghum).

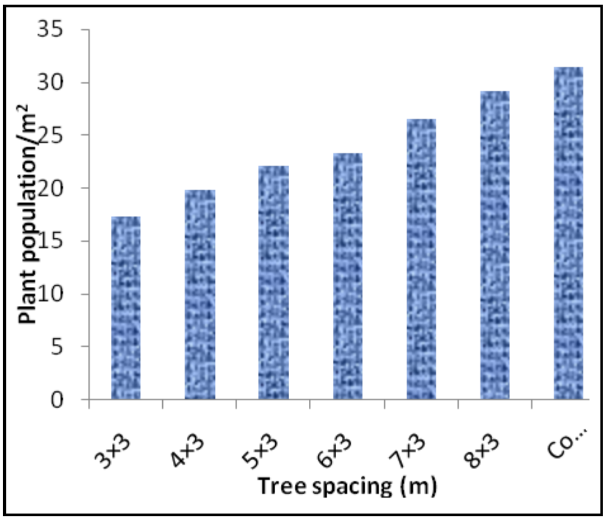

Fig. 2. Plant population/m² of sorghum fodder crop under different spacing's of poplar.

This might be due to higher soil moisture content during July (rainy season) and lesser availability of solar radiation impede the germination of sorghum under different spacings of poplar.Similar findings were reported by Pal *et al.* (2009) in wheat under poplar based agroforestry system, Bargali*et al.* (2004) in chickpea under *Acacia nilotica* based agroforestry system and Gawali*et al.* (2015) also reported lesser plant population of crops under different spacings of multipurpose tree species.

Plant height

Data presented in Table 1 indicates that the maximum plant height (177.81 cm)at 20 DAS was recorded under 8×3m followed by 7×3m (165.50 cm), 6×3m (152.36 cm), 5×3m (143.22 cm), 4×3m

(131.25 cm) and 3×3m (122.60 cm) spacings. A similar trend of growth was observed at 40 and 60 DAS under 8×3 m followed by 7×3m, 6×3m, 5×3m, 4×3m and 3×3m as it follows increasing trend with increase in spacing of poplar. However, in control plant height of sorghum at 20 (183.23 cm), 40 (251.12 cm) and 60 DAS (287.40 cm) was recorded higher over silvi-pastoral system of poplar with different spacings.

TABLE 1
Plant height of sorghum at different stages of growth under different spacings of poplar

Tree spacing (m)	Plant height (cm)		
	20 DAS	40 DAS	60 DAS
3×3	122.60	160.23	172.35
4×3	131.25	173.96	188.76
5×3	143.22	182.32	196.24
6×3	152.36	195.50	200.69
7×3	165.50	202.49	222.12
8×3	177.81	233.87	256.89
Control	183.23	251.12	287.40
CD at 5%	14.86	19.38	21.17

This might be due to the variation in the light intercepted by the fodder crop (sorghum) in open (crop devoid of trees) and under different spacings of poplar and also more competitive between poplar plants and fodder sorghum in different spacings of poplar. The findings of present study also agree with the results of Kaur *et al.* (2010) and Sarvade *et al.* (2014). They reported significantly higher plant height of wheat in sole crop than the intercropping with poplar.

Yield attributing parameters

Number of tillers (m^2)

Data presented in Table 2 shows that the numbers of tillers per m^2 ranged from 34.93 to 59.03 under different spacings of poplar follows increasing trend with increase in tree spacing. At harvest, the higher numbers of tillers per meter square (59.03) were recorded under 8×3 m followed by 7×3m (53.19), 6×3m (47.23), 5×3m (43.52) and 4×3m (38.16) spacings and least (34.93) under 3×3 m spacing. However, the numbers of the tillers at harvest were recorded maximum (64.26) in control (sole sorghum in open).

TABLE 2
Number of tillers (at harvest)of sorghum under different spacings of poplar

Spacings (m)	No. of tillers/m^2 (at harvest)
3×3	34.93
4×3	38.16
5×3	43.52
6×3	47.23
7×3	53.19
8×3	59.03
Control	64.26
CD at 5%	3.51

Leaf area index

In present study, it was observed that the leaf area index at different stages of sorghum growth (20, 40, and 60 DAS) decreases with reducing space in between trees of poplar (Fig. 3).The results indicated that the higher leaf area index (4.50) was recorded under 8×3 m followed by 7×3m (4.40), 6×3m (4.20), 5×3m (4.10), 4×3m (3.90) and 3×3 m (3.80) spacing at 20 DAS. A similar trend was observed at 40 and 60 DAS. At 40 DAS leaf area index ranged from 4.50 to 5.90, at 60 DAS, 5.20 to 6.00 under different spacings of poplar. At 60 days after sowing, leaf area index was recorded maximum (6.00) in 8×3 m and minimum (5.20) under 3×3 m spacing while highest (6.40) was recorded in control (crop devoid of trees). However, highest value of leaf area index at 20 DAS (4.80) and 40 DAS (5.90) was also recorded in control (sole sorghum).

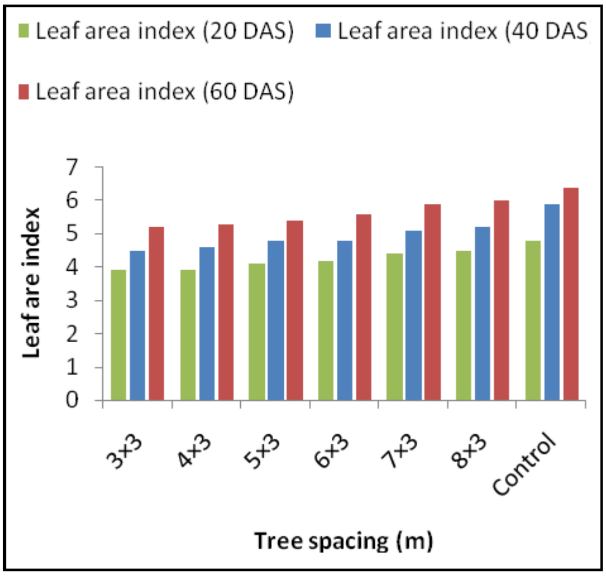

Fig. 3. Leaf area index of sorghum at different stages of growth under various spacings of poplar

The decrease in the leaf area index with the decrease in the spacing may be due to the increase in competition for light, nutrients and moisture between tree and crop components. Thus, competition for utilization of growth resources adversely affected the leaf area index of sorghum fodder crop under different spacings of poplar. Kumar *et al.* (2014) revealed the similar results that leaf area index increased significantly with wider spacing and also with stage of growth.

Yield of sorghum

Fresh fodder yield (t/ha)

The data presented in figure 4 depicts thatmaximum (38.45 t/ha) green fodder yield of sorghum was recorded under 8×3 m spacing followed by 7×3 m (37.98 t/ha), 6×3 m (35.85 t/ha), 5×3 m (34.38 t/ha), 4×3 m (27.78 t/ha) spacings and the minimum (24.27 t/ha) under 3×3 m. The reduction in fresh fodder yield of sorghum under 3 × 3 m, 4 × 3 m, 5 ×3 m, 6 × 3 m, 7 × 3 m and 8 × 3 m spacings of poplar was 44.03, 35.94, 20.72, 17.33, 12.42 and 11.34 per cent, respectively over control (devoid of trees). The lesser availability of solar radiation and higher competition for growth resources in the silvi-pastoral system (poplar + fodder crops) may be responsible for lesser biomass production by fodder crops over control (fodder crops in open).

Thus, competition for utilization of growth resources adversely affected the fodder yield of sorghum under different spacings of poplar. Bhati *et al.* 2004 revealed the similar result of fodder yield of cowpea and other fodder crops under the canopy of different agroforestry trees of arid regions of Rajasthan. Ranjan *et al.* (2016), Ratan *et al.* (2015), Prasad *et al.* (2010), Chesney *et al.* (2010) also reported the corroborative results showing the reduction in grain yield of cowpea due to higher shade under *Eucalyptus tereticornis* based agroforestry system over open condition.

Dry matter yield (t/ha)

As depicted in figure 5, the highest dry matter yield (13.99 t/ha) of sorghum was also recorded in control (crop devoid of trees). Among the different spacings of poplar under study, the dry matter yield of sorghum was recorded maximum (13.05 t/ha) under 8×3 m followed by 7×3m (12.89 t/ha), 6×3m (12.50

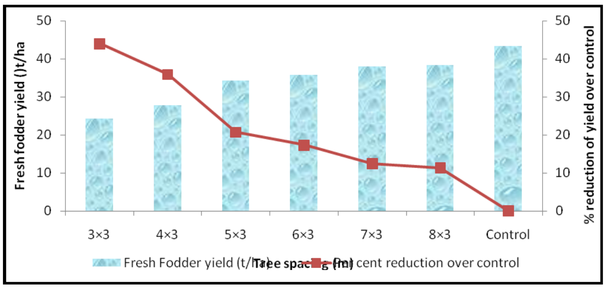

Fig. 4. Fresh fodder yield (t/ha) and % reduction over control of sorghum under different spacings of poplar.

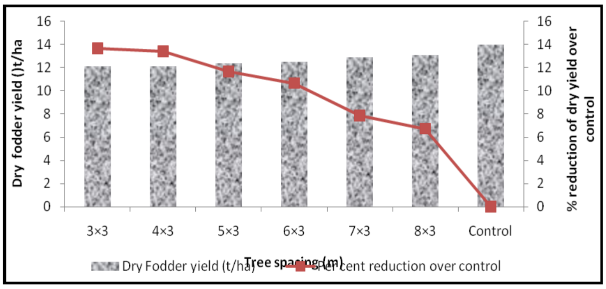

Fig. 5. Dry fodder yield (t/ha) and % reduction over control of sorghum under different spacings of poplar.

t/ha), 5×3m (12.36 t/ha), 4×3m (12.12 t/ha) spacings and minimum under 3×3 m (12.08 t/ha). The reduction in dry matter yield of sorghum under spacings 3×3m, 4×3m, 5×3m, 6×3m, 7×3m and 8×3m of poplar was 13.65, 13.36, 11.65, 10.65, 7.86 and 6.71 per cent, respectively over control (devoid of trees).

The reduced dry matter yield of fodder crops under poplar plantation in present study may be ascribed to competition between tree and crops for light, moisture and nutrients in a poplar based agroforestry system. In intercropping system, competition for light has been reported to have a large influence than either moisture or nutrients and dry mater production bears an almost linear relationship with the quantum of intercepted energy (Monteith, 1977). More light intensity in control increased the photosynthetic efficiency of crops resulting in better growth as reported by Wassinck (1954). The crop growth is mainly affected by light and nutrient availability. Similar results were earlier reported by Kaushik and Kumar (2003), Chesney *et al.* (2010) and Prasad *et al.* (2010) in different agroforestry systems. Sharma *et al.* (2000) also reported that close spacing of poplar inhibit the crop growth of wheat. Similar results were found by Alebachew *et al.* (2015). They reported that poor performance of maize sown adjacent to eucalyptus plantation was due to competition for growth resources between eucalyptus and adjacent crops.

Economic analysis of poplar-based agroforestry systems

In the present study, detailed observations in terms of accurate record of rental value of land, input costs, expenditure on labour and inter-cultural operations, tree and crop growth and their yield, and market price help portray the economic overview of agroforestry systems. *Populus deltoides* based silvi-pastoral systems fetched higher net returns as compared to sole fodder crops (Table 3). It is quite clear from the data presented that the cost of cultivation, gross return and net return increased with the increase in number of trees per hectare in different spacings of poplar. Data presented in Table 3 that the maximum gross return was obtained from poplar+ sorghum system, *i.e.* Rs. 241943 under 3×3 m spacing due to more number of trees in this spacing. However, the gross return decreased with the increase in the spacing of poplar, however the minimum gross return was obtained under sole cropping of sorghum *i.e.*, Rs. 61392. The maximum net return (Rs. 137264) was obtained under poplar+ sorghum under 3×3 m, while the minimum net return was obtained under sole cropping of sorghum *i.e.*, Rs. 25500.

TABLE 3
Economics of sorghum with poplar and control (sole fodder crops)

Spacing (m)	Cost of cultivation (Rs./ha)	Gross return (Rs./ha)	Net return (Rs./ha)	B : C ratio
3×3	104679	241943	137264	2.31
4×3	101409	194781	93373	1.92
5×3	99447	173675	74228	1.75
6×3	98139	154916	56777	1.58
7×3	97827	143244	45417	1.46
8×3	96504	132687	36183	1.37
Control	35892	61392	25500	1.71

Benefit cost ratio

BCR is the most attractive and accepted parameter in agricultural production systems. Higher value of BCR was observed for poplar with sorghum (2.31) under 3×3 m spacing followed by 4×3 m (1.92) and 5×3 m (1.75). It indicates that closer spacing of 3×3 m of poplar is more economically than the other spacings due to more number of trees per unit area and more production of wood (Fig. 6). The lowest value of BCR (1.37) was reported in poplar + sorghum under 8×3 m spacing rather than sole fodder sorghum (control). Thus poplar based silvi-pastoral systemsis found to be more profitable than solefodder crop. Some researchers have reported the higher BCR (more than 2.0) for poplar based agroforestry system in the Indo-Gangetic plains. Banerjee *et al.* (2010), Chisanga *et al.* (2013) also reported that benefit cost ratio (BCR) was maximum (6.63) from silvi-pasture and least from sole agriculture (without trees).

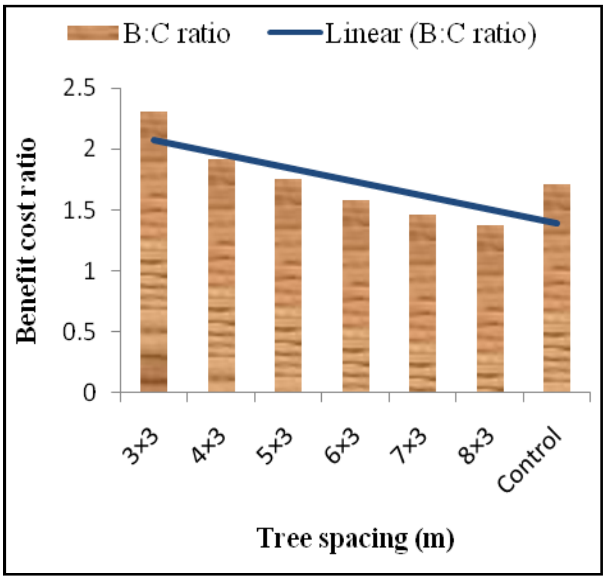

Fig. 6. Benefit cost ratio of sorghum and poplar based agroforestry system under different plant geomitries.

CONCLUSIONS

The current study demonstrates that a poplar-based agroforestry system is economically viable and more profitable than many traditional crop rotations. The study concludes that a poplar-based agroforestry system with a spacing of 8 × 3 m is superior to other spacing geometries in terms of fodder yield, while a higher benefit cost ratio (BCR) was achieved for poplar with sorghum (2.31) under 3×3 m spacing due to the greater number of trees per unit area. Furthermore, financial analysis reveals that the adoption of such systems would enable farmers in the semi-arid environment of northwestern India to double their income (BCR of 1: 2.31), despite the fact that traditional cropping systems are not that economically profitable.

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REFERENCES

Afzal, M., A. Ahmad and A.H.Ahmad, 2012 : Effect of nitrogen on growth and yield of sorghum forage (*Sorghum bicolor* (L.) Moench cv.) Under three cuttings system. *Cercetariagronomice in Moldova*, **45**(4): 57-64.

Alebachew, M., T. Amare, and M. Wendie, 2015 : Investigation of the effects of *Eucalyptus camaldulensis* on performance of neighbouring crop productivity in Western Amhara, Ethiopia, *The Open Access Library Journal*, **2** : 4226-4236.

Banerjee, H., P.K.Dhara, S. Paland S. Maiti, 2010 : Growth and productivity of trees and intercrops under agro-forestry system in red and lateritic Zone of West Bengal. *Indian Journal of Agroforestry*, **11**(2): 85-89.

Bargali, S.S., S.P. Singh, and K.S. Pandya, 2004 : Effect of *Acacia nilotica* on gram crop in a traditional agroforestry system of Chhattisgarh plains, *International Journal of Ecology and Environment Science*, **30**(4): 363-268.

Bhati, T. K., J. C. Tewari, and S. S. Rathore, 2004 : Productive dynamics of integrated farming systems in western Rajasthan, *Diversification of Arid Farming Systems*: 23-30.

Biswal, J., V. Kennady and H. Rahman, 2020 : Impact of methane emission and associated environmental stress on livestock production systems in India. *Journal of entomology and zoology studies*, **8**(3): 113-116.

Chesney, P.E.K., L.A. Simpson, R.N. Cumberbatch, O. Homenauth, and F. Benjamin, 2010 : Cowpea yield performance in an alley cropping practice on an acid infertile soil at Ebini, Guyana, *The Open Agriculture Journal*, **4**: 80-84.

Chisanga, K., D.R. Bhardwaj and S.Sharma, 2013 : Bio-economic appraisal of agroforestry systems in dry temperate western Himalayas. *Journal of Tree Sciences,* **32(**1&2): 43-48.

Emendack, Y., J. Burke, L. Haydee, J. Sanchez and H. Chad, 2018 : Abiotic Stress Effects on Sorghum Leaf Dhurrin and Soluble Sugar Contents throughout Plant development. *Crop Science*, **58** : 1706-1716.

FAO, 2010 : Food and Agriculture Organization. Agriculture Based Livelihood System in Drylands in the context of Climate Change: Inventory of Adaptation Practices and Technologies of Ethiopia: Food and Agriculture Organization, Addis Ababa, Ethiopia.

FAOSTAT, 2017: Food and Agricultural Organization (FAO).

Gawali, A., S. Puri, and S. L. Swamy, 2015 : Evaluation growth and yield of wheat varieties under *Ceiba pentandra*based agrisilviculture system, *Universal Journal of Agricultural Research*, **3**(6): 173-181.

George, S. J., R. J. Harper, R. J. Hobbs and M. Tibbett, 2012 : A sustainable agricultural landscape for Australia: A review of interlacing carbon sequestration, biodiversity and salinity management in agroforestry systems. *Agriculture, Ecosystems and Environment*, **163** : 28-36.

German, L. A., B. Kidane and R. Shemdoe, 2006 : Social and environmental trade-offs in tree species selection: a methodology for identifying niche incompatibilities in agroforestry. *Environment, Development and Sustainability*, **8**(4): 535-552.

ICRAF, 2000 : International Centre for Research in Agroforestry. Tree-Soil-Crop Interaction. In Asian Regional Research Programme. P. 2.

Iptas, S., M. Yilmaz, A. Oz and R. Avciolu, 1997 : Possibilities of utilizing silage corn forage sorghum and sorghumsudangrass hybrids under the ecological conditions in Tokat. In Proc. 1st Turkey Silage Conference, Bursa, Istanbul, Turkey, Hasad Press (eds.): 97-104.

Kaur, N., Baljit Singh, and R.I.S. Gill, 2010 : Agro-techniques for increasing productivity of wheat (*Triticum oestivum*) under poplar (*Populus deltoides*) plantation, *Indian Journal of Agronomy,* **55**(1): 68-74.

Kaushik, N. and V. Kumar, 2003 : Khejri (*Prosopis cineraria*)-based agroforestry system for arid Haryana, India, *Journal of Arid Environments,* **55**: 433-440.

Kumar, S., R.R. Shakhelaand, and N.H. Desai, 2014 : Simarouba (*Simarouba glauca* DC) (TBO) based silvipasture system in semi arid region of Gujarat, *Journal of Agroecology and Natural Resource Management,* **1**(3): 222-223.

Monteith, J. L., 1977 : Climate and the efficiency of crop production in Britain, *Philosophical Transactions of the Royal Society of London Series Biological Sciences,* **281** : 277-294.

Nwogwugwu, J. O., 2020 : Role of functional metabolites in heat stress responses of sorghum bicolor (l) moench., an agroforestry compatible crop. *Nigeria Agricultural Journal*, **51**(3) : 45-53.

Pal, M., G. S. Panwar, C. S. Dhanai, and K. B. Anand, 2009

: Performance of wheat under poplar (*Populus deltoides*) based agroforestry system, *Indian Journal of Agroforestry,* **11**(2): 101-103.

Prasad, J. V. N. S., G. R. Korwar, K. V. Rao, U. K. Mandal, C. A. R. Rao, G. R. Rao, Y. S. B. Ramakrishna, Venkateswarlu, S. N. Rao, H. D. Kulkarni, and M. R. Rao, 2010 : Tree row spacing affected agronomic and economic performance of eucalypts based agroforestry in Andhra Pradesh, Southern India, *Agroforestry Systems,* **78**(3): 253-267.

Ranjan, R. K., H. Kumar, and R. Umrao, 2016 : Efficacy of oat, berseem and lucerne under subabul (*Leucaena leucocephala*) and poplar (*Populus deltoides*) based silvopastoral system, *The Bioscan*, **11**(4) : 2371-2374.

Ratan, N. and U. N. Singh, 2015 : Production potential of berseem in eucalypts based agrosilvicultural system in bundelkhand region (UP) India, *Flora and Fauna*, **21**(1) : 100-102.

Sarvade, S., H. S. Mishra, R. Kaushal, S. Chaturvedi and S. Tewari, 2014a : Wheat (*Triticum aestivum*L.) yield and soil properties as influenced by different agri-silviculture systems of terai region, northern India. *International Journal of Bio-resource and Stress Management*, **5**(3): 350-355.

Sharma, N. K., H. P. Singh, and K. S. Dhadwal, 2000 : Effect of poplar (*Populus deltoides*) on wheat growth at an early stage, *Indian Journal of Soil Conservation*, **28** : 221-225.

Singh, O., 2019 : Feed and fodder development strategies of India. *Progressive Agriculture*, **19**(1): 107-111.

Takkar, P. N., 2006 : Handbook of agriculture.

Thangadurai, R., S. Monisha, S. Rengaraj, S. Jeevanandhan and C. Sivakumar, 2021 : Multicut 10 Cent Fodder Production for Addressing Fodder Shortage in Small and Marginal Farmer. *Biotica Research Today*, **3**(8) : 700-702.

Wassinck, E. C., 1954 : Remark on energy relations in photosynthesis processes, *Advances in Photosynthesis Research,* **8** : 1-19.