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**Research Paper**

# Productivity, moisture and soil-nutrients status in anjan (*Hardwickia binata*)-based three-tier silvopasture system under shrub species and planting densities

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## ABSTRACT

A field experiment was conducted during 2011–2012 to 2016–17 on sandy-loam soil at Indian Grassland and Fodder Research Institute, Jhansi, Uttar Pradesh, to evaluate the performance of anjan (*Hardwickia binata* Roxb.)-based three-tier silvopasture system under different shrub species and tree densities in semi-arid rainfed conditions. The experiment consisted of 9 treatments comprising of 3 planting densities of each shrubs and *H. binata* in alternate row, viz. 312, 208 and 139/ha and 3 shrub species, viz. *kath ber* [*Ziziphus xylopyrus* (Retz.) Willd.]. Indian jujube [*Z. mauritiana* Lam.] and black cutch [*Senegalia catechu* (L.f.) P.J.H. Hurter & Mabb.]. Study revealed that Total green and dry top feed and fire wood obtained from pruning of *Z. mauritiana* and *H. binata* (0.87, 0.36 and 0.42 t/ha) were significantly higher than of *Z. xylopyrus* (0.77, 0.33 and 0.38 t/ha) and *Senegalia catechu* (0.67, 0.31 and 0.36 t/ha). Planting of *H. binata* and shrubs in alternate row at 6 m × 6 m spacing in 3 tier silvopasture system resulted in significantly higher green and dry-forage yield (17.64 and 5.58 t/ha) and crude protein yield (542.5 kg/ha) of buffel grass (*Cenchrus ciliaris* L.) and caatingta stylo (*Stylosanthes seabrana* Maass & Maanetje) intercropping system as compared to 6 m × 4 m (17.23 and 5.43 t/ha and 529.2 kg/ha) and 4 m × 4 m spacing (16.93 and 5.31 t/ha and 512.6 kg/ha) respectively. Moisture content recorded after the monsoon season (October to April) was higher under *Z. mauritiana* (9.09, 9.55 and 10.20%) than *S. xylopyrus* (8.65, 9.12 and 9.77%) and *A. catechu* (8.63, 9.15 and 9.80%) at 0–15 cm, 15–30 cm and 30–60 cm soil depths, respectively. In soil fertility, higher planting density 312/ha of each shrubs and *H. binata* in alternate row resulted in improvement of available nutrients (N, 171.42; P, 7.03 and K, 158.81 kg/ha) and organic carbon (0.410%) than lower planting density 139/ha (N, 162.01; P, 6.64 and K, 150.87 kg/ha and organic carbon, 0.385%) in 6$^{th}$ year of the experiment.

***Key words*** : *Cenchrus ciliaris, Hardwickia binata,* Planting density, Shrub species, *Stylosanthes seabrana*, Three-tier silvopasture systems

Economy of the arid and semiarid farmers depends on the livestock population dominated by grazing based animals like sheep and goats (Kumar *et al.,* 2019. The wastelands and rangelands of arid and semi-arid regions are presently not capable of producing sufficient quantity of fodder for animals during abnormal weather conditions specially during drought years. It is due to continuous over-exploitation of grazing lands, frequent droughts, low and erratic rainfall distribution, people negligence, etc. It is fact that the improvement of animal husbandry is directly correlated with the improvement of degraded grazing lands. Therefore, in this context, development of suitable 3-tier silvopasture system comprising trees, shrubs, grasses and legumes on degraded grazing lands has great potential in enhancing system productivity and fodder availability, and checking soil erosion (Soni *et al*., 2006; Soni *et. al*., 2013; Sharma, 2014). Establishment of 3-tier silvopasture system on degraded grazing lands can serve the important role of bridging the gap in fodder supply during lean period of the year. In 3-tier silvopasture system grasses provide green forage during the monsoon season and tree and shrubs provide top feed during the winter and summer seasons. Three-tier silvopasture system also stabilizes sloping lands from erosion and rehabilitates degraded grazing lands. Soil conditions are also improved by contributions from leaf fall and nitrogen fixation by leguminous tree and shrub species. Incorporation of tree components in fodder production systems enhances the sustainability of systems by increasing income and soil fertility (Patel *et al.,* 2019).

The leaf fodder obtained from trees and shrubs serve as an insurance against fodder scarcity during drought to the

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livestock. Drought-hardy shrubs and tree provide green fodder during lean period, fire wood etc. and also play important ecological role, i.e. arresting soil erosion, phyto-remediation of degraded soils besides the micro-climate modification for creating favourable condition for associated flora and fauna. Optimum plant stand density is primarily a function of the growth potential of the site and the management practices. Though yield per unit area can be substantially greater at higher plant population, poor availability of water and nutrients may limit the productivity (Shinde *et al*., 2007). Plant density affects canopy closure, growth rates, rotation age, wood production, silvocultural and harvesting operations (Singh *et al*., 2004).

Anjan (*Hardwickia binata* Roxb.) is one of the suitable trees for silvopsture system for degraded lands under semi-arid rainfed conditions. It is moderate to large-size tree, leafless for a short time, with drooping slender branchlets and bifoliate leaves. This deciduous tree attains a height of 25–30 m with a clean cylindrical bole. It yields an extremely hard, heavy and durable timber (Roy, 1996) and provides quality fodder rich in term of crude protein (Singh, 1982). The bark yields a red-brown fibre used for ropes. *Anjan* thrives in a dry climate and even withstands for prolonged drought, scanty to moderate rainfall and intense heat during the hot season and is capable of growing on dry shallow soil and rocky ground. In arid and semi-arid regions, an establishment of suitable shrub species and trees provides fodder in drought situation when other species dried (Narain and Kar, 2004). In view of this, the present study was carried out to evaluate the performance of *Hardwickia binata*-based 3-tier silvopasture system under different shrub species and tree densities in semi-arid rainfed conditions.

## MATERIALS AND METHODS

A study was carried out during 2011–2012 to 2016–17 to evaluate the performance of *Hardwickia binata* based 3-tier silvopasture system under different shrub species and tree densities in semiarid rainfed conditions at the Central Research Farm, Jhansi (25° 27’ N, 78° 37’ E, 275 m above mean sea-level) of the Indian Grassland and Fodder Research Institute. The soil of the experimental field was sandy loam, low in organic carbon (0.365 and 0.396%), available nitrogen (152.59 and 166.34 kg/ha) and phosphorus (6.48 and 6.82 kg/ha) and medium in available potash (145.62 and 154.54 kg/ha) in 1st and 6th years of the experiment. The total rainfall received was 1,087.8, 789.3, 1,510.8, 651.9, 713.3 and 827 mm in 54, 50, 71, 43, 48 and 41 rainy days during 2011, 2012, 2013, 2014, 2015 and 2016. Initial moisture contents of experimental field recorded after the monsoon season (October to April) was 6.87, 8.13 and 7.50% at 0–15 cm, 15–30 cm and 30–60 cm soil depths, respectively. Mean annual evaporation rate was 5.16, 5.59, 4.48, 5.60, 6.11 and 5.57 mm/day during 2011, 2012, 2013, 2014, 2015 and 2016, respectively. The experimental field was stony with shallow soil depth and infested with unpalatable and unwanted bushes.

The experiment was laid out in a split-plot design with 3 replications by assigning 3 planting densities of each shrubs and *H. binata,* viz. 312, 208 and 139/ha, at planting spacing of 4 m × 4 m, 6 m × 4 m and 6 m × 6 m as main plot treatment and 3 shrub species planted in association with *Hardwickia binata* in alternate rows viz. *Ziziphus xylopyrus*, *Ziziphus mauritiana* and *Senegalia catechu* as subplot treatment. These treatments were imposed in experimental field during July 2011. Five months old poly-bags raised seedlings of *H. binata*, *Z. xylopyrus*, *Z. mauritiana* and *S. catechu* were planted in alternate row as per treatment (4 m × 4 m, 6 m × 4 m and 6 m × 6 m spacing) in plot size of 24 m × 24 m in field during the monsoon season. Basins of 1 m diameter were made at the base of tree seedlings and life-saving water was applied to the seedlings during the summer season in initial years of establishment. The seedlings of *Cenchrus ciliaris* was planted during the monsoon season at 100 cm × 50 cm spacing and seeds of *Stylosanthes seabrana* @ 4 kg/ha was sown in line between 2 rows of *C. ciliaris* in association with shrub species and *H. binata*. Fertilizer were applied at the rate of 40 kg N, 30 kg phosphorus and 30 kg potash/ha at the time of sowing in 1st year and from 2nd year onwards after the onset of monsoon. The *H. binata* and *Z. xylopyrus*, *Z. mauritiana* and *S. catechu* were pruned once every year from the second year onwards during November–December for proper growth and form.

Pruned yields of shrub species and *H. binata* were recorded during 6th year of the experiment and their growth parameters were measured every year during November–December. *Cenchrus ciliaris* and *S. seabrana* were harvested manually at 15 cm above the ground surface at flowering stage in each year. Growth parameters and fodder yields of *C. ciliaris* and *S. seabrana* were recorded at the time of harvesting. Dry-fodder yield was recorded in each plot on the basis of per square meter area and values were converted into t/ha. Dry-matter yield was computed by drying 500 g plant sample of each treatment and replication in hot-air oven at 70 °C. The crude protein content of the fresh samples was estimated by the procedure of AOAC (1995). Crude protein content expressed as N × 6.25 and crude protein yield was calculated by multiplying crude protein content with dry-forage yield. Soil samples were collected in 1st year and 6th year of the experimentation at 0–15 cm soil layer and analysed for organic carbon, available nitrogen, phosphorus and potash adopting standard analytical methods. Data obtained from all observations were statistically analysed in split-plot design using the technique of analysis of variance (ANOVA). The difference between the treatments means were tested as to their statistical significance with appropriate critical difference (CD) value at 5% level of probability. Soil-moisture content was determined by gravimetric method at 0–15, 15–30 and 30–60 cm soil depth at 2 months intervals from October to April. Sustainable-yield index was calculated as per Singh *et al.* (1990).

$$\text{Sustainable yield index} = \frac{\text{Estimated average yield–estimated standard deviation}}{\text{Maximum yield}}$$

## RESULTS AND DISCUSSION

### *Growth parameters of shrub species and H. binata*

Growth parameters of shrub species were varied significantly among different shrubs. *Ziziphus mauritiana* attained significantly higher height and canopy spread as compared to *Senegalia catechu* and *Ziziphus xylopyrus* during 6th year. However, in collar diameter *S. catechu* recorded significant difference over *Z. mauritiana* and *Z. xylopyrus*. Planting densities of shrubs and tree did not significantly affect the growth parameters of both shrub species and *H. binata* (Table 1).

### *Growth parameters of pasture components*

Growth parameters of pasture components did not vary significantly by different shrub species (Table 1). However, planting of *H. binata* and shrub species in alternate row at 6 m × 6 m spacing in 3-tier silvopasture system resulted in significantly higher height, number of tillers/plant and tussock diameter of *C. ciliaris* as compared to 4 m × 4 m spacing. Similarly, height and branches/plant of *S. seabrana* were also significantly increased under 6 m × 6 m planting spacing of *H. binata* and shrub species in alternate row than 4 m × 4 m spacing. The higher growth parameters of pasture components at low density of *H. binata* and shrub species was might be owing to less competition for moisture, nutrients, light and space as compared to high density. Singh and Pathak (1993) also reported higher growth parameters of pasture at low density of tree.

### *Green and dry top feed yield and fire wood*

Pruning of *Z. mauritiana* and *H. binata* resulted in significantly higher green and dry top feed and fire wood as compared to *Z. xylopyrus* and *S. catechu*. However, top feed and fire wood obtained from *H. binata* were not significantly affected by different shrub species (Table 2). Shukla *et al*. (1998) also found that, *Z. mauritiana* is a hardy species and can be grown successfully with grasses for top feed and fruit under semi-arid rainfed condition. Planting of *H. binata* and shrub species in alternate row at 4 m × 4 m spacing recorded significantly higher total green and dry top feed and fire wood than 6 m × 4 m and 6 m × 6 m spacing. Jat *et al*. (2004) also observed positive relation between tree density and top feed production of *H. binata*.

### *Green-and dry-forage yield of understory pasture*

Green and dry forage yields of both *C. ciliaris* and *S. seabrana* were not influenced significantly by different shrub species (Table 3). However, planting of *H. binata* and shrub species in alternate row at 6 m × 6 m spacing in

**Table 1.** Growth parameters of shrubs and *Hardwickia binata* (2016–17) and pasture components (pooled data of 6 years) in 3-tier silvopasture systems under different treatment

| Treatment | Shrubs | | | *H. binata* | | | *Cenchrus ciliaris* | | | *Stylosanthes seabrana* | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Height (m) | Collar diameter (cm) | Canopy spread (m) | Height (m) | Collar diameter (cm) | Canopy spread (m) | Height (cm) | Tillers/ plant | Tussock diameter (cm) | Height (cm) | No. of branches/ plant |
| *Shrub species* | | | | | | | | | | | |
| *Ziziphus xylopyrus* | 2.32 | 4.20 | 1.55 | 2.35 | 3.48 | 0.87 | 119.3 | 72.6 | 32.3 | 76.8 | 5.8 |
| *Ziziphus mauritiana* | 2.78 | 4.08 | 1.69 | 2.41 | 3.56 | 0.89 | 120.51 | 74.1 | 32.9 | 77.7 | 5.9 |
| *Sengalia catechu* | 2.49 | 4.64 | 1.52 | 2.34 | 3.50 | 0.86 | 118.3 | 72.2 | 32.1 | 76.9 | 5.7 |
| SEm± | 0.06 | 0.06 | 0.03 | 0.02 | 0.03 | 0.01 | 0.7 | 0.4 | 0.3 | 0.4 | 0.1 |
| CD (P=0.05) | 0.23 | 0.25 | 0.13 | NS | NS | NS | NS | NS | NS | NS | NS |
| *Plant spacing (m × m)** | | | | | | | | | | | |
| 4 × 4 | 2.13 | 4.30 | 1.59 | 2.35 | 3.51 | 0.87 | 116.0 | 70.3 | 31.1 | 74.6 | 5.5 |
| 6 × 4 | 2.19 | 4.37 | 1.62 | 2.42 | 3.57 | 0.89 | 119.6 | 73.3 | 32.6 | 77.3 | 5.7 |
| 6 × 6 | 2.10 | 4.25 | 1.57 | 2.34 | 3.47 | 0.85 | 122.4 | 75.3 | 33.6 | 79.5 | 6.1 |
| SEm± | 0.03 | 0.05 | 0.02 | 0.03 | 0.03 | 0.01 | 0.9 | 0.8 | 0.4 | 0.6 | 0.2 |
| CD (P=0.05) | NS | NS | NS | NS | NS | NS | 2.9 | 2.4 | 1.2 | 1.8 | 0.5 |

*Planting spacing (m) of *H. binata* and shrubs in alternate row (density of each *H. binata* + shrubs/ha): 4 m × 4 m (312 + 312), 6 m × 4 m (208 + 208) and 6 m × 6 m (139 + 139)

3-tier silvopasture system resulted in significantly higher green and dry forage of *C. ciliaris* and *S. seabrana* intercropping system as compared to 6 m × 4 m and 4 m × 4 m spacing respectively. Contribution of *S. seabrana* in total dry-forage yields was 37.13%. The higher green and dry yield of pasture at wider spacing revealed that, there was less competition of *H. binata* and shrubs on pasture species at low densities (139 each *H. binata* and shrubs/ha). Khan *et al*. (2000) also concluded that *A. tortilis*-based silvopasture system recorded higher forage yield of *C. ciliaris* and *S. hamata* at wider spacing than narrow spacing, and Gill and Ajit (2004) reported that, with the increase in the tree densities the relative crop yields decreased. Keshwa and Singh (2004) also reported reverse trend in yield of *C. ciliaris* with the decrease in row spacing of *Dichrostachys cinerea.*

### *Crude protein yield*

Establishment of different shrub species in 3-tier silvopasture systems did also not significantly affected the crude protein yields of pasture components (Table 3). However, planting of shrub species and *H. binata* at 6 m × 6 m spacing in alternate row resulted in significantly higher crude protein yields of both *C. ciliaris* and *S. seabrana* as compared to 6 m × 4 m and 4 m × 4 m spacing. This might be owing to optimum availability of space, moisture, nutrients and light to *C. ciliaris* and *S. seabrana* at wider spacing of *H. binata* and shrubs which resulted in higher dry-forage and crude protein yield as compared to narrow spacing.

### *Soil-moisture content*

Moisture content recorded after the monsoon season (October to April) was higher under *Z. mauritiana* than *Z. xylopyrus* and *S. catechu* at 0–15 cm, 15–30 cm and 30–60 cm soil depths (Table 4). This was might be owing to dense and higher canopy spread of *Z. mauritiana* which resulted in better protection of land surface with direct Sun light and moisture conservation. Higher planting density (312/ha) of each shrubs and *H. binata* in alternate row also increased moisture content as compared to lower planting density (139/ha) at all 3 soil depths (Table 4). This was also might be owing to dense canopy of shrubs and tree at higher planting density (312/ha of each) which resulted in better protection of land surface with direct sun light and moisture conservation.

### *Soil-fertility status*

Soil-fertility status of the experimental field did not affect significantly by different shrub species (Table 4). However, higher planting density of 312/ha of each shrubs and *H. binata* in alternate row resulted in improvement in available nutrients (N, 171.42; P, 7.03 and K, 158.81 kg/ha) and organic carbon (0.410%) than lower planting density of 139/ha and OC in 6th year of the experiment. There was increase in available nitrogen, phosphorus and potash and organic carbon in 6$^{th}$ year of the experiment as compared to 1$^{st}$ year. Yadav *et al*. (2007), Ram *et al*. (2007) and Sharma (2015) also reported increased values of organic carbon and available plant nutrients under silvopasture system. Soil nutrient build-up in 6$^{th}$ year of the experiment (organic carbon, nitrogen, phosphorus, potash) might have taken place owing to addition and decomposition of leaf litter of shrubs, tree, grass and legume species.

### *Sustainability yield index*

Overall sustainability yield index of 0.503 of 3 tier silvopasture system showed that system gave sustainable

**Table 2.** Green and dry top feed and dry-fire wood as influenced by shrubs species and spacing in 3-tier silvipasture systems (2016–17)

| Treatment | Green top feed (t/ha) | | | Dry top feed (t/ha) | | | Fire wood (t/ha) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Shrubs | *H. binata* | Total | Shrubs | *H. binata* | Total | Shrubs | *H. binata* | Total |
| *Shrub species* | | | | | | | | | |
| *Ziziphus xylopyrus* | 0.43 | 0.34 | 0.77 | 0.19 | 0.14 | 0.33 | 0.21 | 0.17 | 0.38 |
| *Ziziphus mauritiana* | 0.50 | 0.37 | 0.87 | 0.21 | 0.15 | 0.36 | 0.24 | 0.18 | 0.42 |
| *Sengalia catechu* | 0.33 | 0.34 | 0.67 | 0.17 | 0.14 | 0.31 | 0.20 | 0.16 | 0.36 |
| SEm± | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| CD (P=0.05) | 0.05 | NS | 0.04 | 0.02 | NS | 0.03 | 0.03 | NS | 0.04 |
| *Plant spacing (m × m)** | | | | | | | | | |
| 4×4 | 0.53 | 0.45 | 0.98 | 0.26 | 0.20 | 0.46 | 0.30 | 0.22 | 0.52 |
| 6×4 | 0.39 | 0.33 | 0.73 | 0.18 | 0.14 | 0.32 | 0.21 | 0.16 | 0.37 |
| 6×6 | 0.34 | 0.27 | 0.60 | 0.13 | 0.11 | 0.24 | 0.13 | 0.12 | 0.28 |
| SEm± | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| CD (P=0.05) | 0.03 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.03 | 0.03 |

*Planting spacing (m) of *H. binata* and shrubs in alternate row (density of each *H. binata* + shrubs/ha): 4 m × 4 m (312 + 312), 6 m × 4 m (208 + 208) and 6 m × 6 m (139 + 139) yield over the years and maximum sustainable yield index with 6 m × 6 m spacing (0.516) indicated that planting of *H. binata* and shrub species at 6 m × 6 m spacing in alternate row in 3-tier silvopasture system resulted in more stable yield over the years than planting at 6 m × 4 m spacing (0.502) and 4 m × 4 m spacing (0.491). Similarly, establishment of *Z. mauritiana* in association with *H. binata* in 3-tier silvopasture system also recorded highest sustainable yield index (0.507) as compared to *Z. xylopyrus* (0.503) and *S. catechu* (0.499) which showed that yield obtained from establishment of *Z. mauritiana* in combination with *H. binata* was more consistent over the years as compared to *Z. xylopyrus* and *S. catechu*. Growth parameters of *Z. mauritiana* was consistently more than *Z. xylopyrus* and *S. catechu* over the years which resulted in higher yields and sustainable yield index.

This study confirms that integration of perennial pasture (*Cenchrus ciliaris* and *Stylosanthys seabrana*) and shrub species (*Ziziphus mauritiana*) with anjan tree (*Hardwickia binata*) in alternate row at 6 m × 6 m spacing in 3-tier silvopasture system on degraded lands have great potential in enhancing system productivity, improving soil nutrients status and better soil-moisture content under semi-arid rainfed ecosystem of India. Three-tier silvopasture system

**Table 4.** Moisture content, soil-fertility status and sustainability yield index as influenced by shrubs species and spacing in 3-tier silvopasture systems (2016–17)

| Treatment | Moisture content (%) | | | Available nutrients (kg/ha) | | | | | | Organic carbon (%) | | Sustainability yield index |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0–15 cm | 15–30 cm | 30–60 cm | N Year 1 | N Year 6 | P Year 1 | P Year 6 | K Year 1 | K Year 6 | Year 1 | Year 6 | |
| *Shrub species* | | | | | | | | | | | | |
| *Ziziphus xylopyrus* | 8.65 | 9.12 | 9.77 | 151.95 | 164.50 | 6.48 | 6.82 | 145.66 | 154.48 | 0.363 | 0.391 | 0.503 |
| *Ziziphus mauritiana* | 9.09 | 9.55 | 10.20 | 152.32 | 165.36 | 6.51 | 6.87 | 145.97 | 155.76 | 0.364 | 0.394 | 0.507 |
| *Sengalia catechu* | 8.63 | 9.15 | 9.80 | 153.49 | 169.14 | 6.46 | 6.77 | 145.24 | 153.40 | 0.368 | 0.404 | 0.499 |
| SEm± | 0.06 | 0.06 | 0.07 | 1.16 | 1.42 | 0.04 | 0.06 | 1.24 | 1.18 | 0.003 | 0.004 | 0.001 |
| CD (P=0.05) | 0.26 | 0.25 | 0.26 | NS | NS | NS | NS | NS | NS | NS | NS | 0.003 |
| *Plant spacing (m × m)** | | | | | | | | | | | | |
| 4 × 4 | 9.15 | 9.67 | 10.29 | 154.26 | 171.42 | 6.56 | 7.03 | 146.96 | 158.81 | 0.371 | 0.410 | 0.491 |
| 6 × 4 | 8.74 | 9.22 | 9.88 | 152.08 | 165.58 | 6.47 | 6.79 | 145.20 | 153.95 | 0.364 | 0.394 | 0.502 |
| 6 × 6 | 8.47 | 8.92 | 9.60 | 151.42 | 162.01 | 6.42 | 6.64 | 144.72 | 150.87 | 0.362 | 0.385 | 0.516 |
| SEm± | 0.17 | 0.16 | 0.17 | 2.14 | 2.29 | 0.08 | 0.08 | 1.71 | 1.18 | 0.005 | 0.005 | 0.002 |
| CD (P=0.05) | 0.52 | 0.49 | 0.54 | NS | 7.14 | NS | 0.26 | NS | NS | NS | 0.017 | 0.007 |

*Planting spacing (m) of *H. binata* and shrubs in alternate row (density of each *H. binata* + shrubs/ha): 4 m × 4 m (312 + 312), 6 m × 4 m (208 + 208) and 6 m × 6 m (139 + 139)

**Table 3.** Effect of shrubs species and spacing on green and dry forage and crude protein yields of pasture in 3-tier silvopasture systems (pooled data of 6 years)

| Treatment | Green-forage yield (t/ha) | | | Dry-forage yield (t/ha) | | | Crude protein yield (kg/ha) | | |
|---|---|---|---|---|---|---|---|---|---|
| | *C. ciliaris* | *S. seabrana* | Total | *C. ciliaris* | *S. seabrana* | Total | *C. ciliaris* | *S. seabrana* | Total |
| *Shrub species* | | | | | | | | | |
| *Ziziphus xylopyrus* | 10.78 | 6.46 | 17.24 | 3.41 | 2.02 | 5.43 | 266.7 | 258.4 | 525.2 |
| *Ziziphus mauritiana* | 10.86 | 6.50 | 17.36 | 3.45 | 2.04 | 5.49 | 272.5 | 265.8 | 538.2 |
| *Sengalia catechu* | 10.76 | 6.44 | 17.20 | 3.39 | 2.00 | 5.39 | 265.7 | 255.2 | 520.8 |
| SEm± | 0.07 | 0.02 | 0.07 | 0.02 | 0.02 | 0.02 | 1.8 | 2.8 | 4.6 |
| CD (P=0.05) | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| *Plant spacing (m × m)** | | | | | | | | | |
| 4 × 4 | 10.60 | 6.33 | 16.93 | 3.35 | 1.96 | 5.31 | 261.5 | 251.1 | 512.6 |
| 6 × 4 | 10.78 | 6.45 | 17.23 | 3.41 | 2.02 | 5.43 | 267.2 | 261.9 | 529.2 |
| 6 × 6 | 11.03 | 6.62 | 17.64 | 3.50 | 2.08 | 5.58 | 276.1 | 266.4 | 542.5 |
| SEm± | 0.11 | 0.03 | 0.11 | 0.04 | 0.01 | 0.02 | 2.7 | 0.98 | 3.4 |
| CD (P=0.05) | 0.33 | 0.10 | 0.34 | 0.13 | 0.03 | 0.07 | 8.5 | 3.1 | 10.5 |

*Planting spacing (m) of *H. binata* and shrubs in alternate row (density of each *H. binata* + shrubs/ha): 4 m × 4 m (312 + 312), 6 m × 4 m (208 + 208) and 6 m × 6 m (139 + 139)

*C. Ciliaris*, *Cenchrus ciliaris*; *S. seabrana*, *Stylosanthes seabrana* comprising *H. binata*, *Z. mauritiana, C. ciliaris* and *S. seabrana* is an ideal and profitable alternate land-use option for degraded lands to produce sufficient amount of understory pasture, top feed and fire wood along with improvement of moisture and soil-fertility status and minimize risk due to abnormal weather conditions specially during drought years when other species dried under semi-arid rainfed situation.

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