# Impact of soil moisture dynamics on yield of intercrops and natural gum exudation in rainfed agroforestry system in semi-arid region

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**ABSTRACT:** *The present investigation was carried out in a 7 years-old agroforestry system based on two gum-yielding trees viz. Acacia nilotica and Acacia senegal planted at three spacing viz. 10x10m, 10x5m and 5x5m under unirrigated (rainfed) condition in semi-arid region of Bundelkhand, Central India. The objective of present study was to assess how soil moisture dynamics across different tree spacing influence yield of the intercrops and natural exudation of gum under rainfed semi-arid conditions. The study was conducted during 2019–2020, following a cropping sequence of sesame (Sesamum indicum L.) in kharif and taramira (Eruca sativa Mill.) in rabi season. Soil moisture content was estimated gravimetrically in every month throughout the year. Findings revealed that, tree species, planting spacing or tree density and months had significantly influenced dynamics of soil moisture in 0-30cm soil depth. Soil under A. senegal retained higher moisture compared to A. nilotica. Closer spacing (5×5 m) maintained higher soil moisture than wider spacings (10×5 and 10×10 m). Months of the rainy season recorded higher soil moisture than winter and summer seasons. Maximum soil moisture was observed in Acacia senegal planted at 5x5m in October (82.58mm), while the least in Acacia nilotica at 10x10m in April (9.39mm). Incremental growth in tree's GBH, height and canopy spread varied with spacing. The yield of both tested intercrops remained unaffected by studied tree species, but significantly influenced by planting spacing, with maximum in 10×10 m and minimum in 5×5 m. Both trees naturally exuded gum in summer months (May-June). Acacia senegal recorded higher mean gum yield (33.2g/tree) than Acacia nilotica (12.6g/tree). Both gum-yielding trees exuded maximum gum when planted at 5x5m spacing. The moisture content exhibited positive but weak correlations with tree growth prameters, intercrop's yield and gum exudation. Gum yield positively correlated with the incremental growth of trees. Conclusively, good soil moisture resulting from good monsoon rain is likely to increase tree growth, yield of intercrops and gum exudation; and for optimum and efficient use of resources in agroforestry in semi-arid regions, planting of A. nilotica and A. senegal at 10x5m spacing is recommended.*

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## 1. INTRODUCTION

Rainfed agriculture remains dependent primarily on green water stored as soil moisture, and contributes nearly 80% of global food production. Environmental degradation and global warming threaten rainfed regions of the world (FAO 2020). With changing climatic patterns, the hydrological regimes governing soil moisture availability are being altered thereby affecting crop growth and yields (McCarthy *et al.* 2001). Water availability is a major factor contributing to variability in crop yields under many production conditions (Ritchie, 1983). Variations in seasonal and intra-seasonal precipitation patterns significantly influence the soil water regime. Globally, variability in precipitation strongly regulates soil moisture dynamics, which in turn determines yield of rainfed crops (Thomson *et al.*, 2003). The choice of farming enterprises in rainfed regions is largely guided by the climatic conditions and soil health status. The productivity of rainfed agriculture generally remains low, often ranging from one-third to one-half of that achieved under irrigated conditions. Thus, the adoption of agroforestry in rainfed areas not only enhances biomass production and soil fertility, but also influences soil moisture regimes through canopy cover, root distribution and litter deposition (Prasad *et al.*, 2016).

In arid and semi-arid regions of India particularly in Rajasthan, Gujarat, Haryana, Punjab and Bundelkhand region of central India, the soils are very poor in fertility and often subjected to erosion and land degradation processes (Gupta *et al.*, 2014; Bhan and Arora, 2018). Thus, for such climatic conditions,

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agroforestry land-use is the best strategy for the restoration and revitalization of degraded land resources (Singh *et al.*, 2016, 2017, 2018). For practicing agroforestry on farmland many multipurpose tree species have been identified and advocated. In arid and semi-arid regions, there is a good scope for extending area for large-scale plantation of *A. nilotica* and *A. senegal*. *Acacia nilotica* Willd. ex Del. and *Acacia senegal* (L.) Willd., members of family Fabaceae, produce good quality nutritive fodder (Ginwal and Mandal, 2004); able to tolerate dry spells and high temperature (Fadl, 2013). *A. nilotica,* is found in almost all the states of India, except Kerala, Kashmir and North-East region (Raj *et al.*, 2015). *A. senegal* is found as interspersed species in most of the rangelands and grasslands (Prasad *et al.*, 2015). Both species yield edible gums, called gum-acacia (*A. nilotica*) and gum-arabic (*A. senegal*). Integration of *Acacia senegal* and *Acacia nilotica* in the agroforestry system is a profitable proposition as both the plant species produce edible gum, leaf fodder and wood which can provide an alternative livelihood support to the farmers (Prasad *et al.* 2015). This proposition can be more helpful in rainfed areas where increasing productivity remains a major challenge. These plant species thrive well in Bundelkhand region of Central India (Prasad *et al.*, 2018).

The Bundelkhand region represents a typical semi-arid climatic condition, characterized by a long hot summer, low and erratic rainfall and a short mild winter. The annual rainfall in the region varies from 800 to 1040 mm. The soils are immature and very coarse in texture with low water-holding capacity and poor nutrient status. As nutrients and moisture remain generally low in the soils of arid and semi-arid regions, in such fragile soils, planting geometry directly affects availability of soil moisture and productivity of crops; hence, determining the optimum spacing for gum-yielding trees is crucial. (Joy *et al*., 2018). To work out the optimum planting geometry for *A. senegal* and *A. niotica* in rainfed conditions, a agroforestry model was established under ICAR sponsored Network Project on "Harvesting, Processing and Value Addition of Natural Resins and Gums" at central research farm of ICAR-Central Agroforestry Research Institute (CAFRI), Jhansi in the year 2012. The present investigation was conducted in this well established and rainfed agroforestry system based on two gum-yielding trees viz. *Acacia senegal* and *Acacia nilotica.* The objectives of this study were: (i) to evaluate soil moisture dynamics under different tree densities/ spacings throughout the year, and (ii) to assess how soil moisture variations influence tree growth, intercrop yield and natural gum exudation in semi-arid Bundelkhand.

## 2. MATERIALS AND METHODS

### Site description and environmental setting

The present study was undertaken at research farm of ICAR-CAFRI, Jhansi; located at 24° 11' N and 78° 17' E in Uttar Pradesh. Mean annual rainfall of the region is 867 mm, which is received in on an average 52 rainy days per year. Mean maximum temperature ranges from 23.5 (January) to 47.4 °C (June) and mean minimum temperature from 4.1 (December) to 27.2 °C (June). The hottest months of the region are May and June. The soil of the experimental plot is a mixture of red and black soils, typical of Bundelkhand region. The soil characteristics of experimental plot are as follows: pH: 7.40, electrical conductivity (EC): 330 $\mu S\ cm^{-1}$, organic carbon (OC): 0.65%, available nitrogen (N): 224.60 kg $ha^{-1}$, available phosphorus (P): 9.22 kg $ha^{-1}$, available potassium (K): 203.90 kg $ha^{-1}$, iron (Fe): 16.46 ppm, manganese (Mn): 18.97 ppm, zinc (Zn): 0.11 ppm and copper (Cu): 1.20 ppm.

### Agroforestry system and intercrops

The study was conducted during 2019-2020 in a well-established 7 years-old rainfed agroforestry system wherein two important gum-yielding tree species, namely *A. senegal* and *A. nilotica* were planted in 2012. The dimension of the experimental field is 65 m long and 180 m wide. Entire field was divided into three blocks (65×60 m each) wherein *A. senegal* and *A. nilotica* were planted in different spacing regimes *viz.*, 5×5 m (400 trees $ha^{-1}$), 10×5 m (200 trees $ha^{-1}$) and 10×10 m (100 trees $ha^{-1}$). There are 12 rows in a 5×5 m block; six rows in a 10×5 m block; and six rows in a 10×10 m block. In each block, each row of *A. senegal* is being alternated with the row of *A. nilotica*. In total trial consisted of 294 trees (147 *A. nilotica* and 147 *A. senegal)*. The data on growth of trees after seven and eight years of planting is given in Table 1.

Cropping sequence of sesame (*Sesamum indicum* L.) in *kharif* and taramira (*Eruca sativa* Mill.) in *rabi* season was followed for intercropping. Both the crops were cultivated by adopting standard packages of practices. Sesame (variety RT-351) was sown on 2$^{nd}$ July and harvested on 13$^{th}$ October 2020. Similarly, taramira was sown on 21$^{st}$ October 2019 and harvested on 15$^{th}$ April 2020. To assess the effect of planting spacing on performance of intercrops, samples of understorey crops were taken using quadrat (1 m × 1 m) method from all three spacing regimes. Data on plant population, seed yield, and above-ground dry biomass were recorded. The total rainfall received at Jhansi was 705.7 mm in 2019 and 761.0 mm in 2020. The distribution of rainfall is depicted in Figure 1.

Table 1. Tree growth data of *A. senegal* and *A. nilotica* in rainfed agroforestry system

| Tree species | Spacing | Height (m) | | GBH (cm) | | Canopy spread ($m^2$) | |
|---|---|---|---|---|---|---|---|
| | | 2019 | 2020 | 2019 | 2020 | 2019 | 2020 |
| *Acacia senegal* | 10 m×10 m | 3.90 | 4.76 | 26.2 | 32.6 | 10.0 | 15.2 |
| | 10 m×5 m | 3.14 | 4.13 | 20.7 | 22.6 | 8.6 | 12.7 |
| | 5 m×5 m | 3.61 | 4.79 | 22.8 | 27.5 | 8.8 | 13.4 |
| *Acacia nilotica* | 10 m×10 m | 4.45 | 4.66 | 30.6 | 31.5 | 9.9 | 14.0 |
| | 10 m×5 m | 3.99 | 4.35 | 24.5 | 27.2 | 9.1 | 12.8 |
| | 5 m×5 m | 4.36 | 4.96 | 27.4 | 30.4 | 9.7 | 13.3 |

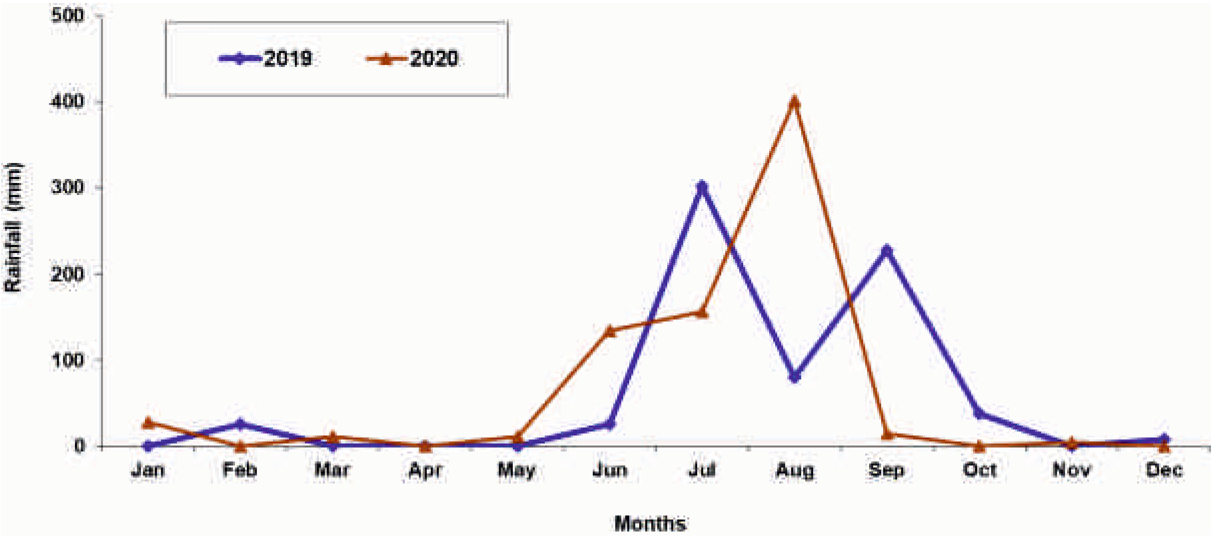


Figure 1. Distribution of rainfall received in Jhansi during 2019 and 2020

**Soil moisture dynamics**

To assess the soil moisture dynamics of the experimental field throughout the year, monthly soil moisture content was measured. For this purpose, two soil samples were collected from under the tree canopy in each spacing and in each tree species at two depths: 0–15 cm and 16–30 cm, using a soil auger. In total, 24 soil samples were collected each month (2 samples × 2 depths × 2 tree species × 3 spacing = 24). The soil moisture monitoring began in November 2019 and continued until October 2020. Samples were collected during the first week of every month, brought to the laboratory, and analyzed for moisture content using the gravimetric method by oven-drying to a constant weight. The soil moisture (%) was calculated as: Soil moisture (%) = $(W_f\text{-}W_d/W_d)*100$; where, $W_f$ is fresh weight of the soil sample, $W_d$ is dry weight of the soil sample. Soil moisture (%) of both the soil layers (0-15 and 16-30cm) was converted into soil moisture (mm) using the following formula.

Soil moisture (mm) =Soil moisture (%)×BD × Soil depth (m) ×10

where, BD is bulk density of soil ($g/cm^3$) assumed to be 1.5$g/cm^3$. Cumulative soil moisture (mm) was computed for 0-30 depth by summing soil moisture (mm) of both the layers of soil *viz.* 0-15 and 16-30cm depths.

**Data analysis**

Soil moisture and intercrop yield data was subjected to factorial ANOVA. Post-hoc analysis was performed using Fisher's least significant difference (LSD) test ($p < 0.05$) to compare means for significant effects. Mean monthly moisture was correlated with tree's incremental growth, gum exudation and crop yield attributes.

## 3. RESULTS

**Soil moisture dynamics**

Month-wise data on soil moisture content is presented in Table 2. As revealed from the data, soil moisture varied significantly with tree species, plantation spacing or tree density, and months. On average, soil under *A. senegal* retained significantly higher moisture compared to *A. nilotica*. Among the spacing, 5x5m recorded significantly higher moisture than 10x5m and 10x10m in both the tree species. Significant interactive complementarity was observed in the soil moisture content due to interactions between tree species and spacing, tree species and months, spacing and months, and tree species, spacing and months. Maximum soil moisture was observed

**Table 2 Dynamics of soil moisture in gum-yielding trees based rainfed agroforestry systems**

| Month | *A. senegal* | | | | *A. nilotica* | | | | Grand |
|---|---|---|---|---|---|---|---|---|---|
| | 5×5m | 10×5m | 10×10m | Mean | 5×5m | 10×5m | 10×10m | Mean | Mean |
| Nov | 37.58 | 31.44 | 31.60 | 33.54 | 37.76 | 32.48 | 32.37 | 34.20 | 33.87 |
| Dec | 32.21 | 27.11 | 27.31 | 28.88 | 28.90 | 25.49 | 23.87 | 26.09 | 27.48 |
| Jan | 53.62 | 43.89 | 36.11 | 44.54 | 51.38 | 40.15 | 37.30 | 42.94 | 43.74 |
| Feb | 32.30 | 30.18 | 28.60 | 30.36 | 34.38 | 30.69 | 28.48 | 31.18 | 30.77 |
| Mar | 20.96 | 18.87 | 17.12 | 18.98 | 19.27 | 17.70 | 15.48 | 17.48 | 18.23 |
| Apr | 11.44 | 10.89 | 9.63 | 10.65 | 11.90 | 10.45 | 9.39 | 10.58 | 10.62 |
| May | 20.40 | 18.21 | 14.74 | 17.78 | 21.14 | 18.85 | 17.70 | 19.23 | 18.51 |
| Jun | 15.41 | 15.41 | 15.00 | 15.27 | 16.58 | 12.96 | 9.50 | 13.01 | 14.14 |
| Jul | 60.17 | 46.60 | 34.80 | 47.19 | 49.26 | 47.71 | 35.05 | 44.01 | 45.60 |
| Aug | 63.86 | 62.96 | 60.36 | 62.39 | 63.09 | 58.83 | 65.09 | 62.34 | 62.37 |
| Sep | 69.01 | 70.44 | 70.95 | 70.13 | 72.02 | 75.17 | 67.22 | 71.47 | 70.80 |
| Oct | 82.58 | 58.85 | 58.83 | 66.75 | 69.19 | 62.77 | 60.36 | 64.11 | 65.43 |
| Mean | 41.63 | 36.24 | 33.75 | 37.14 | 39.57 | 36.10 | 33.49 | 36.38 | 36.80 |
| LSD at 5% for trees: | | | | | 0.389 | | | | |
| LSD at 5% for spacing: | | | | | 0.477 | | | | |
| LSD at 5% for months: | | | | | 0.953 | | | | |
| LSD at 5% for trees x spacing: | | | | | 0.674 | | | | |
| LSD at 5% for trees x months: | | | | | 1.348 | | | | |
| LSD at 5% for spacing x months: | | | | | 1.651 | | | | |
| LSD at 5% for trees x spacing x months: | | | | | 2.335 | | | | |

in *Acacia senegal* planted at 5x5m spacing in the month of October (82.58mm), while the least in *Acacia nilotica* planted at 10x10m spacing in the month of April (9.39mm).

Significant variations were noticed in soil moisture contents of different months. Irrespective of spacing, maximum soil moisture was recorded in the month of September in both the species. Irrespective of months, the mean monthly soil moisture content was significantly higher in 5x5m than 10x5m and 10x10m spacing in both the tree species. In general, soil moisture declined with increase in plantation spacing or decrease in tree density. The months of the rainy season (Jul-Oct) recorded maximum soil moisture followed by winter (Nov-Feb) and the least in the summer season (Mar-Jun) (Figure 2).

**Tree growth**

Mean annual increments in GBH, height and canopy spread of both species are depicted in Figure 3. In *A. nilotica* maximum GBH increased in trees planted at 5x5m spacing followed by 10x5m and the least at 10x10m, while in *A. senegal* maximum GBH increased at 10x10m and least at 10x5m. In both the trees, maximum increment in tree height was recorded at 5x5m spacing. Spread in tree canopy was maximum at 5 x 5m spacing in *A. nilotica* while at 10x10m in *A. senegal*. Irrespective of spacing, *A. senegal* recorded more incremental growth in tree height, GBH and canopy spread than *A. nilotica.*

**Yield of intercrops**

Data on the yield of intercrops are presented in Tables 3 and 4. The planted tree species did not significantly affect the plant population or seed yield of sesame (til). However, the above-ground biomass was significantly higher under *Acacia nilotica* compared to *Acacia senegal*. Different spacing resulted in significant variations in plant population, seed yield, and above-ground biomass, with the highest values recorded at 10 m × 10 m spacing and the lowest at 5 m × 5 m, and *A. nilotica* consistently outperforming *A. senegal*. Among the three spacing, the trend followed was 10 m × 10 m > 10 m × 5 m > 5 m × 5 m (Table 3).

The two-way interaction between tree species and spacing was statistically non-significant for seed yield and above-ground biomass. However, a significantly higher plant population was observed in A. *nilotica* at 10 m × 10 m spacing, likely due to the interactive complementarity between species and spacing.

In the case of *Eruca sativa* (taramira), grown on conserved soil moisture during the winter season, the tree species did not have a significant influence on any of the crop attributes. While tree spacing did not affect

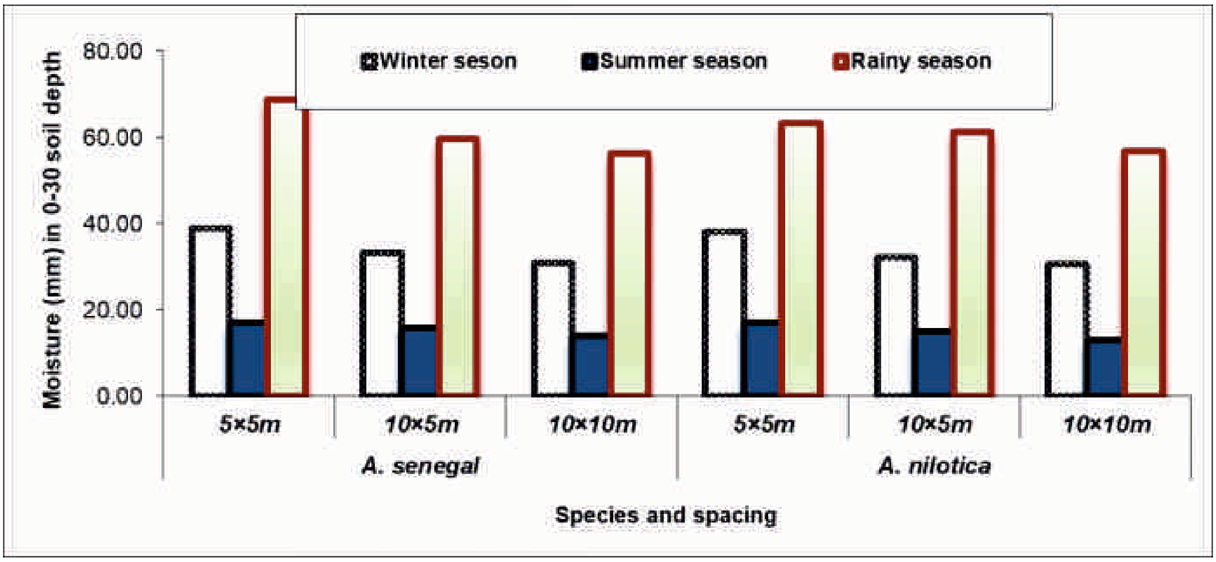


**Figure 2. Seasonal variation in soil moisture in gum-yielding trees based rainfed agroforestry system**

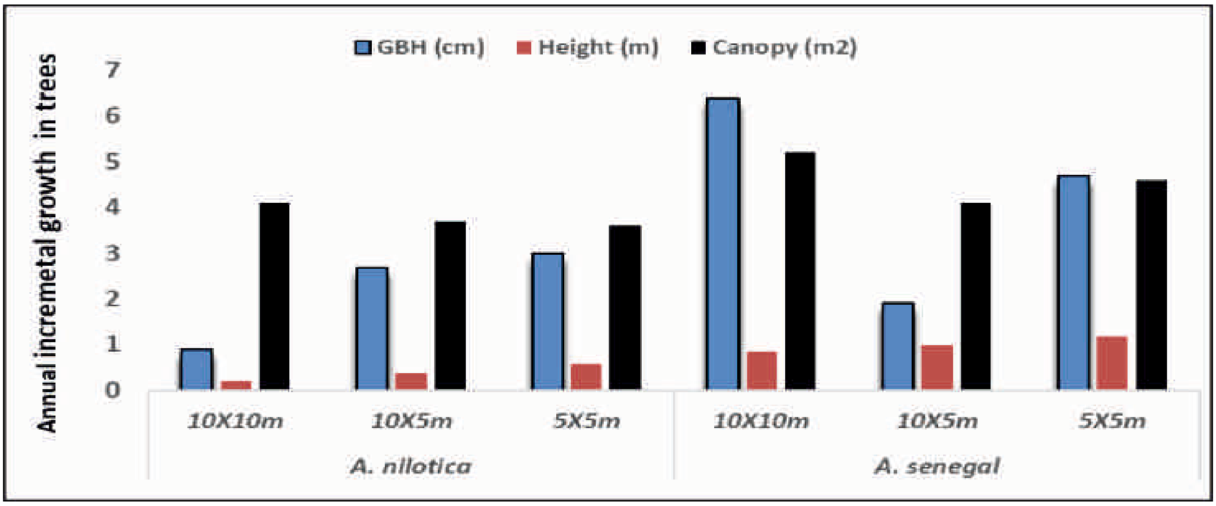


**Figure 3. Annual incremental growth of *A. senegal* and *A. nilotica* in rainfed agroforestry system**

**Table 3. Yield of sesame in gum-yielding trees based rainfed agroforestry system**

| Parameters | Tree species | Spacing (m) | | | Mean |
|---|---|---|---|---|---|
| | | 10 × 10 | 10 × 5 | 5 × 5 | |
| Plant population/$m^2$ | *A. senegal* | 27.67 | 23.67 | 18.00 | 23.11 |
| | *A. nilotica* | 31.67 | 24.0 | 17.67 | 24.44 |
| | Mean | 29.67 | 23.83 | 17.83 | |
| Seed yield (g/$m^2$) | *A. senegal* | 21.63 | 15.99 | 13.79 | 17.14 |
| | *A. nilotica* | 21.77 | 16.16 | 13.90 | 17.27 |
| | Mean | 21.70 | 16.08 | 13.84 | |
| Above ground dry biomass (g/$m^2$) | *A. senegal* | 54.09 | 46.39 | 42.17 | 47.55 |
| | *A. nilotica* | 58.47 | 49.04 | 44.23 | 50.58 |
| | Mean | 56.28 | 47.71 | 43.20 | |

| | LSD at 5% Plant population | LSD at 5% Seed yield | LSD at 5% Above ground biomass |
|---|---|---|---|
| Species | NS | NS | 1.25 |
| Spacing | 1.80 | 1.00 | 1.53 |
| Species × spacing | 2.55 | NS | NS |

**Table 4. Yield of taramira in gum-yielding trees based rainfed agroforestry system**

| Parameters | Tree species | Spacing (m) | | | Mean |
|---|---|---|---|---|---|
| | | 10 × 10 | 10 × 5 | 5 × 5 | |
| Plant population/m$^2$ | *A. senegal* | 9.3 | 8.7 | 8.3 | 8.8 |
| | *A. nilotica* | 9.7 | 9.0 | 8.7 | 9.1 |
| | Mean | 9.5 | 8.8 | 8.5 | |
| Seed yield (g/m$^2$) | *A. senegal* | 60.3 | 51.7 | 40.7 | 50.9 |
| | *A. nilotica* | 59.0 | 56.0 | 48.3 | 54.4 |
| | Mean | 59.7 | 53.8 | 44.5 | |
| Above ground dry biomass (g/m$^2$) | *A. senegal* | 196.0 | 179.3 | 143.0 | 172.8 |
| | *A. nilotica* | 194.7 | 170.7 | 146.7 | 170.7 |
| | Mean | 195.3 | 175.0 | 144.8 | |

| | LSD at 5% Plant population | LSD at 5% Seed yield | LSD at 5% Above ground biomass |
|---|---|---|---|
| Species | NS | NS | NS |
| Spacing | NS | 7.1 | 15.4 |
| Species × spacing | NS | NS | NS |

**Table 5. Effect of tree spacing on gum exudation and its yield in rainfed agroforestry systems**

| Tree Species | Spacing | Number of trees exuding gum | Mean gum yield (g/tree) | Mean number of gum tears/tree |
|---|---|---|---|---|
| *Acacia senegal* | 10 m × 10 m | 3.0 | 34.3±25.08 | 3.0±1.53 |
| | 10 m × 5 m | 5.0 | 20.8±4.68 | 2.0±0.32 |
| | 5 m × 5 m | 13.0 | 37.6±11.09 | 4.7±1.12 |
| | Total/ mean | 21.0 | 33.2±7.63 | 3.8±0.76 |
| *Acacia nilotica* | 10 m × 10 m | 7.0 | 7.6±2.87 | 2.6±0.78 |
| | 10 m × 5 m | 12.0 | 13.4±3.18 | 4.0±0.86 |
| | 5 m × 5 m | 6.0 | 16.6±8.08 | 5.2±1.54 |
| | Total/mean | 25.0 | 12.6±2.56 | 3.9±0.60 |

the plant population, it caused significant variations in seed yield and above-ground biomass. The highest seed yield and biomass were recorded under the 10 × 10 m spacing, whereas the lowest values were observed under the 5 × 5 m spacing (Table 4). A similar trend was observed for both tree species. The interaction effect between tree species and spacing was non-significant for all crop attributes.

Natural exudation and gum yield from trees

During summer months, the natural exudation of gum was observed in the both gum yielding trees *viz. A. senegal* and *A. nilotica*. First instance of gum exudation in *A. senegal* was noticed in 1$^{st}$ week of April while in *A. nilotica* it was observed in 2$^{nd}$ week of May 2020. The flushes of gum exudation continued until 2$^{nd}$ week of June 2020. The data on mean gum yield (Table 5) reveals that tree spacing caused variations in number of exuding trees, mean gum yield and mean gum tears. On average, irrespective of tree spacing, *Acacia senegal* recorded higher gum yield (33.2 g/tree) compared to *Acacia nilotica* (12.6 g/tree), although the number of gum tears per tree was lower in *A. senegal*. With respect to spacing, *A. senegal* planted at 5 m × 5 m and *A. nilotica* at 10 m × 5 m recorded the maximum number of gum-exuding trees. Both species, when planted at 5 m × 5 m spacing produced the highest mean gum yields and mean gum tears. Across spacing, the mean gum yield of *A. senegal* ranged from 20.8 to 37.6 g/tree, whereas in *A. nilotica* it ranged from 7.6 to 16.6 g/tree. Similarly, the mean number of gum tears per tree ranged from 2.0 to 4.7 in *A. senegal* and from 2.6 to 5.2 in *A. nilotica*. In total, 21 trees of *A. senegal* and 25 trees of *A. nilotica* exuded gum during the summer months.

## 4. DISCUSSION

Our results indicate that on an average *A. senegal* recorded significantly higher soil moisture than *A.nilotica,* which can be attributed to the distinct root morphology of *A. senegal* that offers least competition to associated vegetation, and help in preserving more soil moisture in upper soil layer of 0-30cm depth (Gregory 1996). Significantly higher soil moisture in both tree species planted at 5x5m spacing than that planted at 10x5 and 10x10m spacing is attributed to the higher evaporation losses caused by comparatively more open surface in wide spacing. In drylands, evaporation from the soil surface can reach up to 30–60% of the total amount of rainfall (Wallace, 1991). Significant variation in soil moisture recorded in different months with maximum moisture in the months of the rainy season seems to be obvious due to variations in rainfall distribution over the year and the dry conditions that prevailed in the winter and summer months. The interactive complementarity in soil moisture content might have resulted from the tree-specific characteristics, variable evaporation losses and distribution pattern of rainfall. Apparently, soil moisture dynamics was influenced by the tree's characteristics such as its ability to absorb moisture and its physiological processes like litter fall. The trees can improve soil structure, infiltration, water retention, and at the same time compete with other plants for soil moisture (Ong *et al.*, 1992).

Our results showed that among spacing regimes, *A. senegal* planted in wide spacing (10×10 m) and *A. nilotica* planted in close spacing (5×5 m) attained maximum incremental GBH whereas maximum incremental growth in height was at 5×5m spacing in both the trees. The differences in incremental tree growth under different spacing regimes could be due to the variations in genetic make-up of the test plant species and micro-site environment. Malimbwi *et al.* (1992) suggested that plant's height is generally sensitive to the variations in the site quality. Sibomana *et al.* (1997) reported significant increase in plant's height with the increase in tree to tree spacing. In closely spaced plantations (higher density), competition for available resources is greater, whereas in widely spaced plantations (lower density), competition is reduced. In the present study, trees planted at wider spacing exhibited a greater canopy spread, which gradually decreased as the planting density increased. These findings conform to the results of Prasad et al (2020) who reported that both the species recorded maximum canopy spread and utilizable biomass in 10×10 and minimum in 5×5 m spacing; however, total biomass found higher in close spacing (5×5 m). According to Nagar *et al* (2015), crown development is related to the planting density. Available soil moisture apparently influenced tree growth. Irrespective of tree species and spacing, the mean monthly soil moisture content positively, though non-significant, correlated with the incremental growth in GBH ($R^2$ 0.031), tree height ($R^2$ 0.289) and canopy spread ($R^2$ 0.488) (Figure 4).

The poor degree of correlation between soil moisture and the incremental tree growth may be due to overriding effects of spacing or tree density. In semi-arid areas water availability is a primary factor controlling plant growth (Bewley and Krochko, 1982) and in dry environments about 90% of the diameter growth in woody plants is attributed to water availability (Zahner, 1968).

Tree species did not influence yield of either associated crops (sesame and taramira). However, spacing caused significant variation in grain yield of both the inter-crops. In general, grain yield of the intercrops declined with the increase in planting spacing of *A. senegal* and *A. nilotica*, which can be attributed to availability of more open area for crop growth. These findings are in confirmation of Prasad et al (2022a) who studied performance of inter-crops grown in rainfed agri-silviculture system and reported that planting spacing of *A. senegal* and *A. nilotica* had a significant effect on the growth and yield of understory crops. They also reported that wide planting yielded the maximum growth and yield of intercrops, while close planting produced the minimum.

Interestingly, our results show that soil moisture was maximum in 5x5m spacing, which declined with the increase of spacing to 10x5 and 10x10m. The contrasting trend in grain yield in respect to tree spacing needs some explanation. It appears that availability of more open space for crop plants in wide spacing greatly increased utilization of rainfall water and trees posed minimal competition for crop roots. Since, woody plants presumably used subsoil water

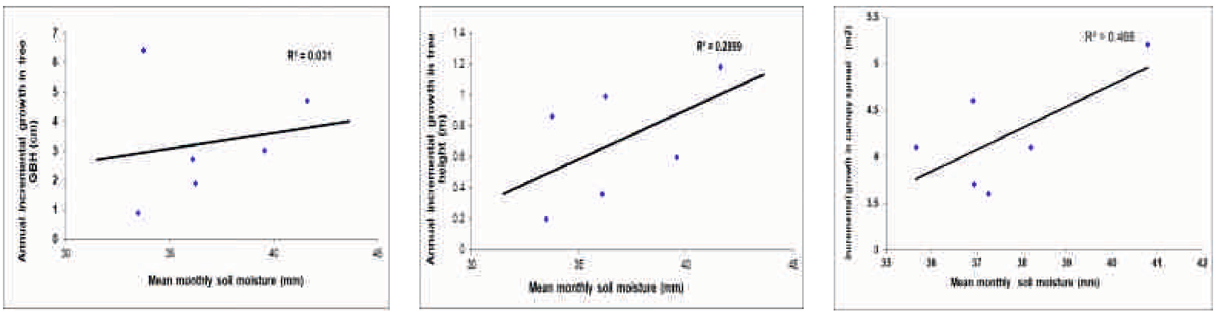

**Figure 4. Effect of mean monthly soil moisture content on tree's incremental growth in rainfed agroforestry systems**

and thus, did not affect the establishment, growth or yield of associated crops (Walker *et al.*, 1981; Smit and Rethman, 2000). Soil moisture content apparently played a positive role for crop yield. Irrespective of the tree species and plantation spacing, the grain yield of both the intercrops did not exhibit any trend with mean monthly moisture content. However, irrespective of tree species, a positive but non-significant correlation was found between monthly moisture content and grain yield of intercrops within all the spacing (Figure 5). The degree of correlation was better for winter season crop ($R^2$ 0.3264) in 10x10m spacing in comparison to others. In 10 x10m and 5 x 5m spacing, the shading effect of trees appears to have overriding effects resulting in poor correlation between crop yield and soil moisture.

Results of present study on gum exudation reveals that planting spacing has caused variations in number of gum exuding trees, mean gum yield and mean gum tears. *A. senegal* recorded more gum yield than *A. nilotica*. Maximum number of *A. senegal* trees exuding gum were planted at 5x5m and *A. nilotica* at 10x5m. Both the trees planted at 5x5m spacing yielded maximum mean gum yield and mean numbers of gum tears. The variation in gum exudation pattern and gum yield in *A. senegal* and *A. nilotica* is attributed to species specific genetic variability, morphological traits and site conditions. Gray et al (2013) found wide variation in *A. senegal* provenances in respect to water use efficiency and gum arabic production. Mohamed (2005) studied the suitability of *Acacia senegal* stands for agroforestry with regard to soil moisture depletion and physiological traits; and reported that as the tree size increases the amount of water depleted from the soil profile also increases. Significant positive correlation was found between the amount of water in the profile and the tree photosynthetic rate. They concluded that, in *A. senegal* agroforestry, tree density affects the competition for soil water between agroforestry system components.

In present study, the gum exudation and its yield was not influenced significantly by soil moisture content. Irrespective of tree species and spacing, mean monthly moisture content had positive but non-significant correlation with mean gum yield ($R^2$=0.163), number of trees exuding gum ($R^2$=0.314) and number of gum-tears/tree ($R^2$=0.588). However, the mean gum yield was significantly correlated (Figure 6) with the annual incremental growth in the tree GBH ($R^2$ 0.760) and the tree height ($R^2$ 0.778). Our findings conforms to Prasad *et al.* (2022b) who assessed relationship between natural gum exudation in *A. senegal* and soil water content in agroforestry systems in both rainfed and irrigated conditions; and reported that the degree of non-significant positive correlation between mean gum yield and soil water content was better in rainfed condition than that in irrigated agroforestry system. They further reported that the number of trees exuding gum also increased with soil water content. The rainfall in preceding month of gum exudation had direct effect on mean gum yield. Our results are also in line with Gray *et al.* (2013) who observed that the gum

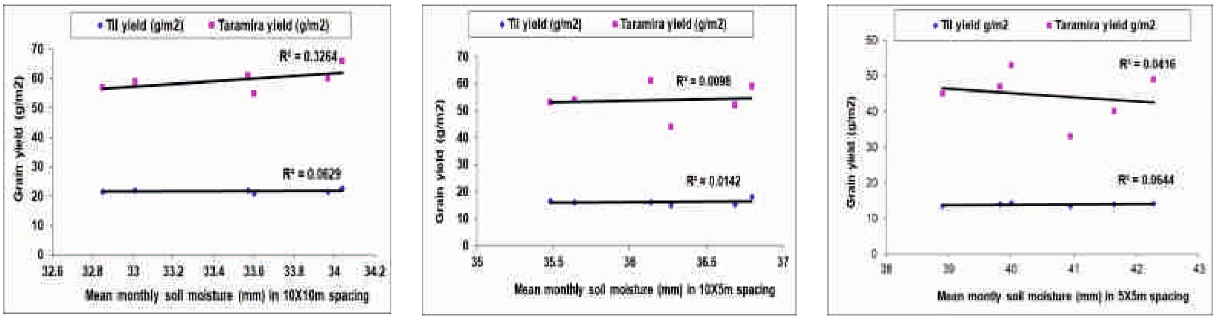


**Figure 5. Relationship between monthly soil moisture and inter-crop yield in different plantation spacing in rainfed agroforestry systems**

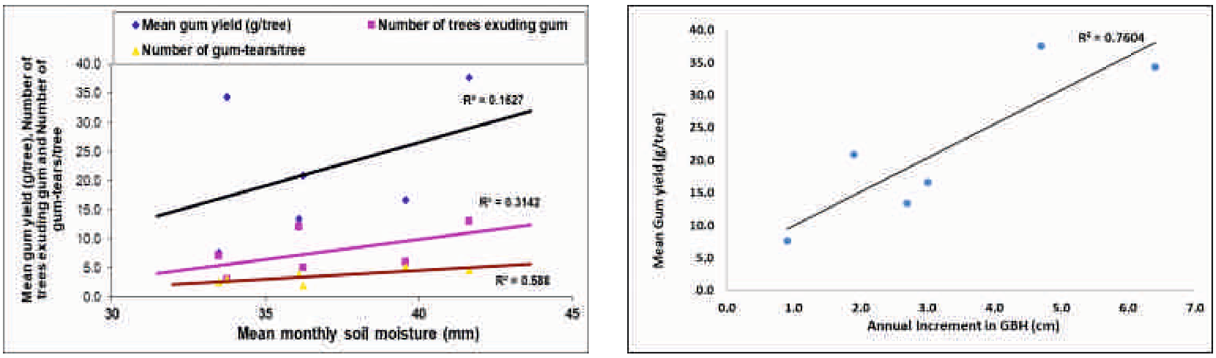


**Figure 6. Relationship between monthly soil moisture and gum exudation; and mean gum yield and annual increment in tree GBH in rainfed agroforestry systems**

yield declines with increasing water use efficiency of the stand. Better tree growth is likely to yield more gum as the tree growth directly related to rainfall and soil moisture. Thus, it can be construed that in good rainfall years, better exudation from gum-yielding trees can be expected in summer season (Prasad et al 2022b).

## 5. CONCLUSION

The study revealed that tree species, planting spacing, and seasonal variations significantly influenced soil moisture dynamics in a rainfed agroforestry system based on *Acacia nilotica* and *Acacia senegal* in semi-arid Bundelkhand, Central India. *A. senegal* maintained higher soil moisture than *A. nilotica*, with the highest moisture observed under close spacing (5 × 5 m) and during the rainy season. Tree growth parameters varied with spacing, while intercrop yields of sesame and taramira were unaffected by tree species but were highest under wide spacing (10 × 10 m) and lowest under close spacing (5 × 5 m). Natural gum exudation occurred in summer, with *A. senegal* producing higher gum yield, particularly under close spacing. Overall, wide spacing favors intercrop productivity, close spacing enhances gum yield, and medium spacing (10 × 5 m) offers a balanced approach for optimizing both gum and intercrop production in *Acacia nilotica* and *Acacia senegal* based agroforestry systems in semi-arid conditions of Bundelkhand region.

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