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# Observations on rooting patterns of *Colophospermum mopane* in agroforestry systems of hot arid Rajasthan

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**Abstract**
Root architecture of 12-years old *Mopane* (*Colophospermum mopane*) along a soil depth gradient of up to 2.5 m was studied with a focus to record the belowground development and biomass production. In the study, the rooting pattern of *C. mopane* indicated that > 70% roots were confined to upper 60 cm soil layer. The root spread was 2.48 fold higher than the crown spread. The angles of primary roots were more than 66°. The total root biomass varied from 5.13 kg to 13.80 kg and average root: shoot ratio was 0.20. The inferences of the results have been discussed in the context of the ecological niche of the species, and its usefulness in agroforestry systems.

**Keywords:** Arid region, Mopane, Root angle, Root spread, Rooting pattern

Tree plays an important role in ensuring livelihood security of arid region. The absence of adequate information on belowground rooting pattern, leads to problems in the designing and managing of agroforestry systems. Competition between trees and intercrops exist belowground for soil moisture and nutrients, apart from aboveground competitions for light (Ong and Huxley, 1996). Though deficiency of the soil nutrients also has a major impact on the crop yields of the system, competition for soil resources particularly soil water, generated by roots is said to be the main factor affecting crop yields followed by light (Gao *et al.,* 2013). An understanding of the rooting pattern is very important especially in arid zones, in order to forecast vegetation dynamics.

Root architecture determines many of the vital functions of a tree such as, competition for resource uptake, stability through anchorage, etc. Root distribution can be extensive but many factors including the type of soil, tree species, health, age, environmental stresses, planting density and silvicultural management influence the ultimate root structure. Shoot- root ratio determines the yield of tree, and intercrops as well. Role of roots in the biological and ecological competitions in the agroforestry systems are pertinent, which in turn is expressed by the vigour and growth of trees. Intensity of competition is regulated by rooting depth/ root spread and appears to be the major constraint that affects stability and function of the agroforestry systems. Eis (1974) observed that tap roots in *Tsuga heterophylla, Thuja plicata* and *Pseudotsuga menziesii*, grew to about 50% of its final depth in 3-5 years, and to 90% in 8 years. In 20-year-old trees of *Picea sitchensis*, more than 80% of total cross sectional area is comprised of 3-10 prominent lateral roots (Coutts, 1983). In the eastern United States, the ratio of root spread to crown radius was measured after excavation of lateral roots in several species by Gilman (1990), who recorded that average root spread exceeded crown radius by a factor of 1.7 in green ash (*Fraxinus pennsylvanica*) and in poplar (*Populus* sp.) and in the case of red maple (*Acer rubrum*), it is >3. In most of the species maximum root biomass was allocated in the top 30 cm of the soil layer, which also provides enough absorptive surfaces to exploit water and nutrients from the top soil, does not offer much physical support to the shoot system (Shukla and Ramakrishnan, 1984). Chauhan *et al.* (2009) excavated root system of thirteen tree species and recorded that 83 to 100 per cent root system is distributed in the top one meter.

*Mopane* (*Colophospermum mopane* (Kirk ex Benth) J. Leonard) is a multipurpose tree belonging to the family Leguminosae introduced to India from southern Africa (Subbulakshmi *et al*., 2017). Being a drought hardy species, *C. mopane* can withstand harsh climatic conditions of arid regions. It was planted in arid Rajasthan to stabilize sand dunes and to provide fuel wood, fodder, shade, shelter to the local communities. Under agroforestry systems, *C. mopane* was observed to have better height and collar diameter growth than sole tree plantations (Patidar *et al*., 2008; Singh and Singh, 2015), which at later stages, affect the growth and yield of inter-

-crops due to competition for moisture and nutrition (Yadava *et al*., 2013).

To minimize the competitive effects in agroforestry systems, an understanding of the rooting pattern of tree species is essential, which will help in applying management practices like regular shoot pruning, root pruning, creating root barriers, application of fertilizers, and irrigation. Hence, the present study was conducted to determine the rooting pattern and biomass of *C. mopane* trees grown in agroforestry systems at 12 years of its age in arid western Rajasthan for proper management of the species leading to better tree-crop production.

The study was conducted at ICAR- Central Arid Zone Research Institute, Regional Research Station, Bikaner, situated in north western India (located at $11^0$ 19' N latitude and $77^0$ 56' E longitudes and an altitude of 300 m above mean sea level). The mean annual rainfall of the region is 255 mm and very high mean evaporation of 1255 mm year$^{-1}$. The mean maximum and minimum temperatures are 49 $^0$C and 5 $^0$C, respectively with less relative humidity. The soil of this region is sandy loam with an average pH of 8.5.

The rooting pattern and characteristics of root in a 12-years old *C. mopane* plantation grown under agroforestry system at spacing of 6 m x 5 m with cluster bean and green gram in *kharif* and mustard and barley in *rabi* season was assessed. The entire root system of tree of *C. mopane* was excavated manually. The method used for this study was destructive sampling method with five trees in a row and three replications. Healthy trees with average growth were selected randomly based on height and girth at breast height (GBH). The diameter at breast height (DBH), height and crown spread of each selected tree was measured. During digging, the horizontal spread of roots was measured and after excavation, the whole root system was realigned as far as possible into its original position. The roots originated from the tap root or main root were designated as primary roots irrespective of their size. Roots originated from primary and secondary roots are called as secondary and tertiary roots, respectively (Chaturvedi and Das, 2002). Root angles were measured with the help of angular instrument. Observations on roots were made in different soil zones (*w.r.t.* depth) *i.e*., Zone I (0-30 cm), Zone II (31-60 cm), Zone III (61-90 cm), Zone IV (91-120 cm), Zone V (121-150 cm), Zone VI (151-180 cm) and Zone VII (181-210 cm) (Fig 1). Root and shoot biomass, root: shoot ratio and the ratio of root and crown spread were also calculated. All biomass estimates were based on oven dry weights. The data were analyzed for standard deviation.

**Fig 1.** Root system of *C. mopane*

The height and diameter at breast height of *C. mopane* trees varied between 3.3 m to 4.55 m and 7.96 cm to 19.43 cm. The average crown spread of *C. mopane* was 4.05 m (Table 1). Root spread to crown width ratios depend on tree species, stand density and kind of soil. In the present study, average horizontal root spread ranged from 12 cm to 238 cm at different depths (Table 2). Maximum root spread was observed in upper zones. The root spread exceeded the crown spread and it was 2.48 fold higher than the crown spread. Similar results of higher root spread than crown spread were observed in many other trees by several researchers. Harry and Smith (1964) observed root spread to crown width ratio of 2.4 in lodgepole pine. Root spread was found 1.2 fold higher than crown width in six-year-old trees of *Prosopis cineraria, Eucalyptus tereticornis* and *Populus deltoides* (Toky and Bisht, 1992). A 1.13 to 1.64 fold greater root spread than crown width was reported by Chaturvedi and Das (2002) in *A. nilotica, D. sissoo, P. dulce, C. fistula* and *S. cumini*. Singh and Singh (2015) recorded 1.77 times greater rooting area than canopy area in twenty one year old *C. mopane* in agroforestry systems in western Rajasthan. However, these species were situation specific where roots extended for moisture and nutrients.

The average vertical root spread (main root depth) of 210 cm was observed in *Colophospermum mopane*. Similar observation was reported by Toky and Bisht (1992) in *Prosopis cineraria*, *Acacia nilotica* and *Eucalyptus tereticornis* where the root depth was 233 cm. It was clear that the deep rooted (main roots) species take up nutrient and water more efficiently from deeper layers, as well as provide firm anchorage to the tree in soil, thereby making the tree wind firm (Chaturvedi and Das, 2002). In the present study, deep main roots of *C. mopane* showed its suitability to dry conditions.

**Table 1**. Above ground morphometric characteristics and biomass of 12 year old *C. mopane* trees

| Tree parameters | Minimum | Maximum | Mean | Standard deviation |
|---|---|---|---|---|
| Height (m) | 3.3 | 4.55 | 3.91 | 0.45 |
| DBH (cm) | 7.96 | 19.43 | 14.33 | 4.78 |
| Crown spread (m) | 3.55 | 4.65 | 4.05 | 0.39 |
| Shoot biomass (kg/tree) | 22.44 | 67.41 | 38.52 | 17.82 |
| Root biomass (kg/tree) | 5.13 | 13.80 | 7.52 | 3.61 |
| Root: shoot ratio | 0.17 | 0.23 | 0.20 | 0.02 |

Root branch angles are significant component of root system architecture. Fitter (1987, 1991) predicted that the roots with branching angles greater than 75° is the optimum branching angle. This angle depends on the growth rate and age of the parent root and the diffusivity of a local limiting resource. In *C. mopane,* the primary root angles varied from 66.67° to 81.67° (Table 2). Primary roots (88%) of Zone I, II, V, VII had more than optimum branching angle of 75° which allowed the roots to reach the outer shell of the parent root's depletion zone the fastest and capture nutrients. Chaturvedi and Das (2002) measured the root branch angles of eight tree species and it ranged between 60° (*S. cumini)* and 86° (*C. fistula*). In another study, it was 67° in *Prosopis cineraria* to 85° in *Dalbergia sissoo* (Toky and Bisht, 1992).

Root diameter is a critical indicator of root physiological function and tensile properties. With an increase in root diameter, cellulose percentage increases while lignin percentage decreases, with consequent decline in tensile strength (Zhang *et al.,* 2014; Lv and Chen, 2013), which is the essential indicator of roots ability to resist external forces (Roering *et al.,* 2003). In the current study, average diameter of primary roots varied between 3.87 cm and 0.57 cm. Primary roots were thicker in upper zones of the soil (up to 60 cm; Table 2). This might be due to two anatomical traits *viz*., greater cortical thickness and more cortical cell layers (Jiacun *et al*., 2014). This type of lateral root system leads to more belowground competition for nutrient and moisture with agriculture crops in agroforestry systems.

The maximum number of primary roots (up to 12) was recorded in Zone I and the minimum (of 1) in Zone V. No primary roots were observed in Zone IV and VI. The number of secondary roots varied from 2 to 22. There was absence of secondary roots in Zones IV, V, and VI. The zone-wise distribution of the number of roots indicated that top 60 cm soil contained 72% (48% in Zone I + 24% in Zone II) of primary roots and 85% of secondary roots (67% in Zone I + 18 % in Zone II) (Fig 1). Similar results were reported in sixteen year old *Pinus radiata*, in which lateral roots were limited to the upper 1 m of the soil profile, and up to 75% of lateral roots spread in the 0-50 cm zone (Watson and O' Loughlin, 1990). Deeper zone of soil had less number of lateral roots when compared with upper zones. The accumulation of more root biomass in the upper layers of soil gave access to more moisture and nutrients available in the top soil. Similar observations on the root distribution of five multipurpose tree species were recorded earlier (Chaturvedi *et al*., 1992; Dhyani *et al*., 1990).

The root: shoot ratios remain more or less constant and are characteristic of the species (Penka, 1965). However, it may differ from sole tree systems to silvopastoral trial with the cropping season and environmental factors also (Cannell and Willet, 1976; Gautam *et al*., 2003; Chaturvedi *et al.,* 2016). It may tend to decrease with tree growth (Ulrich *et al*., 1981). In the present study, the above ground biomass and root biomass ranged between 22.44 to 67.41kg and 5.13 to 13.80 kg, respectively. Root biomass accounted for 16% of the total tree biomass.

**Table 2.** Average morphometric characteristics of primary and secondary roots of *C. mopane*

| Zone | Primary root | | | | Secondary root |
|---|---|---|---|---|---|
| | Number | Rooting angle | Root diameter (cm) | Root spread (cm) | Number |
| I (0-30 cm) | 12 | 75.50 | 3.87 | 238 | 22 |
| II (31-60 cm) | 6 | 78.83 | 3.77 | 192.33 | 6 |
| III (61-90 cm) | 3 | 66.67 | 1.47 | 12 | 3 |
| IV (91-120 cm) | 0 | 0 | 0 | 0 | 0 |
| V (121-150 cm) | 1 | 80 | 0.8 | 15 | 0 |
| VI (151-180 cm) | 0 | 0 | 0 | 0 | 0 |
| VII (181-210 cm) | 3 | 81.67 | 0.57 | 12 | 2 |

The root: shoot ratio varied between 0.17 and 0.23 (Table 1), which were in conformity with the earlier findings of Singh and Singh (2015) who recorded root: shoot ratio of 0.22 in *C. mopane* in agroforestry systems of arid Rajasthan. Similar results were observed in *S. grandiflora, A. lenticularis, D. sissoo* and *A. procera* where the ratio ranged between 0.19 and 0.22 (Chaturvedi and Das, 2002).

From the present study, it was concluded that the deep rooted system of *C. mopane* is suitable for dry and hot regions of the country. However, its lateral spread and accumulation of secondary roots in the upper 60 cm soil layer may lead to competition with agricultural crops and may not be suitable in agri-silvi systems. Hence, it may be grown for greening of wastelands or on sand-dunes in desert areas of Rajasthan.

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