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Influence of soil water regime on nutrient mobility and uptake by *Dalbergia sissoo* seedlings

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Nutrients used for plant growth and biomass productions generally come from the internal cycling of reserve materials which require water for their solubilization and translocation. Nutrient absorption is governed by the interaction occurring at the soil-root interface, including (a) root morphology and growth rate, (b) nutrient absorption kinetics of the root; and (c) soil nutrient supply (Guiterrez-Boem & Thomas 1999). Decrease in soil water availability affects the rate of diffusion of many plant nutrients and finally the composition and concentration of soil solution. Over a period of water stress a marked decrease in nutrient uptake is reported (Marschner 1986) through decreased transfer of ions to the root. Thus, it will be of significant use to quantify the level of water stress above which the mobilization and absorption of nutrients are adversely affected. *Dalbergia sissoo* Roxb was the selected species because of its timber value and social acceptability in the arid and semi-arid areas of western India. The objective of this study was to determine the effect of soil water stress on the availability of soil nutrients, their distribution in different parts and total nutrient uptake by *D. sissoo* seedlings.

The experiment was carried out at the experimental farm of Arid Forest Research Institute (AFRI) Jodhpur (26° 45′ N latitude and 72° 03′ E longitude). Mean monthly minimum and maximum temperature was 10.0°C and 41.3°C, respectively during the experimental period. Rainfall was 237 mm and total pan evaporation was 2109 mm (August 1998 to May 1999). Soil was a loamy sand (coarse loamy, mixed hyperthermic family of Typic Haplocambids) and had pH 8.3, EC 0.5 dSm^{-1} and organic carbon 0.18%. Soil water content at field capacity (-0.03 MPa) was 10.7% (w/w) and 3.2% at –1.5 MPa. The soil had 91.5% sand, 7.1% silt and 1.4% clay and low nitrogen and available phosphorus. Four months old seedlings of *Dalbergia sissoo* was used in the study. Seedlings were planted in galvanized iron containers of 45 m diameter and 55 m depth, filled with 120 kg loamy sand soil. At the time of treatment application, average seedling height and collar diameter were 52 cm and 0.4 cm, respectively. The experiment had five treatments comprising varying water stress in terms of irrigation levels. Each treatment was taken in eight replications and experiment was laid in Randomized Complete Block Design. Soil of all the containers was fully saturated by addition of 82.0 mm water in the first week of October 1998 after proper establishment of the seedlings. Drainage of excess water was allowed till the soil water ceased to drain down. Soil water content was continuously monitored gravimetrically (sampling of soil each time) after oven drying of the soil samples at 110°C temperature to a constant weight. Irrigation levels were defined on the basis of soil water content at suction pressures of –0.03 MPa (10.7%), -0.05 MPa (9.9%), -0.10 MPa (7.4%), -0.50 MPa (5.6%), -1.00 MPa (4.3%) and –1.50 MPa

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(3.2%). The seedlings were re-irrigated by addition of differences in soil waster content between –0.05 to –0.10 MPa (W_1 i.e., 20 mm), -0.10 to –0.50 (W_4 i.e., 14 mm), -0.50 to –1.00 MPa (W_3 i.e., 10 mm) and –1.00 to –1.50 MPa (W_4 i.e., 8 mm) when the soil water content approached to 7.4%, 5.6%, 4.3% and 3.2% in the respective treatments. In addition, there was a control (W_5) in which no further irrigation was done. The experiment was terminated in the first week of May 1999 when the seedlings of W_5 treatments suffered permanent wilting (4.2 mm i.e., 0.56%).

Soil samples were collected in bulk, air-dried at room temperature, ground and passed through a 2 mm sieve. pH, EC, available NO_3-N, NH_4-N and PO_4-P were determined (Jackson 1973). Ca, Mg and K were extracted with ammonium acetate and Zn, Cu, Fe and Mn were extracted with DTPA. Leaf, stem and root of harvested seedling were sampled, dried at 80°C and ground. Nutrients were determined after digestion using Tecator model 5012 Auto Analyzer and Perkin Elmer Model – 3110 double beam atomic absorption spectrophotometer. All the data were statistically analyzed.

Availability of soil nutrients decreased when compared with the initial soil data (Table 1). Mean data of all the treatments indicated that decrease was 2% for P and 54% for Ca compared to the initial values. NH_4-N and NO_3-N decreased by 12% and 44%, respectively, whereas K, Ca, Mg, Zn, Fe and Mn decreased by 24%, 6%, 12%, 15%, 25% and 18%, respectively. Among the treatments, PO_4-P, NH_4-N, K, Ca, Cu and Fe showed decreasing trend with increase in water stress except in the soil of W_1 and W_2 treatments for NH_4-N and K, respectively. It might be due to efficient uptake under sufficient soil water availability in W_1 and W_2 treatments. Comparatively high concentration of NH_4-N and NO_3-N in W_3 treatment was believed to be due to soil drying and low uptake by the seedlings under water deficit and was similar to dry season increase in NH_4-N pool (Garcia-Mendez *et al.* 1991). The decrease in PO_4-P availability with water deficit (W_1 to W_5 treatments) and/or due to decreased diffusive flux of nutrients during water stress (Schaff & Skogley 1982). Availability of K also followed the same trend and decreased with increasing water stress. It indicated that nutrient availability increased with soil water availability. Increase in diffusive K flux in the soil and the efficiency of applied K with increased soil moisture are well documented in the other studies (Zeng & Brown 2000). The decrease in availability of Cu, Fe Mn and Zn with decresing soil water <W_2 was suggested to be due to high soil pH rich in $CaCo_3$ and therefore not readily available to plant roots. Hagen & Tucker (1982) reported that active $CaCO_3$ releases bicarbonate ions into the soil, which decreased the solubility of Fe being high among the micronutrients studied.

Nutrient concentrations in plant tissues generally followed trend: leaf>root>stem, except for K and Mg (Table 2). Considering the treatments, Fe followed the trend leaf>root>stem, whereas N, Ca and Zn followed this trend only for the seedlings of

Table 1. Soil nutrient availability under influence of varying levels of irrigation. Values are mean of three replications.

Nutrient	Initial soil	Treatments					F value
		W_1	W_2	W_3	W_4	W_5	
NH_4-N (mg kg^{-1})	2.2	1.9	1.8	2.3	1.8	1.7	16.81**
NO_3-N (mg kg^{-1})	10.4	5.6	4.7	6.5	6.3	5.9	NS
P (mg kg^{-1})	10.0	10.9	10.0	9.7	9.4	9.0	139.18**
K (mg kg^{-1})	106.0	81.4	82.8	80.7	78.4	76.6	6.39**
Ca (mg kg^{-1})	6.6	6.4	6.4	6.2	6.1	5.9	4.60*
Mg (mg kg^{-1})	0.4	0.4	0.4	0.3	0.4	0.4	NS
Zn (mg kg^{-1})	13.1	10.6	10.9	11.0	11.3	11.6	12.49**
Cu (mg kg^{-1})	0.7	0.4	0.4	0.3	0.3	0.1	68.70**
Fe (mg kg^{-1})	7.9	6.2	6.0	6.0	5.8	5.7	11.57**
Mn (mg kg^{-1})	6.3	5.2	5.7	5.3	5.1	4.5	4.00*

*Significant at <0.05 and NS is non significant >0.05; **Significant at <0.01.
W_1, W_2, W_3 W_4 and W_5 are 20, 14, 10 and 8 mm irrigation levels and 82.0 mm to 4.2 mm soil water content, respectively.

W_3, W_4 and W_5 treatments. The order of P concentration was root>leaf>stem whereas N and Zn followed this only in W_1 and W_2 treatments. The concentration of K and Mg was in order leaf>stem>root for all the treatments and Ca for the seedlings of W_1 and W_2 treatments. Concentration of Mn was high in root whereas Cu concentration was variable. In leaf, concentrations of N, P, Ca, Mg, Zn and Mn increased with increasing water stress whereas Fe, K and Cu followed the reverse trend (Table 2). The increasing trend was also observed in stem for the mineral elements of Fe, Cu and Zn whereas N, P, Ca and K decreased with water stress. In root, generally the concentration of P, K and Ca increased whereas Cu, Fe, Zn and Mn decreased with increasing water stress level. Concentration of N and Mg was variable to soil water stress. Seedlings of W_5 treatment behaved differently with significantly high concentration of Ca in leaf, K, Cu and Fe in stem and Mn in root. General increase in concentration of the mineral elements in leaf, stem and root with decreasing soil water availability might be due to decrease in total biomass of seedlings. Increasing stress decreased leaf area affecting carbon assimilation and decreased C:N ratio and thus increased

Table 2. Effect of varying levels of irrigation on nutrient composition in different components of *D. sissoo* seedlings. Values are mean of three replications.

Nutrient	Seedling components	Treatments					F value
		W_1	W_2	W_3	W_4	W_5	
N (g kg^{-1})	Leaf	22.7	23.0	30.0	32.8	29.6	13.75**
	Stem	19.3	20.1	22.1	20.4	20.4	3.75*
	Root	30.9	26.6	27.4	31.0	22.8	NS
P (g kg^{-1})	Leaf	1.4	1.5	1.6	1.7	1.5	NS
	Stem	1.5	1.4	1.3	1.2	1.1	15.19**
	Root	1.4	1.6	1.6	1.9	1.7	51.79**
K (g kg^{-1})	Leaf	39.8	39.4	31.6	33.0	38.7	105.55**
	Stem	13.0	12.2	15.2	17.2	24.7	25.55**
	Root	12.2	13.2	14.0	14.4	16.9	7.79**
Ca (g kg^{-1})	Leaf	10.7	13.5	15.1	18.1	28.9	80.36**
	Stem	9.5	7.7	4.6	3.8	3.7	45.40**
	Root	6.9	7.5	7.2	8.3	14.0	84.20**
Mg (g kg^{-1})	Leaf	1.7	1.8	1.9	1.9	1.9	NS
	Stem	1.4	1.3	1.4	1.4	1.4	NS
	Root	1.0	1.1	0.9	1.0	1.1	6.41**
Zn (mg kg^{-1})	Leaf	41.4	43.0	46.5	44.3	40.3	5.90**
	Stem	29.0	32.5	35.9	36.4	31.3	7.04**
	Root	49.4	43.3	42.5	39.5	40.3	3.38*
Cu (mg kg^{-1})	Leaf	16.0	17.0	9.7	3.6	5.5	240.35**
	Stem	3.6	3.4	6.6	11.9	13.6	79.36**
	Root	19.1	11.0	7.0	4.7	4.7	144.31**
Fe (mg kg^{-1})	Leaf	711.9	668.1	568.4	527.8	570.7	141.22**
	Stem	197.3	268.7	292.0	296.4	369.9	24.48**
	Root	569.5	562.2	475.5	411.6	498.8	283.36**
Mn (mg kg^{-1})	Leaf	28.6	29.9	40.9	41.0	41.2	20.24**
	Stem	36.3	33.7	44.6	39.9	45.3	4.07*
	Root	49.7	40.0	44.5	38.5	71.1	24.45**

*Significant at <0.05 and NS is non significant >0.05; **Significant at <0.01.
W_1, W_2, W_3 W_4 and W_5 are 20, 14, 10 and 8 mm irrigation levels and 82.0 mm to 4.2 mm soil water content, respectively.

Table 3. Total nutrients contents in 9 months old *Dalbergia sissoo* seedlings as affected by varying levels of water stress. Mean of three replications.

Nutrient	Treatments					F value
	W_1	W_2	W_3	W_4	W_5	
N (g seedling^{-1})	2.75	2.29	0.94	0.71	0.22	163.76**
P (g seedling^{-1})	163.33	145.14	52.55	41.09	13.60	254.26**
K (g seedling^{-1})	2.35	1.98	0.69	0.50	0.22	321.68**
Ca (g seedling^{-1})	1.02	0.91	0.30	0.22	0.11	370.14**
Mg (mg seedling^{-1})	152.37	135.97	47.47	35.30	12.72	309.99**
Zn (ng seedling^{-1})	4.56	3.86	1.48	1.02	0.35	485.83**
Cu (mg seedling^{-1})	1.45	0.98	0.41	0.19	0.08	967.89**
Fe (mg seedling^{-1})	47.21	39.43	14.56	10.20	4.73	723.85**
Mn (mg seedling^{-1})	4.43	3.41	1.57	1.03	0.53	366.09**

**Significant at <0.01.
W_1, W_2, W_3 W_4 and W_5 are 20, 14, 10 and 8 mm irrigation levels and 82.0 mm to 4.2 mm soil water content, respectively.

nitrogen. Increased N in stem and root with increasing water stress might be due to reduced translocation from root to the above ground parts (Ericsson 1995). High nitrogen in root of unstressed seedlings compared to the other might be due to high rate of N_2 fixation. Decreased soil water availability reduced K, Cu, Fe and Mn concentration in leaf probably due to decrease in mobility as a result of increased impedance (Seiffert *et al.* 1995). Decreased K concentration in the leaf of stressed seedlings might be due to retranslocation of K from leaf to stem as indicated by the increased concentration of K in stem of stressed seedlings. Frank (1972) demonstrated that decreasing water supply produces a definite increase in N concentration; decrease K concentration and variable effect of P, Ca and Mg concentration in plants.

Total nutrient uptake followed the pattern of biomass accumulation (Table 3). Total nutrients content of all the mineral elements decreased with increasing water stress. Decrease in Zn, Cu, Fe and Mn uptake in leaf, stem and root under soil water stress might be due to decrease in total biomass from W_1 to W_5 treatments as evidenced by negative correlations of total mineral nutrients uptake with water stress.

Conclusively, results of this study demonstrated better nutrient mobility and uptake at soil water availability >W_3 (-0.50 MPa) and therefore this level is recommended as the optimum for *D. sissoo* seedlings for better growth and biomass production.

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