



UTILIZATION OF TEXTILE INDUSTRIAL EFFLUENT FOR RAISING *AZADIRACHTA INDICA* A. JUSS SEEDLINGS IN INDIAN DESERT

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Submitted 20 May 2009; accepted 16 Jun. 2009

Abstract. A field experiment was conducted during 1993–1995 to study the effect of industrial effluent on the initial growth of *Azadirachta indica* A. Juss. (Neem) in arid region. The effluent released from textile industry had high pH, EC, SAR and RSC. Various treatments were: irrigation with effluent only (W_1), effluent mixed with canal water at 1:1 ratio (W_2), gypsum-treated effluent (W_3), gypsum-treated soil (W_4) and wood ash-treated soil (W_5). W_5 was the best treatment where neem attained 218 cm height, 118 cm crown diameter and 11.2 cm collar circumference at 28 months of age; followed by W_1 treatment, where trees were on an average 186 cm tall and had 104 cm crown diameter and 9.4 cm collar circumference. Growth of the seedlings was the poorest in W_2 treatment. Increase in biomass accumulation over W_2 treatment ($1.89 \text{ kg tree}^{-1}$) was 3.6 fold in W_5 , 2.1 fold in W_1 , 2.0 fold in W_4 and 1.4 fold in W_3 treatments. Though effluent application increased soil organic matter, electrical conductivity and in some cases pH also, but gypsum- and wood ash- treated soil ameliorated the pH by 0.25 units in comparison to the initial data. These results suggest that industrial wastewater can be effectively used to boost up establishment and growth of Neem (*Azadirachta indica*) in arid zone. Addition of wood ash improves the rate of growth. Irrigation with industrial effluent caused slight increase in electrical conductivity and decline in the soil pH.

Keywords: afforestation, arid region, biomass, growth, tree seedlings, soil properties, wastewater use.

1. Introduction

Increasing population is placing increasingly greater demand for the resources to meet their requirements. This leads to industrialization and consequent pressure on the existing natural resources. Increasing urban population and the consequent industrialization draw heavy quantity of water and provide a large quantity of wastewater or municipal effluent. The problems are further aggravating for disposal of these effluents. One of the important measures is using these effluents in tree plantations to control land degradation and improve environmental conditions. Uneven distribution of rainfall, long dry spells, soil water stress and nutrient deficiency constitutes the major constraint in the establishment of planted tree seedlings in dry areas, where better-quality water is becoming an increasingly scarce resource. Both the need to conserve water and to safely and economically dispose of wastewater, make the use of municipal effluent in tree plantation a very feasible option (Singh and Bhati 2005). In many parts of the world, municipal wastewater is used for the irrigation of various crops including agronomic, horticultural and tree crops (Mathur and Sharma 1984; Stewart *et al.* 1986; Urie 1986). Trees and shrubs are a better alternative than agricultural crops because of high growth rates and potential to produce high biomass on annual basis. Trees have ability to sustain very high loading rate because of profuse root system to control leaching, salinity and toxicity of the soil and have no link with food chain.

There are myriad of industries in the Indian arid zone utilizing substantial quantities of scarce water. Traditional textile finishing industry consumes about 100 liters of water to process about 1 kg of textile material. These industries are particularly in dominance in western Rajasthan pumping out millions of litres of effluent containing different dyes including azo dyes, which are released unchanged into water bodies (Zollinger 1987; Pierce 1994). Though fungal decomposition of these dyes have been reported (Paszezynski *et al.* 1993; Young and Yu 1997; Selvan *et al.* 2006), utilization of this effluent for irrigation of tree plantations will be beneficial in increasing biomass production, preventing surface water logging and environmental pollution and recharging of ground water supplies (Aggarwal and Kumar 1990). But, there are many associated problems, including the build up of salts in the soil to toxic levels (Armitage 1985). To avoid harmful effects of effluent to plantations or soil, it needs to be managed. The management options may be treatment of effluent itself or soil amendments to ameliorate sodicity and salinity levels of the textile effluent or the soil under effluent application. Gypsum is reported for its beneficial effects in terms of soil salinity-sodicity amelioration and influence on crop production/seedling growth (Qadir *et al.* 1998; Haisheng *et al.* 2008). Likewise, the ash generated as a by-product of combustion of fuel-wood, has potential to use as a fertilizer in forest systems (Augusto *et al.* 2008), as the wood ash is a source of potassium, calcium, magnesium, and other trace

minerals (Pitman 2006) and supposed to be beneficial in soil improvement and seedling growth.

With this background an experiment was started in July 1993 using industrial effluent from nearby textile industries for establishment of *Azadirachta indica* Juss, which is a multipurpose species with ability to withstand varying adverse site conditions, i.e. high pH, salinity, sodicity, shallow soil depth, etc. We tested a hypothesis that as an alternative to harmful disposal of industrial effluent it could be used to increase biomass production in parched lands of Indian arid Zone and how much beneficial the amendments in terms of gypsum and wood ash treatments are to increase establishment and growth of *A. indica*. Results on the performance of *Azadirachta indica* using textile industrial effluent as irrigation water under different management practices are reported in this paper.

2. Materials and methods

2.1. Site conditions

The experimental site is situated at Jodhpur (26°45' N latitude and 72°03' E longitude) in the northern tropical zone north-western Rajasthan, India. Three seasons in a year are summer, monsoon and winter. The summer from March to middle of July is the most dominant season characterised by high temperature reaching up to 48 °C and strong hot wind. The period from Mid July to September is the monsoon season and receives most of the rainfall. The winter season lasts from November to February. Minimum temperature recorded during the experimental period of July 1993 to November 1995 was 4.8 °C, in February 1994. The soil of the experimental site is loamy sand with 81% sand, low in organic matter and soil nutrients. Soil depth is 80 cm underlain with hardpan of calcium carbonate, locally called 'murrum' layer.

2.2. Plantation establishment

The experiment was started in July 1993 by planting one-year-old seedlings of *Azadirachta indica* (30 cm tall) in 60 cm × 60 cm × 60 cm pit size. Treatments in the form of effluent irrigation and the management practices were: W₁ – irrigation with effluent only, W₂ – irrigation with effluent mixed with canal water at 1:1 ratio, W₃ – irrigation with gypsum-treated effluent, W₄ – soil treated with gypsum, and W₅ – soil treated with wood ash. Wood ash was collected from nearby village where wood is the main source for energy generation. Gypsum and wood ash were applied for their known beneficial effects in terms of sodicity-salinity amelioration and potential fertilizer effects, respectively. Each treatment was triplicated, and the experiment was laid in Randomised Block Design. Each plot had four experimental trees at 4 m × 4 m spacing, which were also taken for growth observation. A boundary row of trees was planted around the experimental block to avoid border effects. Gypsum/ wood ash were thoroughly mixed with pit soil prior to plantation, while the wastewater was treated at the time of irrigation. Earthen rings were made around the plants in such a way as to avoid the direct contact of seedlings with the effluent. The experiment was terminated in November 1995.

2.3. Irrigation and protection measures

Effluent irrigation was given at the rate of 30 liters per plant at monthly interval in winter (October to February) and fortnightly in summer (March to June). The textile effluent was pumped from the nearby sewer to a storage tank near the experimental field. From there effluent was applied by buckets in the rings around the plants. In W₃ treatment, effluent was left for 24 h after gypsum treatment and the plants were irrigated next day. Effluent samples were collected in polythene bottles at every application and analyzed. Plants were protected from termites by applying 0.20 per cent solution of Chloropyrophos, twice in the first year (November 1993 and February 1994) and once in the second year (October 1994).

2.4. Observations

Growth data were recorded quarterly. In the first year, only height was recorded, whereas in the subsequent years, height, crown diameter and collar girth (15 cm above the ground level) of all the seedlings were measured. Soil samples were collected initially in July 1993) and again at 28 months after effluent irrigation (October 1995) using mechanical auger up to a soil depth of 0–75 cm and 50 cm away from the plants. The soil core was divided into three soil layers, i.e. 0–25 cm, 25–50 cm and 50–75 cm soil layers. The samples were then air-dried, ground and passed through 2 mm sieve and analyzed for pH, EC, organic matter, gypsum requirement of the soil and nitrogen and phosphorus availability by standard methods of Jackson (1973). A single soil core was excavated using mechanical auger and the soil core was divided into 0–25, 25–50 and 50–75 cm soil layers to determine soil water content (SWC). The soil samples were put immediately into a polyethylene bag to avoid water losses during transport to laboratory. Sampling was carried out in July 1995 and again in October 1995 to observe changes in soil water content and its use in seedling growth. Soil water content was estimated by oven drying of the sample at 110 °C for constant weight. Gravimetric soil water content was converted to mm using the following equation to give total soil water to the soil depth of 0–75 cm.

$$\text{Soil water (in mm)} = \% \text{ soil water} \times \text{soil depth in mm} \times \text{bulk density of soil} / 100 / \text{density of water}$$

For aboveground biomass estimation, a representative seedling having dimensions equivalent to average height, girth and crown diameter of the seedlings in a plot was felled. Foliage, branches and stem were separated and their fresh weight recorded. Dry biomass was recorded after oven drying the samples at 70–80 °C to a constant weight.

2.5. Statistical analysis

The data collected were statistically analyzed using SPSS statistical package. Since the experiment was laid in complete randomized design, the data were analyzed using a one-way ANOVA using data of height, crown diameter, collar girth, seedling dry mass as the dependent

variables. Treatments were the main factors. To know the soil water depletion by the seedling in different treatments and changes in soil properties were tested using a two-way ANOVA. Treatments and the soil layers were considered as the main factors. Survival data was arcsine transformed and per cent soil water content was square root transformed to reduce heteroscedasticity (Sokal and Rohlf 1981). Duncan Multiple Range Tests (DMRT) were also performed for the entire analysis to obtain the homogenous subsets among the treatments and soil layers. To obtain the relations between seedling growth, soil water depletion and biomass production, a Pearson correlation was performed. Regression models were developed to predict the dry biomass of seedling by observing collar diameter and height of the seedling.

3. Results

3.1. Environmental parameters

The mean monthly minimum temperature was 10.3 °C and the mean monthly maximum temperature was 42.6 °C (Fig. 1a) during the experimental period of July 1993 to November 1995. There were two maxima of the mean monthly maximum temperature, the highest maxima was in May–June, and the second maxima – in October. Mean annual rainfall during the period was 420 mm and mean annual potential evapotranspiration was 2539 mm showing heavy moisture deficit in the experimental period (Fig. 1b).

3.2. Effluent characteristics

Textile effluent had high pH, EC, Na, K and P and low Ca, Mg and the micronutrients (Table 1). Chemical oxygen demand (COD) was within the permissible limit (EPR, 1993). Total solid (TS), total suspended solid

(TSS) and total dissolved solid (TDS) were high in the effluent (permissible limit 100 mg L⁻¹; EPR 1993). Chloride was low but sodium absorption ratio was high.

3.3. Seedling survival

The casualties were replaced in the first year and the percent survival was recorded at the age of 28 months in November 1995. The lowest survival was in the seedlings irrigated with pure effluents (W₁ treatment). The survival was the highest in the seedlings irrigated with effluent and canal water at 1:1 ratio (W₂ treatment). It did not differ ($P > 0.05$) between W₄ and W₅ treatments.

3.4. Growth variables

Seedling height in December 1993 did not differ ($P > 0.05$) due to treatment, though the seedlings were relatively taller in W₁ and shortest in W₃ as compared to the other treatments. In the subsequent years, height, crown diameter and collar circumference differed ($P < 0.01$) between the treatments. At 28 months of age seedling height varied between the treatments, and the tallest seedlings were in W₅ (Table 2) However, the seedlings of W₁ and W₅ did not differ ($P > 0.05$) in height, crown diameter and collar circumference. The seedlings of W₂ treatment were the lowest in these growth variables. As compared to W₂ treatment, the seedling heights in W₁, W₃, W₄ and W₅ were 1.7, 1.3, 1.4 and 2.0 fold greater in the seedlings of respective treatments. Similar trend was also observed for crown diameter and collar circumference both in December 1994 and November 1995. These growth variables were positively related with soil water content in July 1995 in 0–25 cm soil layer ($r = 0.743$, $P < 0.01$, $n = 15$), and in October 1995 in both 0–25 cm ($r = 0.592$, $P < 0.05$) and 50–75 cm ($r = 0.683$, $P < 0.01$) soil layers.

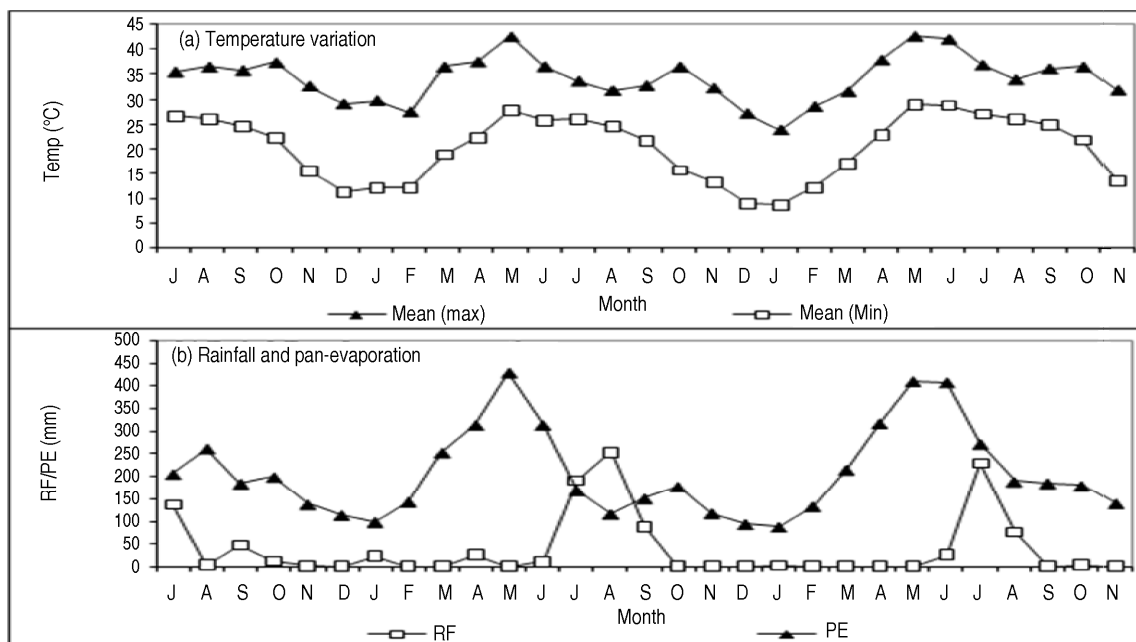


Fig. 1. Changes in mean monthly maximum and mean monthly minimum temperature (a) and rainfall and panevaporation at the site (b) during the experimental period from July 1993 to November 1995

Table 1. Chemical composition of textile effluent at the factory site and application site (drainage passing through the experimental site)

Effluent parameters	Factory	Application site	
		Range	Mean
pH	9.5	8.82–11.8	9.7
Electrical conductivity (dSm ⁻¹)	4.30	3.82–10.7	5
Total suspended solid (mg l ⁻¹)	2000	3.42–19.3	7.5
Total dissolved solid (mg l ⁻¹)	2800	3.12–18.8	6.5
Total solid (mg l ⁻¹)	4800	6.54–38.1	14.0
Sodium adsorption ratio (SAR)	6.25	30–153	128
Chemical oxygen demand (mg l ⁻¹)	300	160–800	1025
Ionic composition			
K (mg l ⁻¹)	40.00	25–30	38.0
Ca (mg l ⁻¹)	28.00	Traces–30	10.2
Mg (mg l ⁻¹)	6.00	Traces–8	4.0
Cl (mg l ⁻¹)	18.46	410–806	680.0
Na (mg l ⁻¹)	139.5	600–5500	2069
NH ₄ -N mg l ⁻¹	0.03	Traces	Traces
NO ₃ -N mg l ⁻¹	0.001	Traces	Traces
PO ₄ -P (mg l ⁻¹)	16.39	4.39–20.41	14.26
Cu (mg l ⁻¹)	Nil	Traces	Traces
Fe (mg l ⁻¹)	Trace	Traces–0.67	0.35
Mn (mg l ⁻¹)	Nil	Traces	Traces
Zn (mg l ⁻¹)	Nil	Traces	Traces

Table 2. Average growth of *Azadirachta indica* seedlings irrigated with textile effluent. Values are mean of three replications with \pm SE

Treat	Height			Crown diameter		Collar circumference	
	1993	1994	1995	1994	1995	1994	1995
W ₁	41.7 \pm 1.8	89.0 \pm 2.9	186.0 \pm 7.8	46.0 \pm 2.5	103.7 \pm 6.1	3.93 \pm 0.23	9.83 \pm 0.88
W ₂	39.0 \pm 7.4	75.3 \pm 2.3	110.3 \pm 6.1	28.3 \pm 0.3	68.3 \pm 0.3	2.63 \pm 0.19	5.80 \pm 0.17
W ₃	27.3 \pm 1.5	62.0 \pm 1.0	137.0 \pm 8.1	33.0 \pm 1.5	95.3 \pm 6.9	2.57 \pm 0.15	7.17 \pm 0.20
W ₄	39.0 \pm 3.1	63.0 \pm 3.0	148.7 \pm 9.9	26.7 \pm 1.7	94.0 \pm 2.9	2.43 \pm 0.09	7.03 \pm 0.12
W ₅	36.7 \pm 5.2	101.0 \pm 3.0	217.7 \pm 18.8	45.7 \pm 2.7	118.3 \pm 4.4	4.03 \pm 0.15	11.23 \pm 0.67
One-way ANOVA							
F value	1.607	43.40	14.483	22.915	14.583	22.592	19.025
P value	NS	P < 0.01	P < 0.01	P < 0.01	P < 0.01	P < 0.01	P < 0.01

Table 3. Growth increments affected by different treatments of the seedlings irrigated with textile industrial effluent. Values are mean of three replicates with \pm SE

Treatment	Height		Crown diameter	Collar girth
	1993–94	1994–95	1994–95	1994–95
W ₁	113.8 \pm 2.5	109.1 \pm 7.7	126.7 \pm 17.6	149.2 \pm 9.3
W ₂	104.8 \pm 31.7	46.3 \pm 4.7	141.3 \pm 3.5	123.0 \pm 19.8
W ₃	128.1 \pm 12.5	120.7 \pm 10.2	181.5 \pm 20.6	181.5 \pm 20.6
W ₄	64.9 \pm 22.1	137.2 \pm 20.8	254.0 \pm 13.3	189.5 \pm 6.3
W ₅	183.3 \pm 27.9	114.8 \pm 11.9	159.9 \pm 8.1	178.0 \pm 6.6
One-way ANOVA				
F value	3.774	7.973	8.472	3.870
P value	P < 0.05	P < 0.01	P < 0.01	P < 0.05

Percent increments in growth variables varied ($P < 0.001$) between the treatments (Table 3). Height increment was greater in 1993–94 than in 1994–95. It was the highest in the seedlings of W₅ in 1993–94 and in W₄ treatment in 1994–95. But the differences in the height increments between the seedlings of W₁, W₃ and W₅ treatments were not significant ($P > 0.05$, DMRT). The lowest height increment was in W₄ in 1993–94 and

in W₂ ($P < 0.05$) in 1994–95. The increments in crown diameter ($P < 0.05$) and collar circumference ($P < 0.05$) were greater in the seedlings of W₄ treatment. The lowest increments were in the seedlings of W₁ for crown diameter and in the seedlings of W₂ for collar circumference in 1994–95. Height increment was positively related with soil water content ($r = 0.696$, $P < 0.01$) in 50–75 cm soil layer in October 1995.

3.5. Seedling dry biomass

Regression model developed between above-ground dry biomass and height and collar diameter indicated a non-linear relation (Table 4). In different combinations, collar diameter X height of *A. indica* was found best in predicting dry biomass and was related by power equation. Values of R^2 were the highest, whereas those of RMSE were the lowest in the regression equations. The value of adjusted R^2 value was very close to the observed value in the regression equation.

Dry biomass varied ($P < 0.05$) between the treatments (Table 5). Both the stem and foliage (leaf + branch) biomass was the highest ($P < 0.05$) in the seedlings of W_5 treatment. The differences in foliage biomass due to treatments were significant ($P < 0.05$) but stem biomass did not differ ($P > 0.05$) between W_1 and W_2 treatments. The lowest biomass of stem and foliage was in the seedlings of W_2 treatment. Accumulation of biomass in W_5 treatment was 3.6 fold; whereas in W_1 treatment it was 2-fold greater as compared to the seedlings in W_2 treatment. Biomass allocation to foliage was the highest (90.7%) in W_1 and reduced to the lowest in the seedling of W_5 treatment, whereas the allocation to stem was the lowest in W_1 and the highest in W_5 treatments. Production of above-ground biomass ranged from 1.13 tons ha^{-1} in W_2 to 4.19 tons ha^{-1} in W_5 treatment. The biomass was positively related with soil water in 0–25 cm ($r = 0.782$, $P < 0.01$) soil layer in July 1995 and in 0–25 cm ($r = 0.636$, $P < 0.05$) and 50–75 cm ($r = 0.658$, $P < 0.01$) soil layer in October 1995.

3.6. Soil moisture storage and depletion

Soil water content (SWC) varied significantly ($P < 0.05$) between the treatments (Fig. 2). SWC was the lowest in the soil of W_1 in July 1995 (48.33 mm in 0–75 cm soil layer) and in W_2 treatment in October 1995 (22.14 mm). In July 1995, SWC was greater by 15%, 13%, 1% and 30% in W_2 , W_3 , W_4 and W_5 treatments, respectively, than in W_1 treatment, but in October 1995, the SWC was only greater in W_4 (by 8%) and W_5 (by 19%) treatments. Considering the soil layers, SWC was the lowest in 0–25 cm soil layer and increased to the highest value in 50–75 cm soil layer. Treatment X soil layer interaction was significant ($P < 0.05$) in July 1995. Depletion in soil water (i.e. soil water use, SWU) between July and October 1995 ($SWC_{July} - SWC_{October}$) was greater ($P < 0.05$) in W_5 (at par to W_2 and W_3 treatments) as compared to those in W_1

and W_4 treatments. SWU did not differ ($P > 0.05$) between the soil layers but it was relatively greater from 25–50 cm soil layer as compared to those in 0–25 and 50–75 cm soil layers. SWU was greater from 0–25 cm soil layer in W_1 , W_4 and W_5 treatments, from 25–50 cm soil layer in W_3 and from 50–75 cm soil layer in W_2 treatments. SWU in 0–25 cm soil layer was positively correlated with seedling height ($r = 0.557$, $P < 0.05$), crown diameter ($r = 0.579$, $P < 0.05$) and dry mass production ($r = 0.557$, $P < 0.05$), and in 50–75 cm soil layer – with height increment ($r = 0.0696$, $P < 0.01$) and collar circumference increment ($r = 0.595$, $P < 0.05$).

3.7. Changes in soil properties

Initial soil in July 1993 was low in organic matter (0.270% at 0–25 cm depth), low in nitrogen (59 kg ha^{-1}) and phosphorous (P_2O_5 12 kg ha^{-1}) and had pH 8.79 and electrical conductivity of 0.24 dSm^{-1} . In October 1995, soil pH did not differ between the treatments (Table 6). However, DMRT indicated significant difference in the soil pH of W_3 (highest) and W_4 (lowest). There was a decrease in soil pH in W_1 , W_2 , W_4 and W_5 as compared to the soil outside the area. The soil of W_3 treatment showed higher pH than the control soil. Electrical conductivity (EC) and soil organic matter (SOM) differed ($P < 0.05$) due to both treatments and soil layers (Table 6). As compared to the soil of control, electrical conductivity increased with effluent irrigation. The increase in EC was significantly greater ($P < 0.05$) in the soil of W_4 and W_5 treatments than for the other treatments. The EC was the lowest in W_2 , which did not differ ($P > 0.05$) with the EC of W_3 and W_1 soils. There was an increase in soil organic matter resulting from effluent application as compared to 0.264 (0–75 cm soil layer) in July 1993. SOM was significantly ($P < 0.05$) greater under W_1 treatment (1.8 fold increase) than those in the soil of the other treatments. Lowest SOM was under W_3 treatment regime (Table 6). Considering the soil layers, (mean of treatments) soil pH was the lowest ($P > 0.05$), whereas electrical conductivity and soil organic matter were the highest ($P < 0.05$) in 0–25 cm soil layers. SOM was negatively correlated with soil water content ($r = -0.603$, $P < 0.01$) in 25–50 cm soil layer in both July 1995, and October 1995, whereas EC was positively correlated with SWC in 50–75 cm in July 1995 ($r = 0.736$, $P < 0.05$) and in October 1995 ($r = 0.714$, $P < 0.05$) in 25–50 and 50–75 cm soil layers.

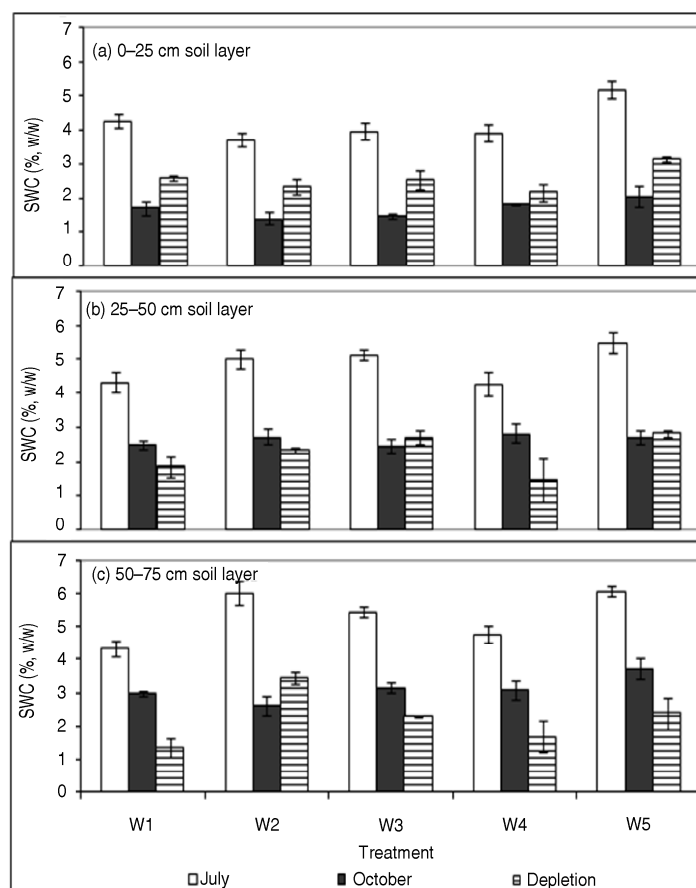
Table 4. Different regression models for predicting above ground dry biomass (TB) of *A. indica* using height (H) and collar diameter (D).

Variable	Model	R^2	Adjusted R^2	MSE	F value
H	$TB = 79.620575 \times H^{0.538091}$	0.853	0.842	0.010807	75.33**
D	$TB = 1.333216 \times D^{0.519074}$	0.810	0.796	0.013631	55.58**
D^2H	$TB = 141.522858 \times D^2H^{1.576239}$	0.844	0.832	0.099676	70.09**
DH^\dagger	$TB = 106.151454 \times DH^{1.057165}$	0.924	0.842	0.041611	75.52**
D^2	$TB = 1.777466 \times (D^2)^{1.038148}$	0.810	0.796	0.054524	55.58**

† Best-fit model; Significant at **, $P < 0.01$

Table 5. Dry mass accumulation of 28 months old *Azadirachta indica* seedlings affected by textile effluent application. Values of three replications \pm SE

Treatment	Branch + leaf		Stem		Total
	Mean	% allocation	Mean	% allocation	
W ₁	3.62 \pm 0.09	90.7	0.37 \pm 0.03	9.3	3.99 \pm 0.11
W ₂	1.62 \pm 0.05	85.7	0.27 \pm 0.01	14.3	1.89 \pm 0.06
W ₃	2.05 \pm 0.14	78.8	0.55 \pm 0.01	21.2	2.60 \pm 0.16
W ₄	2.86 \pm 0.06	77.3	0.84 \pm 0.02	22.7	3.70 \pm 0.07
W ₅	4.69 \pm 0.18	69.5	2.06 \pm 0.11	30.5	6.75 \pm 0.27
One-way ANOVA					
F value	116.396		202.590		146.602
P value	P < 0.01		P < 0.01		P < 0.01

**Fig. 2.** Soil water depletion in different soil layers between July 1995 and October 1995 as a result of growth of *Azadirachta indica* seedlings. Error bars are \pm SE of three replicates

4. Discussions

4.1. Seedling survival and growth

Survival and growth response through space and time is usually influenced by genetic characters of the plants, site conditions and the management practice adopted. The lowest survival in the seedlings of W₁ treatment was due to direct application of the textile effluent, whereas addition of canal water to the effluent reduced the toxic effect resulting in the highest survival of *Azadirachta indica* seedlings in W₂ treatment. Significant differences ($P < 0.05$) in seedling height, crown diameter and collar girth in the subsequent observations indicated the effects of the effluent irrigation and the management practices (Table 2). Aggarwal and Kumar (1994) also reported

non-significant effect of soil treatments on the initial growth of *E. camaldulensis*, *A. nilotica* and *Azadirachta indica*, irrigated with textile effluent in arid zone of India. Relatively lesser height, crown diameter and collar circumference in the seedlings of W₂, W₃ and W₄ than those in the seedlings of W₁ treatment indicated that *A. indica* could be grown by direct application of the effluent. However, the enhanced growth in the seedling of W₅ treatment suggests the beneficial effects of wood ash on *A. indica* seedlings. A 2.8 to 5.9 fold increase in height in November 1995 compared to that in December 1993 indicated irrigation-influenced growth of *A. indica* seedlings. However, the growth was relatively less as compared to 26 months old *A. indica* seedlings grown under rainwater harvesting (Gupta 1994). This indicated a growth-

Table 6. Changes in soil physico-chemical properties under textile effluent irrigation of *Azadirachta indica* seedlings. Values are mean of three replicate with \pm SE. Significant at *, $P < 0.05$; **, $P < 0.01$

Treatment (T)	Soil layer (L)	pH	EC (dSm ⁻¹)	SOM (%)
Initial	0–25	8.79 \pm 0.12	0.24 \pm 0.02	0.270 \pm 0.026
	25–50	9.10 \pm 0.16	0.33 \pm 0.06	0.312 \pm 0.012
	50–75	9.20 \pm 0.09	0.30 \pm 0.05	0.221 \pm 0.041
W ₁	0–25	8.71 \pm 0.36	0.56 \pm 0.04	0.602 \pm 0.096
	25–50	8.93 \pm 0.18	0.47 \pm 0.08	0.414 \pm 0.065
	50–75	8.84 \pm 0.16	0.44 \pm 0.09	0.384 \pm 0.027
W ₂	0–25	9.05 \pm 0.22	0.46 \pm 0.09	0.351 \pm 0.019
	25–50	8.62 \pm 0.47	0.40 \pm 0.07	0.316 \pm 0.026
	50–75	8.80 \pm 0.28	0.37 \pm 0.06	0.305 \pm 0.034
W ₃	0–25	9.14 \pm 0.29	0.51 \pm 0.09	0.292 \pm 0.038
	25–50	9.23 \pm 0.22	0.45 \pm 0.06	0.271 \pm 0.034
	50–75	9.20 \pm 0.07	0.44 \pm 0.06	0.270 \pm 0.016
W ₄	0–25	8.42 \pm 0.18	1.02 \pm 0.04	0.448 \pm 0.018
	25–50	8.61 \pm 0.41	0.71 \pm 0.12	0.341 \pm 0.037
	50–75	8.71 \pm 0.31	0.55 \pm 0.04	0.300 \pm 0.009
W ₅	0–25	8.74 \pm 0.31	0.69 \pm 0.08	0.345 \pm 0.033
	25–50	8.85 \pm 0.14	0.54 \pm 0.11	0.323 \pm 0.053
	50–75	8.92 \pm 0.11	0.67 \pm 0.11	0.283 \pm 0.035
Two-way ANOVA model				
Treatment		1.960ns	9.836**	8.746**
Soil layer		0.127ns	5.489**	7.513**
T X L		0.282ns	1.512ns	1.155ns

reducing effect of textile effluent similar to the observation on *Eucalyptus camaldulensis* seedlings irrigated with textile effluent (Bhati and Singh 2003). Higher concentration of sodium than of the bivalent Ca and Mg, sodium adsorption ratio (SAR), total solid, total suspended solid and total dissolved solid might have affected the osmotic relations of the seedlings and caused Mg and micronutrients deficiency affecting growth (Swaminathan and Vaidheeswaran 1991; Singh and Bhati 2003).

Relatively greater growth increment in 1993–94 than in 1994–95 was due to more rain in 1994 (596.2 mm) as compared to that in 1995 (339.6 mm) influencing soil water use and growth (Fig. 1b). Rainfall-dependent growth increments have also been recorded in the other studies (Gupta 1994; Singh *et al.* 2004). The highest increments in the seedlings of W₅ in 1993–94 and in the seedlings of W₄ in 1994–95 suggested the beneficial effects of wood ash and gypsum application in the respective treatments (Table 3). Ameliorative effects of gypsum not only influenced the height increments but also the crown diameter and collar circumference increments. A positive correlation between seedling growth variables and SWC ($r = 0.696$, $P < 0.01$) in 50–75 cm soil layer in October 1995 suggested beneficial effects of soil water available in deeper soil layers in post-monsoon period.

4.2. Seedling dry biomass

Power as the best-fit model for predicting the dry biomass of *A. indica* seedling suggested that non-linear fitting was more appropriate than linear. The best combination of collar diameter and height was linear multiplication related by power equation as it indicated the highest R^2 , adjusted R^2 and F values and the lowest MSE value as compared to the other combinations (Table 4). The highest biomass production (4.19 tones ha⁻¹) in the seedlings

of W₅ treatments as compared to those in the other treatments was due to the beneficial effect of wood ash and the nutrients/ micro-nutrient available in the wood ash, which not only ameliorated the effects of industrial effluent but also provided micro-nutrients for growth and productivity of the seedlings (Table 5). Application of wood ash produced a strong nutrient effect influencing growth and productivity of the seedlings. Twofold greater biomass in the seedlings of W₁ treatment than in the W₂ treatment was due to increased soil organic matter and the available PO₄-P and K in the effluent. Despite of higher concentration of Na ions in the effluent, greater growth and biomass production in W₁ seedling indicated the tolerance of *A. indica* species towards Na ion concentration. It is further supported by relatively greater proportions (90.7%) of foliage in W₁ as compared to those in the seedlings of the other treatments. Though, there was 1.13 tons ha⁻¹ (W₂) to 4.19 tones ha⁻¹ (W₅) dry biomass production in the present study but it was less than the dry biomass (1.69 to 6.39 tons ha⁻¹) of 26 months old *A. indica* seedlings under water harvesting and conservation measures (Gupta 1994). This indicated a negative effect of textile effluent on growth and biomass production. Singh and Bhati (2003) recorded 32 % reduction in dry biomass of 9 months old *Dalbergia sissoo* seedlings irrigated with textile effluent.

4.3. Soil moisture storage and depletion

Variations in soil water content (SWC) among the treatments were due to effluent irrigation, soil management practices and soil water use by the seedlings. However, the highest SWC in W₅ treatment in both July 1995 and October 1995 was due to increased soil water retention capacity of the soil resulting from wood ash application (Fig. 2). The variability in soil water use (SWU) was

indicated by significant ($P < 0.05$) differences in soil water depletion between July 1995 and October 1995. The greatest soil water depletion in W_5 treatments suggests greater storage capacity of soil under wood ash treatment as compared to the soil under the other treatments. It was evinced by greater growth and biomass production in W_5 treatment and a negative correlation between growth variables and SWU in 0–25 cm soil layer in July and October 1995. Though, SWU did not differ ($P > 0.05$) among the soil layers but relatively greater use from 25–50 cm soil layer as compared to those in 0–25 and 50–75 cm soil layers have indicated that application of 30 liters of effluent per month was not sufficient to meet the growth requirement of the seedlings and the seedlings are meeting their requirement of water from the deeper soil layers (Gupta 1995).

4.4. Changes in soil properties

The changes in soil properties were expected due to alkaline nature of the effluent. The decomposition of dyes available in effluent may contribute to percent soil organic matter (SOM) which increased in comparison to the initial value in July 1993 (Table 6). Addition of the effluent increased ($P < 0.05$) SOM in W_1 soil (1.8 fold) compared to the soil of other treatments, whereas the lowest SOM under W_3 treatment was probably the effect of sedimentation during gypsum treatment reducing organic load. An increase in soil pH due to W_2 and W_3 treatments was expected because of higher pH (9.7) of the effluent (Croner *et al.* 1984), but the lowest organic load in W_3 as compared to the other treatments might also be responsible for increased pH of the soil. However, moderate to slight decrease in soil pH in the rest of treatments may be attributed to the decomposition of the added organic matter and/ or ground vegetation into organic anions and consequent buffer action, similar to the observations of (Nihlgard *et al.* 1988) that the organic acids derived from decomposition of litter of tree and ground vegetation caused decrease in pH. The increase in pH of deeper soil layers might have been due to the precipitation of organic anions in the form of organic aluminum complexes (Cronan and Aiken 1985).

An increase in electrical conductivity of soil was due to small doses of effluent irrigation restricting the leaching of the salts to lower horizons. When effluent was diluted with the canal water, the increase in electrical conductivity of soil was smaller. The maximum increase in electrical conductivity was observed in gypsum-treated soil followed by ash-treated soil (W_5). This may be attributed to the effect of added salts. Increase in pH and EC of soil after irrigation with textile effluent has been reported by Ajmal and Khan (1985) and with wood ash – by Hakkila (1989). However, the application of wood ash produced a strong nutrient effect as observed through the growth data. This nutrient effect probably is due to mineralisation of organic matter at high pH (Karisto 1979). Application of wood ash not only suppresses the effect of sodium carbonate/ bicarbonate by enhancing the concentration of Ca and Mg but also increases the availability of macro and micronutrients to the plant causing favourable

influence on seedling growth (Silfverberg and Huikari 1985; Pitman 2006). Wood ash is reported to be used as a fertilizer in plantations (Hakkila and Kalja 1983; Haverlaen 1986) and in nursery (Rikala 1986).

5. Conclusions

The study suggests the beneficial effects of gypsum and wood ash application as the soil amendment. Wood ash-treated soil irrigated with textile effluent (W_5) was the best treatment where *A. indica* seedlings attained the highest growth and produced 6.75 kg of dry biomass. Addition of wood ash to the soil (coupled with effluent irrigation) ameliorated the effects of sodium carbonate/ bicarbonate by enhancing the concentration of Ca and Mg and increased the availability of macro and micronutrients (Hakkila 1989; Silfverberg and Huikari 1985). Though effluent application increased electrical conductivity and in some cases pH also, but gypsum- and wood ash-treated soil ameliorated pH by 0.25 units in comparison to initial value (Infalt and Young 2008). Therefore, it is concluded that *Azadirachta indica* can be established in arid zone using the irrigation of textile effluent. Apart from solving the problem of effluent disposal, this will lead to increased biomass production in the area. However, the addition of wood ash to soil, which is generally available in rural areas, will improve the biomass production. Further, increase in the quantity of effluent irrigation may improve the leaching of salts to lower strata, will prevent increase in electrical conductivity and may meet the increasing demand of water by growing seedlings.

Acknowledgements

The authors are thankful to the Director, AFRI for providing necessary facilities.

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TEKSTILĖS PRAMONINIŲ NUOTEKŲ NAUDOJIMAS *AZADIRACHTA INDICA* A. JUSS SODINUKAMS AUGINTI INDIJOS DYKUMOSE

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Santrauka

Eksperimentas vyko 1993–1995 m. siekiant ištirti pramoninių nuotekų poveikį *Azadirachta indica* A. Juss. (*Neem*) sodinukų augimo pradžia sausringuose regionuose. Tekstilės pramonės išleidžiamų nuotekų didelės pH rodiklio reikšmės, elektrinis laidumas, natrio adsorbcijos santykis ir natrio karbonato liekana. Tiriant taikyti įvairūs dirvožemio apdorojimo būdai: drėkinta tik nuotekomis (W_1), nuotekos maišytos su kanalo vandeniu santykiu 1:1 (W_2), nuotekos veiktos gipsu (W_3), į dirvožemį dėta gipso (W_4) ir dirvožemis tręštas medienos pelenais (W_5). Efektyviausias buvo W_5 apdorojimo būdas. 28 mėnesių augalai siekė 218 cm aukštį, jų vainiko skersmuo buvo 118 cm, žiedo perimetras – 11,2 cm. Stebint W_1 apdorojimo tipą, medžiai buvo vidutiniškai 186 cm aukščio, vainikas – 104 cm skersmens, žiedai 9,4 cm perimetro. Blogiausiai sodinukai augo apdorojant W_2 būdu. Nors naudojant nuotekas dirvožemio organinių medžiagų kiekis, elektrinis savitasis laidumas ir kai kuriais atvejais pH reikšmė padidėjo, tačiau gipsu ir medienos pelenais apdorotame dirvožemyje pH padidėjo per 0,25 vienetus, palyginti su pirminiais duomenimis. Šie rezultatai rodo, kad pramoninės nuotekos gali būti efektyviai naudojamos *Neem* (*Azadirachta indica*) želdinti ir auginti sausose teritorijose. Medienos pelenai pagerino augimo spartą. Drėkinimas pramoninėmis nuotekomis lėmė nežymų elektrinio savitojo laidumo augimą ir dirvožemio pH sumažėjimą.

Reikšminiai žodžiai: miško želdinimas, sausringos teritorijos, biomasė, augimas, medžių sodinukai, dirvožemio savybės, nuotekų naudojimas.

ПРИМЕНЕНИЕ СТОКОВ ОТ ТЕКСТИЛЬНОЙ ПРОМЫШЛЕННОСТИ ДЛЯ ВЫРАЩИВАНИЯ РАССАДЫ *AZADIRACHTA INDICA* A. JUSS В ПУСТЫНЯХ ИНДИИ

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Резюме

Экспериментальное поле возделывалось в 1993–1995 гг. с целью изучить воздействие промышленных стоков на начало роста *Azadirachta indica* A. Juss. (*Neem*) в засушливых районах. В стоках от производства текстиля высоко значение pH, электропроводимость, соотношение адсорбции натрия и остаток карбоната натрия. Применялись разные способы обработки почвы: орошение только стоками (W_1); смесью стоков с водой из канала в соотношении 1:1 (W_2); стоками, обработанными гипсом (W_3); обработка почвы гипсом (W_4) и удобрение древесной золой (W_5). Наиболее эффективным способом оказалась обработка древесной золой. Высота растений в возрасте 28 месяцев составляла 218 см, венчик в поперечнике – 118 см, цветок – 11,2 см. После обработки почвы по типу W_1 растения достигали 186 см в высоту, венчик в поперечнике – 104 см, цветок – 9,4 см. Наименее эффективным для растений способом оказалась обработка почвы по типу W_2 . Несмотря на то, что при применении стоков количество органических веществ в почве, электропроводимость и в некоторых случаях значение pH увеличилось, однако при обработке почвы гипсом и древесной золой pH увеличилось более чем на 0,25 единиц по сравнению с начальными данными. Эти результаты показали, что промышленные стоки могут эффективно применяться для озеленения и выращивания *Neem* (*Azadirachta indica*) на засушливых территориях. Древесная зола ускоряла рост растений. Орошение промышленными стоками способствовало незначительному увеличению электропроводимости и уменьшению в почве pH.

Ключевые слова: озеленение лесов, засушливые территории, биомасса, рост, рассада, свойства почвы, использование стоков.

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