Indian Journal of Agricultural Sciences **82** (2): 146–51, February 2012
https://doi.org/10.56093/ijas.v82i2.15290

Changes in soil properties under tree species

I S SINGH[1], O P AWASTHI[2], R S SINGH[3], T A MORE[4] and S R MEENA[5]

Central Institute for Arid Horticulture, Beechwal, Bikaner, Rajasthan 334 006

Received: 5 October 2011; Revised accepted: 15 November 2011

ABSTRACT

A study was conducted to study the effects of ber (*Ziziphus mauritiana* Lamk), drumstick (*Moringa olerifera* Lam), karonda (*Carissa congesta* Wt.) and khejri (*Prosopis cineraria* L. Druce) on the physical and chemical properties of soil at different depths (0–15, 15–30, 30–45 and 45–60 cm). The increase in the porosity and water-holding capacity and decrease in the bulk density (of subsurface soils) in the sites under plantations were marginal, when compared to open sites. There was slight decrease in the *p*H of soil under vegetated area, whereas no appreciable change in EC was observed. There was an appreciable increase in the organic carbon (0.04 to 0.13%) and available nitrogen content (69 to 100 kg/ha) in the sites under vegetation. Fruit plants, particularly ber and drumstick growing in the arid region indicated the process of deposition of bases such as Ca and Mg in the surface layers from lower strata. Overall results showed that exchangeable cations such as Ca, Mg, and Na and available P and K have depicted a poor potential activity in the maintenance of fertility which is affected by the young nature of plantation. The increase/decrease of soil properties due to the influence of plantation was more in surface (0–15 cm) and subsurface (15–30 cm) than in the sub-surface layers of 30–45 and 45–60 cm. The results obtained from the physical and chemical analyses indicated that among the four different fruit plantations, ber recorded substantial improvement and maintenance in soil fertility followed by drumstick. The nutrient return through litter fall followed the order K > N > Ca in *Z. mauritiana* and *M. olerifera* and N > Ca > K, Ca > N > K in *C. congesta* and *P. cineraria* respectively. The soils belong to the order Entisol and the calcareous *p*H is well adopted for the plantation of these fruit trees.

Key words: Exchangeable cations, Loamy sand soils, Nutrient distribution, Soil properties, Tree species

Tree species like ber (*Ziziphus mauritiana* Lamk), drumstick (*Moringa olerifera* Lam), karonda (*Carissa congesta* Wt.) and khejri (*Prosopis cineraria* L. Druce) are considered excellent for improvement of desert soil in Western Rajasthan owing to their faster growth habit, tolerance to adverse climate and edaphic factors and assured economic returns. These species can be grown on marginal soils having poor soil fertility status (desert soils) and are also fairly tolerant to soil moisture deficit, high soil temperature and frost.

An evaluation of soil properties under different arid fruit tree covers is an important area of research to understand the impact of fruit trees on soil's properties. Changes in soil physical and chemical properties through plantation have been reported by various workers (Singh *et al*. 2010). In tree plantation considerable amount of nutrients are incorporated into the soil through leaf litter fall and its recycling which in turn balance the nutrient reserve of the soil. The amount of nutrient elements present and their distribution in various soil strata are basically related to the growth and development of young plantations. Vegetation reacts with the aerial environment in many ways and often develops specific soil profile for particular tree species (Sharma and Gupta 2001). Different fruit tree species give rise to different soil properties even in the same climatic conditions having similar parent material. Plant roots system also plays an important role in nutrient recycling. Moreover, the effect of different vegetations to enrich nutrient status depends on various factors such as the leaf chemistry, behavior of nutrient, nature of soil, organic matter accumulation, microbial activity and quantity of nutrient bearing minerals (Gedda 2003). The chemical properties of soil pertaining to distribution of nutrients in soil strata is an index to evaluate the degree of leaching and conservation potential of essential mineral elements. Therefore, this study was carried out to evaluate the effect of different tree species on the physical and chemical properties of loamy sand soils.

[1]Senior Scientist, Soil Chemistry (e mail: induciah@rediffmail.com); [2] Principal Scientist, Horticulture (e mail: awasthiciah@yahoo.com); [3]Principal Scientist, Horticulture (e mail: rssingh1@)yahoo.com); [4]Director, Horticulture (e mail: tamore@indiatimes.com), [5]Scientist, Senior Scale (e mail: srm.extn@gmail.com), Agricultural Extension

Table 1 Vegetational parameters of study sites

Site	Location	Sequence	Age (year)	Species	Av. ht. (m)	Av. girth (cm)	Canopy diameter (E-W) (m)	Canopy diameter (N-S) (m)	Plant / ha
I	CIAH, Farm	Dune soil							
II	CIAH, Farm	Diversified plantation	5	*Ziziphus mauritiana* Lamk	3.5	67.0	4.05	4.35	156
III	CIAH, Farm	Diversified plantation	5	*Moringa olerifera* Lam	4.8	88.0	3.90	3.45	156
IV	CIAH, Farm	Diversified plantation	5	*Carissa congesta* Wt.	2.1	35.0	2.70	2.70	1111
V	CIAH, Farm	Diversified plantation	5	*Prosopis cineraria* L. Druce	3.0	46.0	2.55	2.40	156

MATERIALS AND METHODS

The study was conducted during 2008–09 at Central Institute for Arid Horticulture, Bikaner located between 28° N latitude and 73° 18' E longitude with a mean annual rainfall of 250 mm. To determine the impact of change in soil property beneath the canopy area, four perennial tree crops, viz ber, karonda, drumstick, and khejri grown as filler plant in aonla based diversified cropping models field at a spacing of 8m × 8 m on loamy sand soils were selected for the study. The vegetation parameters of these plants are given in Table 1. Changes in soil property beneath the aonla canopy however could not be studied because the plants suffered severe mortality during the third year of its crop growth owing to low temperature (–2°C) coupled with severe frost injury and as a consequence of which it did not add sufficient leaf litter fall to the soil.

Soils at four depths (0–15, 15–30, 30–45 and 45–60 cm) were sampled from 10 random locations per sub-habitat (ber, drumstick, karonda and khejri). The soil samples from each sub-habitat were bulked for each depth, thoroughly mixed and a composite sample taken for analysis. This procedure was followed for short-range spatial variability between individual soil samples (Belsky *et al*. 1989). Soils were analysed for bulk density, particle density, porosity, water holding capacity, *p*H, electrical conductivity (EC), per cent organic carbon, available N, P and K, exchangeable cations such as Ca^{2+}, Mg^{2+} and Na^{+} in the laboratory following standard methods described by Jackson (1973). Core samples with the help of standard core (4.5 cm diameter) were collected for determining soil bulk density using core method (Blake and Hartge 1986). The soil physical and chemical analyses for the various sub-habitats were done in duplicate to verify the results.

RESULTS AND DISCUSSION

Soil physical properties

The results of physical properties of soils are given in Table 2. Reduction in bulk density of soil under all the four tree species, i e ber, drumstick, karonda and khejri was noticed as compared to control site (no plantation). Bulk density decreased with increasing depth; however, this change was not substantial. Accumulation of litter and humus on soil surface reduced the bulk density, reaching 1.37 Mg/m^3 while the lowest bulk density in sub-layers was about 1.41Mg/m^3. The decrease in bulk density may be attributed to increased interaction between soil and plant roots, addition of organic matter (leaf litter), increased concentration of roots which lead to loosening of soil and the greater soil faunal activity (Balamurugan *et al*. 2000). An inverse relationship between bulk density and soil organic carbon was found. Change of bulk density may affect soil porosity and water-holding capacity. Therefore, as a result of decrease in bulk density of soil, an increase in porosity and water holding capacity of soils under all the four tree species was recorded as compared to control site. Results showed that water-holding capacity was the lowest for khejri (5.22%) and highest (6.17%) for ber. The effect being attributed to increased micropores of soil particles due to higher availability of organic carbon obtained from higher annual return of leaf litter. The result is also in agreement with the findings of Sharma (2005) who reported *Prosopis cineraria* exhibited maximum water storage under the tree canopy as compared to open spaces. Hence all the soil physical properties have been shown to depend largely on carbon balance (Singh *et al*. 2010).

Soil chemical characteristics

Changes in the soil chemical properties are given in Table 2. The soil reaction (*p*H) ranged from 8.1 to 8.3. No regular trend in soil *p*H along the depth of these soils was observed. However, slight reduction in *p*H as compared to control site was evident in soils under all the tree species. This decrease in *p*H may be due to litter fall and applied manures, which on decomposition is known to produce weak acids (Vijay Shankarbabu *et al*. 2007).

The surface soil being rich in organic matter, the upper horizons (0–15 and 15–30 cm) show the value of organic carbon content that ranges from 0.04 to 0.13% under different tree species (Table 2). This may be due to favourable soil temperature and moisture conditions in the soil. The maximum amount of organic carbon was observed at the surface layer under ber (0.13%) and drumstick (0.10%) plantations, respectively where the canopy growth, stem girth (Table 1) and overall root biomass was maximum. However, no substantial crop induced change was recorded at the surface layer of karonda and khejri plantations, which might be due to lower canopy growth and subsequently less addition of biomass in the surface soils. This is in accordance with the findings of Awasthi and Singh (2010) who reported an improved organic carbon status of soil under the canopy of ber plants. Content of organic carbon underneath the canopy of all the plantations, in general, decreased with depth. The differences between the four depths point to a strong stratification of soil organic carbon at 0–15 and 15–30 cm soil depths, where the sub-surface carbon contents (particularly, 30–45 and 45–60 cm depths) under all the tree species accounted for 50 to 83% of surface carbon. The stratification ratios (0–15 cm soil organic carbon divided by 30–45 cm SOC contents) were 1.44, 1.66, 1.20 and 1.33 under ber, drumstick, karonda and khejri plantations respectively. Similar results were reported by Franzluebbers (2002) who found generally higher stratification ratios under hot and low organic matter environments.

The contents of exchangeable cations, viz calcium, magnesium and sodium were recorded to be lower under all the tree species except the ber tree compared to control site. This might be due to a part of absorbed nutrients retained in the plant systems for making their tissues because of the young nature of plantations. Among the four fruit plantations, calcium [3.7 to 6.5 cmol (P^+)/kg] and magnesium [0.8 to 1.6 cmol (P^+)/kg] content was the highest in soils under ber tree which might be due to comparatively deeper root system which could absorb the nutrients at some depth and deposited at the surface. Calcium was the most dominant exchangeable cation, followed by magnesium and sodium. Calcium in general was the highest in the surface horizons for all the studied soils. This might be attributed to calcium addition at the surface by wind also (Singh *et al*. 2010). Exchangeable magnesium and sodium showed light differences between the surface and subsurface horizons. This suggests that the content of exchangeable cations, though small tend to accumulate in the upper soil layers (Zhenghu *et al*. 2007). Exchangeable sodium occurred in narrow range and it was distributed almost evenly along the vertical soil strata. Total bases recorded under all the fruit trees were at par with the values recorded in control. These results are quite expected as the plants in the younger stage consume nutrients more for their development and return less to soil (Singh *et al*. 2010).

The soil available nitrogen is also concentrated in the top 15 cm under the canopy of all trees. Furthermore, the variation in available N content in the soil column is higher under ber and drumstick trees than karonda and khejri. At all the depths the soil available N content is lower under karonda and khejri trees, possibly suggesting that less N storage from comparatively lesser litter input (Table 4). The available N in the open spaces of study sites ranged from 60 to 70, whereas under vegetation varied from 69 to 100 kg / ha, respectively. Many studies on soil nutrient status have shown that soils under trees are richer in nutrients compared with barren soil (Sharma 2003). The results related to available nutrient status of bare soils are in agreement with the values reported by Sharma (2005). The result is in close conformity with the findings of Sharma and Gupta (2001) who stated that leaf litter is related more closely with N-cycling as nitrogen is bound up in organic molecules. Sharma (2005) also reported that available N content in soil under *Prosopis cineraria* and *Acacia albida* was considerably higher than that of the bare field.

The content of available phosphorus showed a decreasing pattern with depth; however, surface layers registered the highest content of available phosphorus under plantation sites including control. The concentration of available phosphorus in bare field ranged from 9.4 to 11.4 kg/ha. Available phosphorus content was recorded to be decreased in soil under the plantations (6.0 to 9.0 kg/ha) compared to control site. In spite of the young nature and less contribution of nutrient (P) through the litterfall, among all the plantations karonda and khejri had registered slightly higher P content in the soil strata. The exact reason behind this increase is not known. Thus, the result revealed that in case of soil enrichment by young plantation, the parent material may determines more significantly the fraction of available P rather than the amount of litter fall received to the soil surface and characteristics of litter material.

The available K content in the open spaces (control) of study sites ranged from 348 to 477 kg/ha, whereas the same in the sites under plantation ranged from 182 to 468 kg/ha in the whole profile, respectively. Among the tree plantations, soils under ber plantation showed lower quantities of available potassium. This may be attributed to higher requirement of potassium by ber plantation due to greater leaf size as compared to other plantations. In general, no improvement in soil available K content had taken place due to young nature of plantation. The results also depict that in spite of young nature of plants the contents of K seems to be at par with the control site which may be due to constant replenishment of K by the plant roots and addition of substantial amount of leaf litter to the soil mass.

Only marginal decrease in nutrient status after five years of plantation suggests the sustainability of the system. It has been observed that the cited arid fruit tree species require very little mineral nutrient input and are able to thrive best on sandy soils of poor nutrient regimes. In general, the soils under ber were richer in organic carbon and some other nutrient content than that of under karonda, drumstick and khejri plantations including control. Higher nutrients in soil under the ber tree were obviously due to comparatively higher canopy coverage and leaf size than rest of the trees, resulting in higher litter fall, whereas the minimum nutrient concentrations was recorded under the khejri plantation.

Correlation study

Correlation analysis of soil chemical elements with

Table 2 Physical and chemical properties of soils under the tree species

Soil depth (m)	BD (Mg/m^3)	Porosity (%)	WHC (%v/v)	*p*H	EC (dS/ m)	Org.C (%)	Ca	Mg	Na	N	P_2O_5	K_2O
							(cmol (p+)/kg)				(kg/ha)	
Bare soil (control)												
0–0.15	1.58	42.7	5.12	8.5	0.17	0.04	5.1	1.2	1.6	70	11.4	477
0.15–0.30	1.58	42.7	5.12	8.5	0.16	0.04	4.6	1.2	0.5	60	10.7	433
0.30–0.45	1.60	42.0	5.07	8.5	0.12	0.03	4.5	0.5	0.7	65	9.4	348
0.45–0.60	1.60	42.0	4.77	8.5	0.12	0.03	4.5	0.5	0.7	65	9.4	348
Ber												
0–0.15	1.37	45.2	6.17	8.2	0.21	0.13	6.5	1.6	0.3	100	7.6	223
0.15–0.30	1.39	45.0	6.04	8.1	0.20	0.10	5.5	1.5	0.3	94	7.6	199
0.30–0.45	1.44	42.8	5.85	8.2	0.18	0.09	5.1	1.3	0.3	88	7.5	182
0.45–0.60	1.44	42.8	5.80	8.2	0.19	0.07	4.8	0.8	0.2	88	7.3	182
Drumstick												
0–0.15	1.40	44.7	5.85	8.3	0.19	0.10	4.5	0.9	0.4	94	7.3	468
0.15–0.30	1.41	44.4	5.75	8.1	0.19	0.08	4.5	0.7	0.4	90	6.3	430
0.30–0.45	1.45	42.7	5.64	8.3	0.18	0.08	4.0	0.6	0.3	80	6.3	336
0.45–0.60	1.45	42.7	5.57	8.3	0.18	0.05	3.8	0.7	0.3	80	6.0	330
Karonda												
0–0.15	1.45	42.9	5.40	8.2	0.19	0.06	3.9	0.9	0.2	86	8.2	301
0.15–0.30	1.47	41.9	5.35	8.2	0.18	0.05	3.6	0.6	0.1	82	8.0	288
0.30–0.45	1.48	41.7	5.35	8.2	0.18	0.05	3.5	0.7	0.1	80	8.0	253
0.45–0.60	1.48	41.7	5.34	8.4	0.16	0.04	3.5	0.7	0.1	80	7.3	270
Khejri												
0–0.15	1.46	42.0	5.30	8.2	0.19	0.05	3.6	1.6	1.2	75	9.0	312
0.15–0.30	1.46	41.8	5.30	8.3	0.18	0.05	3.0	1.4	0.8	70	8.5	300
0.30–0.45	1.49	41.3	5.25	8.2	0.16	0.04	3.0	1.4	0.6	70	8.6	294
0.45–0.60	1.50	40.5	5.22	8.3	0.16	0.04	2.8	0.6	0.4	69	8.5	300

organic carbon and bulk density has been carried out but in case of the elements, viz Mg^{2+} and Na^+ the level of significance was not very high (Table 3). The regression equations may provide the tentative record of chemical elements after estimating only few parameters to which these were correlated. Simple correlation coefficients of Mg^{2+}, Na^+, available N and P contents of soils under ber plantations with organic carbon are significant at a level of 0.1–5.0%, likewise correlation coefficients of N, P and K contents under drumstick and karonda with organic carbon are significant at a level of 1.0–5.0%. In most of the cases positive relation exists between organic carbon vs. nutrients. Correlation study of organic carbon under khejri plantation with all the nutrients revealed that the levels of significance are not satisfactory at all. Most of the correlations between bulk density and nutrients are negative except magnesium which depicts positive correlationship under all the plantations. This indicated that soil chemical properties were gradually improved while bulk density reduced under the plantation process. However, under ber plantation the positive correlation exists with most of the nutrients and the level of significance are highly satisfactory. Among the chemical properties, increase of organic carbon was the most internal and fundamental factor leading to such a change. Numerous studies suggest a strong correlation between available forms of nutrients with organic matter (Sharma and Gupta 2001).

Nutrient contribution by tree species

The amount of nutrients returned through litterfall varies depending upon the age and growth of trees, quantity of litterfall addition and concentration of nutrients in litterfall (Singh *et al.* 2007). Total litter fall (Table 4) was substantially higher under ber (577 kg/ha) than in drumstick (237 kg/ha), karonda (125 kg/ha) and khejri (60 kg/ha) plantations. Among the various nutrients, return of nitrogen, potassium and calcium were higher under all the four species. The phosphorus and magnesium returns were considerably lower. Similar results were reported in different plantations by Awasthi and Singh (2010).The nutrient returns followed the order K > N > Ca in *Z. mauritiana* and *M. olerifera*; N > Ca > K, Ca > N > K in *C. congesta* and *P. cineraria* respectively. In all the tree plantations studied, less nutrients were returned in *P. cineraria* plantation which is attributed to lower litter fall and small size of leaf owing to less vegetative growth and due to slow initial growth.

Table 3 Correlation and regression analysis of nutrient element content in the soil with organic carbon and bulk density

	Ber		Drumstick		Karonda		Khejri	
Organic carbon vs	'r'	Regression equation	'r'	Regression equation	'r'	Regression equation	'r'	Regression equation
Calcium	0.887	Y = +27.331 X +2.818	0.740	Y = +10.182 X +3.365	0.542	Y = +11.315 X +3.086	0.443 (NS)	Y = +22.857 X +2.071
Magnesium	0.834	Y = +13.647 X +0.005	0.445	Y = +2.676 X +0.513	0.313 (NS)	Y = +4.473 X +0.530	0.505	Y = +32.142 X –0.211
Sodium	0.464	Y = +1.786 X +0.095	0.266 (NS)	Y = +1.025 X +0.269	0.541	Y = +3.552 X –0.035	0.557	Y = +27.857 X -0.508
Available N	0.820	Y = +199.925 X +73.585	0.753	Y = +228.929 X +67.914	0.615	Y = +165.789 X +74.342	0.432 (NS)	Y = +171.428 X +63.385
Available P	0.771	Y = +6.405 X +6.884	0.758	Y = +17.380 X +5.106	0.682	Y = +28.684 X +6.488	0.227 (NS)	Y = +9.285 X +8.247
Available K	0.864	Y = +727.204X +126.714	0.696	Y = +1950.797 X +211.287	0.373 (NS)	Y = +857.894 X +238.671	0.192 (NS)	Y = +250.000 X +290.200
Bulk density vs								
Organic carbon	–0.854	Y = –0.532 X +0.845	–0.683	Y = –0.617 X +0.960	–0.306 (NS)	Y = –0.166 X -0.292	–0.645	Y = –0.194 X +0.332
Calcium	–0.880	Y = –16.900 X +29.243	–0.900	Y = –11.183 X +20.134	–0.625	Y = –7.065 X +14.023	–0.625	Y = –9.715 X +17.458
Magnesium	–0.754	Y = –7.693 X +12.147	–0.645	Y = –3.503 X +5.726	–0.322 (NS)	Y = –2.490 X +4.408	–0.708	Y = –13.549 X +21.260
Sodium	–0.472	Y = –1.133 X +1.863	–0.681	Y = –2.366 X +3.728	–0.418 (NS)	Y = –1.486 X +2.321	–0.784	Y = –11.813 X +18.205
Available N	–0.920	Y = –139.802 X +289.731	–0.930	Y = –255.220 X +450.326	–0.735	Y = –107.336 X +240.191	–0.560	Y = –66.839 X +169.888
Available P	–0.675	Y = –3.497 X +12.423	–0.708	Y = –14.663 X +27.412	–0.392 (NS)	Y = –8.938 X +21.013	–0.446	Y = –5.492 X +16.782
Available K	–0.899	Y = –471.614 X +860.812	–0.669	Y = –1692.804 X +2781.878	–0.659	Y = –819.884 X +1485.900	–0.352 (NS)	Y = –137.564 X +504.770

NS, Not significant; Y, nutrient content in the soil; X, organic carbon ; bulk density

Table 4 Litter production and nutrient returns under the tree species

Species	Litter yield (kg/ha)	Litter nutrients (kg/ha)				
		N	P	K	Ca	Mg
Ber	577	7.61	0.52	8.20	5.77	2.02
Drumstick	237	5.07	0.95	6.35	3.00	0.60
Karonda	125	1.82	0.10	1.25	1.45	0.63
Khejri	60	1.17	0.07	0.57	1.26	0.24

From the study, it is evident that both soil physical and chemical properties are improved under all the four plantations. The high average organic carbon and available nitrogen may be related to greater return of nitrogen and carbon through litter fall in plantation areas. Moreover, it has been amply observed that these species of fruit crop require very little mineral content and are able to thrive best on sandy soils of poor nutrient regimes. It can also be inferred here that control site had resulted in loss of soil nutrients through leaching and wind erosion *inter-alia* no replenishment of nutrients was made through litter fall. Among the tree plantations, ber resulted in greater improvement in soil properties. The process of fertility improvement although is very low in arid regions but satisfactory increase in soil organic carbon content may be helpful in improving the productivity potential of sandy soils.

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