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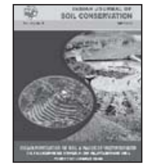

Amelioration of Vertisols with sand for management of soil physical, chemical and hydraulic properties in south India

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ABSTRACT

Sand can be used for increasing water intake capacity and reduce dispersion ratio in a Vertisol. A study was conducted at Bellary, India with amended soil with 12 sand and soil mixtures ranging from 0:1 to 1:1 ratio on weight basis. The analysis indicated significant decrease of available water; plastic and liquid limits; dispersion ratio; available N, P and K; and increase in bulk density with increase of sand in mixture. The increase in hydraulic conductivity was below 1.0 cm/hr^{-1} upto 0.4:1 ratio and increased significantly to 3.63 cm/hr with increase in sand. The changes were assessed based on a regression model of soil and sand ratios. Each parameter was assessed using weighted scores based on linear scoring method. The sum of scores indicated that 0.4:1 of sand and soil was superior for different parameters. The ratio was also superior for retaining soil moisture for a longer period in Vertisols.

1. INTRODUCTION

Vertisols are typically dark colored soils characterized by higher clay content and dominated by smectite group of minerals. These soils are known as black cotton soils in India and are extensively used for cultivation of different crops (Murthy, 1988). Vertisols and associated vertic soils in peninsular India cover an area of 73 million hectares which constitute nearly 22.2% of the total geographical area of the country (Narayana, 1986). One of the common features of these soils is expansion and shrinkage on wetting and drying. Low infiltration rate, high plasticity and stickiness, low organic matter, high cation exchange capacity, calcareous nature and alkaline reaction are some of the properties associated with these soils. Though Vertisols are considered as highly productive soils in many regions of the world, it remains a challenge for their optimum utilization (Coulombe *et al.,* 1996). The crop cultivation practices in Vertisols are particularly affected by the sticky nature, poor infiltration and impeded internal drainage under wet condition, while it would become much more complex due to soil hardness under dry condition (El-Swaify, 1985). Thus cultivation practices must coincide with the specific range of soil water content at which the soil is trafficable and of a consistency which would allow easy land preparation and can produce good soil tilth.

In a study by Somasundaram *et al.,* (2011), the authors have managed the Vertisols characterized by incorporation of residue, conservation bench terrace and contour furrow areas in the Chambal region of India. In arid and semi-arid tropical region of India, farmers traditionally apply sand as soil amendment to improve the permeability and workability in black soils. Addition of sand and mixing with the soil would restrict the swelling and shrinkage properties, influence the soil macropores and increase the permeability, reduce the plasticity thus leading to easy agricultural operations for enhancing the crop productivity. Though it seems obvious that sand would influence the hydrological behavior of a black soil, little investigation of that behavior on the soils has been reported. By and large, farmers would apply sand mulch of 10-16 cm depth in black Vertisols in South India to make the soils workable. In a study by Guled *et al*., (2003), application of sand mulch of 7.5-10 cm depth gave 50% higher yield under sorghum-sunflower system compared to 'no mulch' in Karnataka in South India. Even in Alfisols of Anantapur in Andhra Pradesh in south India, farmers apply sand to reduce soil crusting, apart from better pegging and pod development in groundnut (Mishra, 2002). Though there is an immediate benefit of sand to bring soils under good tilth, the long term effects of application of chemically inert sand material are needed to be examined. Based on a laboratory study, Mishra *et al.,* (2001) reported that addition of bentonite clay in Alfisols increased soil erodibility (dispersion ratio), surface cracking and plastic limits of bentonite : soil mixtures. In a study by Mandal *et al.,* (2005), the authors observed the influence of rock fragments on hydraulic behaviour of a bare natural semi-arid Alfisol. In the present study, we have evaluated the effect of different proportions of sand and soil mixtures on soil physical, hydraulic and chemical parameters in an arid black Vertisol.

2. MATERIALS AND METHODS

A laboratory experiment was conducted to find out the effect of 12 sand and soil (Vertisol) mixtures on weight basis (0:1 to 1:1) on soil physical, hydraulic and chemical parameters of Central Soil & Water Conservation Research & Training Institute, Bellary in Karnataka during 2008. A site that was chosen for the study was an arid Vertisol belonging to 'Bellary series' classified as Typic Pellusterts. The soils are derived from granite, gneiss and schist. The soil has an infiltration rate of 0.8 cm h^{-1} and bulk density of 1.22 Mg m^{-3}. It has a pH of 8.9 and electrical conductivity of 0.12 dS m^{-1}. The clay content increased with depth from 45% on surface to 51% at 0.75 to 0.90 m. The field capacity at 1/3 atmosphere and wilting point varied from 35 to 47% and 26 to 30% from top soil to 0.90 m soil depth respectively. The available N, P_2O_5 and K_2O were 179, 22 and 580 kg ha^{-1} (Patil and Sheelavantar, 2006).

The soil was dried, pounded and passed through 2 mm sieve and thoroughly mixed with sand in 12 different proportions. The different treatments of sand and soil examined in the study are as follows:

(i)	T1 = 0 : 1	(ii)	T2 = 0.05 : 1
(iii)	T3 = 0.1 : 1	(iv)	T4 = 0.2 : 1
(v)	T5 = 0.3 : 1	(vi)	T6 = 0.4 : 1
(vii)	T7 = 0.5 : 1	(viii)	T8 = 0.6 : 1
(ix)	T9 = 0.7 : 1	(x)	T10 = 0.8 : 1
(xi)	T11 = 0.9 : 1	(xii)	T12 = 1 : 1

The experiment was conducted in a completely randomized design with 3 replications. Sample of 6 kg mixture was prepared and used for each treatment. All the parameters were determined by taking a sample from the 6 kg mixture for each treatment. The mixture was filled in a polythene bag of 30 cm height and 10 cm diameter. While filling the mixture in the bag, care was taken to consolidate the mixture by tapping it to maintain the same height in all the bags. Small holes were made on the periphery and the bottom of the bags. The bags were kept in a tub filled with water up to a depth of 25 cm. The samples were kept inside the tub for 48 hours and in between water was put in the tub to maintain water level in the tub. After 48 hours, the soil was completely saturated. Then they were taken out and kept outside for 24 hours for draining the excess water and bringing the soil moisture to field capacity. The weight of the samples was taken every day for 22 days to find out the moisture depletion pattern in different treatments.

The properties of native and amended soil (mixture) were compared to determine the effect of adding sand to native black soil. The different soil parameters viz., texture (percent sand, silt and clay mixture), moisture retention (by weight basis) at 0.033 Mega pascal (MPa) representing field capacity and 1.5 MPa representing permanent wilting point, available water, hydraulic conductivity, bulk density, dispersion ratio, liquid limit, plastic limit, available N, P_2O_5 and exchangeable K_2O were determined under each sand and soil mixture (Black, 1965; Jalota *et al.,* 1994).

The particle size analysis was carried out by the International Pipette method (Gee and Bander, 1986). The bulk density was determined by packing the sand and soil mixture within a core (Blake and Hartge, 1986). Soil water retention at field capacity and wilting point were measured using pressure plate apparatus at 0.033 and 1.5 MPa (Cassel and Nielsen, 1986). The available water was determined as a difference of field capacity and wilting point. The plastic limit (% moisture) for each mixture was found by a plastic limit test glass plate, while the liquid limit (% moisture) was determined by using liquid limit apparatus. The hydraulic conductivity of mixtures was determined using the constant head permeameter (Klute, 1965). The dispersion ratio, a measure of soil erodibility was determined by the ratio of 'percent silt and clay of the mixture dispersed in water by end-over-end shaking in one litre cylinder' to the 'percent silt plus percent clay' obtained from the particle size analysis (Bowels, 1984). The available N was determined by alkaline-$KMnO_4$ method (Subbaiah and Asija, 1956), which takes care of easily oxidizable N. The available P_2O_5 was determined by sodium bicarbonate ($NaHCO_3$) extraction followed by colorimetric analysis (Olsen *et al*., 1954). The exchangeable K_2O was determined by emission spectrometry of 1.0 N ammonium acetate extracts (Jackson, 1962). The extract was determined by using flame photometer. The soil water characteristics of the amended soil were compared with the findings of Saxton (1986) for validation.

The effects of changes in combination of sand, silt and clay on soil physical, hydraulic and chemical parameters were assessed based on the best fit regression model of each parameter through different sand and soil ratios (Draper and Smith, 1998). All the parameters were tested using a one-way analysis of variance and Student's't' comparison of means at $p < 0.01$ level of significance.

The superior soil physical, hydraulic and chemical parameters were identified based on analysis of scores determined for each parameter. An efficient mixture of sand and soil could be identified for maximum soil water retention for a longer period, apart from significant improvement of soil environment as measured by soil physical, hydraulic and chemical parameters. To know the best proportion of sand and soil mixture, we converted all the soil properties into 'scores' and then added the score value of each soil property for all the treatments. In linear scoring function, the soil properties were ranked in either ascending or descending order depending on whether a higher value was considered 'good' or 'bad' in terms of soil function with the objective to achieve the highest score value '1' for a good condition and the lowest value '0' for a bad condition for each soil property. The selection of a suitable sand (%) based on linear score values could be made based on the analysis.

3. RESULTS AND DISCUSSIONS

The particle size distribution results indicated that the mean clay content reduced from 57.9 to 27.4%, while the silt content reduced from 17.7 to 7.9% and the sand content increased from 24.2 to 65.5% by systematic addition of sand. With the addition of sand, the textural class of mixtures changed as follows:

(i) T1 : Clay (native soil)
(ii) T2 : Clay
(iii) T3 : Clay
(iv) T4 : Clay
(v) T5 : Sandy clay
(vi) T6 : Sandy clay
(vii) T7: Sandy clay loam
(viii) T8 : Sandy clay loam
(ix) T9 : Sandy clay loam
(x) T10:Sandy clay loam
(xi) T11 : Sandy clay loam
(xii) T12 : Sandy clay loam

Based on Analysis of Variance, the effects of changes in the sand and soil ratios on soil physical, hydraulic and chemical parameters were analyzed. The descriptive statistics of soil physical parameters are given in Table 1.

Influence of Sand and Soil Mixture on Field Capacity, Permanent Wilting Point and Available Water

The mixture of sand and soil ratios had a significant influence on the field capacity, permanent wilting point and available water of the Vertisol. Based on the least significant

Table: 1
Effect of different sand and soil mixtures on soil physical-hydraulic-chemical parameters in a black Vertisol

Treatment (Sand : Soil)	Sand (%)	Silt (%)	Clay (%)	Field capacity (%)	Wilting point (%)	Available water (%)	Bulk density (Mgm^{-3})	Dispersion ratio	Hydraulic conductivity ($cm\ hr^{-1}$)	Liquid limit (%)	Plastic limit (%)	Soil N ($kg\ ha^{-1}$)	Soil P ($kg\ ha^{-1}$)	Soil K ($kg\ ha^{-1}$)
T1 (0 : 1)	24.2	17.7	57.9	32.6	16.3	16.2	1.28	0.75	0.25	55.5	23.2	267	20.7	544
T2 (0.05 : 1)	30.5	16.5	43.0	32.2	16.2	15.9	1.28	0.64	0.36	52.8	20.2	22	19.0	505
T3 (0.1 a: 1)	36.4	14.2	49.6	30.5	15.9	14.4	1.32	0.72	0.44	51.8	19.5	236	15.1	498
T4 (0.2 : 1)	40.9	16.2	43.0	27.9	14.9	13.1	1.34	0.68	0.60	45.8	18.5	227	15.7	496
T5 (0.3 : 1)	45.9	16.9	37.1	25.8	14.2	11.5	1.38	0.72	0.76	44.0	17.6	210	15.1	478
T6 (0.4 : 1)	49.7	14.6	35.9	23.6	12.6	10.8	1.38	0.66	1.07	41.6	16.8	210	15.1	449
T7 (0.5 : 1)	53.7	11.5	34.9	20.3	11.0	9.3	1.44	0.67	1.40	39.3	14.5	196	15.1	379
T8 (0.6 : 1)	55.9	10.9	33.1	20.4	10.3	10.0	1.41	0.59	1.76	38.6	12.2	165	15.1	356
T9 (0.7 : 1)	58.7	9.4	31.0	19.6	10.3	9.3	1.45	0.54	2.25	36.2	11.5	159	15.1	352
T10 (0.8 : 1)	59.9	9.0	31.0	18.5	10.0	8.4	1.45	0.55	2.80	32.6	10.4	1501	12.9	318
T11 (0.9 : 1)	61.6	8.9	29.0	17.3	8.7	8.6	1.45	0.52	3.31	31.6	9.3	131	10.6	303
T12 (1 : 1)	65.5	7.9	27.4	16.4	7.7	8.7	1.48	0.51	3.63	30.1	7.8	125	8.4	291
Mean	48.6	12.8	37.8	23.8	12.40	11.4	1.39	0.63	1.55	41.6	15.1	192	14.8	414
SEM (±)	0.10	0.04	0.03	0.20	0.14	0.22	0.005	0.004	0.03	0.4	0.3	4.5	0.3	5.1
LSD (P<0.01)	0.40	0.11	0.12	0.78	0.57	0.89	0.02	0.02	0.11	1.6	1.2	18.1	1.3	20.4

SEM: Standard error of mean
LSD: Least significant difference

difference (LSD) values at $p < 0.01$ level, there was a significant difference in the measurements made on field capacity, permanent wilting point and available water at different sand and soil ratios. The changes in the field capacity, permanent wilting point and available water at different sand and soil ratios are depicted in Fig 1. The field capacity decreased significantly from 32.6 to 16.4% when sand and soil ratio increased from 0:1 to 1:1. It decreased up to a ratio of 0.5:1, and became a plateau subsequently. This was evident from the regression model fitted for the data with coefficient of determination (R^2) of 0.991 (significant at $p < 0.01$) for assessing the changes in field capacity influenced by sand and soil ratios.

The different sand and soil ratios significantly influenced the permanent wilting point based on the study. It decreased from 16.3 to 7.7% when sand and soil ratio increased from 0:1 to 1:1. It decreased up to a ratio of 0.6:1, and became a plateau subsequently based on the regression model with R^2 value of 0.952 (significant at $p < 0.01$). The available water significantly decreased from 16.2 to 8.7% when sand: soil ratio increased from 0:1 to 1:1. The regression model indicated that the available water decreased up to a ratio of 0.8, and became a plateau subsequently. The model gave R^2 of 0.963 (significant at $p < 0.01$) for predicting the available water at varying sand and soil ratios.

Influence of Sand and Soil Mixture on Hydraulic Conductivity, Bulk Density and Dispersion Ratio

The study indicated that the varying mixtures of sand and soil significantly influenced the changes in hydraulic conductivity, bulk density and dispersion ratio observed in the Vertisol. The changes in the hydraulic conductivity, bulk density and dispersion ratio at different sand and soil ratios are depicted in Fig 2. Based on LSD criteria, the hydraulic conductivity significantly increased from 0.25 to 3.63 cm hr^{-1} when sand and soil ratio increased from 0:1 to 1:1. It increased at all levels of sand and soil mixtures. The regression model gave R^2 of 0.997 for predicting hydraulic conductivity through sand and soil ratios which was significant at $p < 0.01$ level.

The bulk density increased significantly from 1.28 to 1.48 Mg m^{-3} when sand and soil ratio increased from 0:1 to 1:1. It gradually increased up to a ratio of 0.7, and became a plateau subsequently with R^2 of 0.949 (significant at $p < 0.01$) based on the regression model calibrated for assessing changes in bulk density at different sand and soil ratios. The increase in the ratio of sand and soil mixture from 0:1 to 1:1 significantly decreased the dispersion ratio of the mixture from 0.75 to 0.51. The dispersion ratio significantly decreased up to sand and soil ratio of 0.7:1, and became a plateau subsequently. The decrease in dispersion ratio

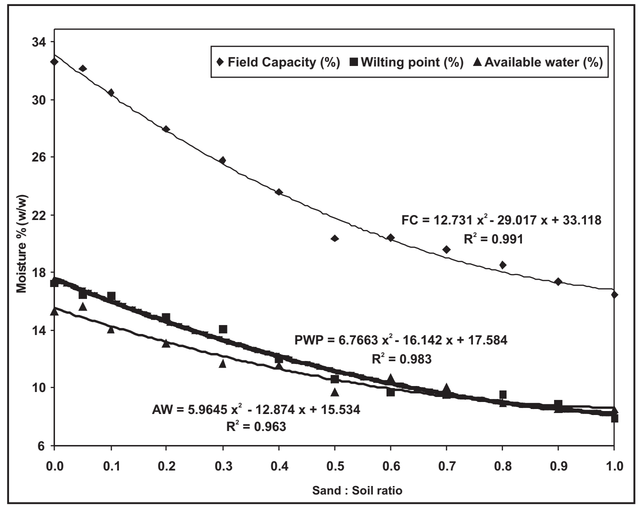

Fig. 1. Effect of sand and soil ratio on field capacity, wilting point and available water in an arid Vertisol

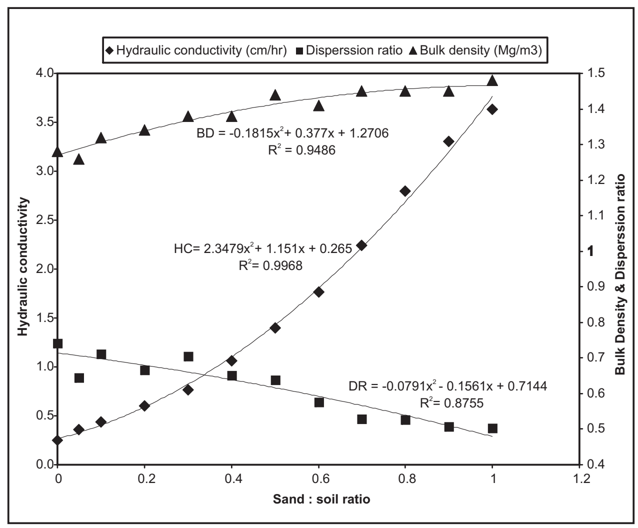

Fig. 2. Effect of sand and soil ratio on hydraulic conductivity, bulk density and dispersion ratio in an arid Vertisol

indicated a decrease in soil erosivity. The regression model for predicting changes in dispersion ratio as influenced by sand and soil ratios gave R^2 of 0.875 (significant at $p < 0.01$) based on the analysis.

Influence of Sand and Soil Mixture on Liquid and Plastic Limits

The addition of sand has significantly decreased both liquid and plastic limits in the arid Vertisol. The changes in the liquid and plastic limits at different sand and soil ratios are depicted in Fig 3. The liquid limit significantly decreased from 55.5 to 30.1%, while the plastic limit significantly decreased from 23.2 to 7.8% when the sand and soil ratio increased from 0:1 to 1:1. The liquid limit significantly decreased up to sand and soil ratio of 0.8, and became a plateau subsequently based on the regression model which gave R^2 of 0.987 (significant at $p < 0.01$) for assessing changes in the parameter. The plastic limit decreased up to sand and soil ratio of 1:1 based on the regression model with maximum R^2 of 0.980 (significant at $p < 0.01$) for assessing changes in the parameter.

Influence of Sand and Soil Mixture on Soil Fertility of N, P_2O_5 and K_2O

The available N, P_2O_5 and exchangeable K_2O were significantly influenced by different mixtures of sand and soil in the arid Vertisol. The changes in the available N, P_2O_5

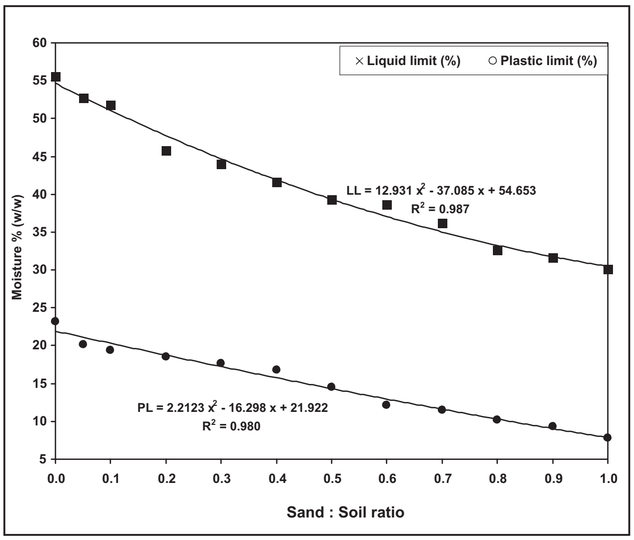

Fig. 3. Effect of sand and soil ratio on liquid and plastic limits in an arid Vertisol

and exchangeable K_2O at different sand and soil ratios are depicted in Fig 4. The available soil N significantly decreased from 267 to 125 kg/ha when sand and soil ratio increased from 0:1 to 1:1. It decreased up to a ratio of 0.6:1, and became a plateau subsequently. The regression model for assessing the changes in available N at varying sand and soil ratios gave R^2 of 0.959 (significant at $p < 0.01$).

The available P_2O_5 significantly decreased from 20.7 to 8.4 kg/ha with an increase in the mixture of sand and soil ratio from 0:1 to 1:1. However, the rate of change in the soil P_2O_5 was erratic at different ratios indicating a decrease up to a ratio of 0.1:1, constant from 0.1:1 to 0.7:1, followed by a decrease up to a ratio of 1:1. The regression model gave R^2 of 0.755 (significant at $p < 0.05$) for predicting the changes in available P_2O_5 through different mixtures of sand and soil. The exchangeable K_2O decreased significantly from 544 to 291 kg/ha when sand and soil ratio increased from 0:1 to 1:1 with an erratic rate of decrease. Initially, it decreased up to sand and soil ratio of 0.1:1, followed by plateau up to 0.3:1,

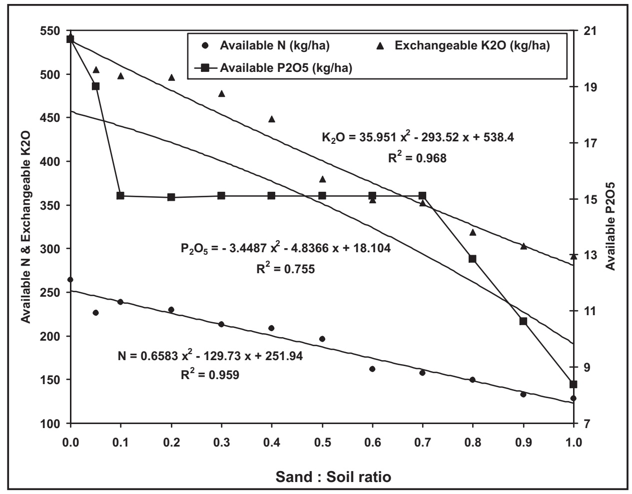

Fig. 4. Effect of sand and soil ratio on soil fertility of N, P_2O_5 and K_2O in an arid Vertisol

and decrease up to a ratio of 1:1. The regression model for predicting changes in exchangeable K_2O through varying sand and soil ratios gave R^2 of 0.968 (significant at $p < 0.01$).

Linear Scoring Method for Selection of Superior Sand and Soil Mixtures

Based on the linear scoring method described by Liebig *et al.,* 2001, we converted all the soil properties into scores and are graphically depicted in Fig 5. For soil properties like available N, P_2O_5 and exchangeable K_2O and available water, we followed 'more is better' and each observation was divided by the highest observed value. Thus the highest observed value received a score of 1, while all others received a score of < 1. For soil properties like bulk density and dispersion ratio, we followed 'less is better'. Accordingly, the lowest observed value received a score of 1, while all others received a score of < 1. In this case, the lowest observed value was divided by each observed value to get the score for each sand and soil mixture. For properties like hydraulic conductivity and plasticity index (liquid limit – plastic limit), observations were scored as 'more is better' up to a threshold value and were then scored as 'less is better' above the threshold. Here we added sand to soil in equal proportion from a ratio of 0.05 to 1 and chose 'median' value of hydraulic conductivity (1.231 cm hr^{-1}) and plasticity index (25.6) among the treatments as threshold values. We considered the 'median' as threshold value of hydraulic conductivity and plasticity index parameters, since the extreme values in the data will have a lower effect on the 'median' compared to 'mean' or 'mode' of observations. When we added the score values for all treatments, the sand and soil mixture at 0.4:1 ratio attained maximum score value as depicted in Fig 5. The analysis indicated that maximum number of parameters have fallen in the grid formed by the score values on Y-axis in the range of 0.70 to 1.00 intercepted with the sand and soil ratio on X-axis in the range of 0.40 to 0.45%. The present investigation proved that maximum benefit can be achieved by mixing sand and soil in a proportion of 0.4:1 i.e., at 40% level by weight basis in an arid Vertisol.

Influence of Sand and Soil Mixture on Soil Moisture Observed on Different Days

As the drying process of soil samples progressed, the soil moisture was found to significantly decrease under all

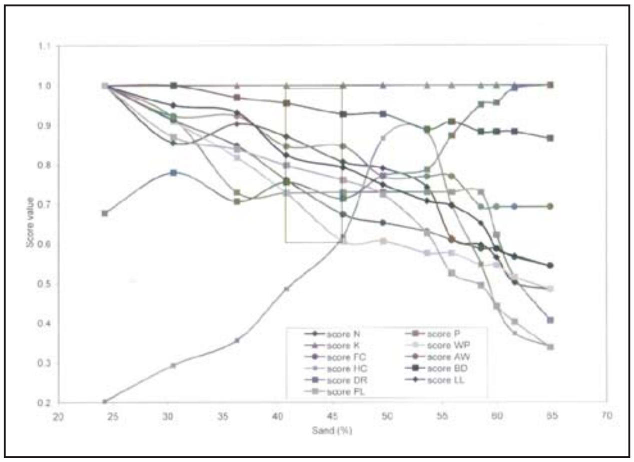

Fig. 5. Selection of suitable sand (%) based on score values of soil physical, hydraulic and chemical parameters

the 12 mixtures of sand and soil considered in the study. The mean daily soil moisture of 12 treatments of sand and soil mixture along with the LSD values at $p < 0.01$ level of significance are given in Table 2. Based on the analysis of variance, the treatments differed significantly from each other for the percent of soil moisture maintained on different days of study period. Each treatment had a significant influence on the soil moisture observed during the 22 days of study period. A graphical plot indicating changes in soil moisture on different days is given in Fig 6. The soil moisture significantly decreased up to 6 days and became asymptotic subsequently in most of the treatments. Based on the best-fit regression model of soil moisture observed on different days, the coefficient of determination (R^2) indicating the predictability of changes in soil moisture was significant for all the 12 mixtures of sand and soil considered in the study. The estimate of R^2 ranged from 0.90 for T2 (0.05:1) to 0.98 for T9 (0.7:1). The rate of decrease in soil moisture over 22 days was significant under all the 12 treatments of sand and soil mixture. The standard error of the predicted soil moisture based on the regression models calibrated for different treatments ranged from 0.61% under

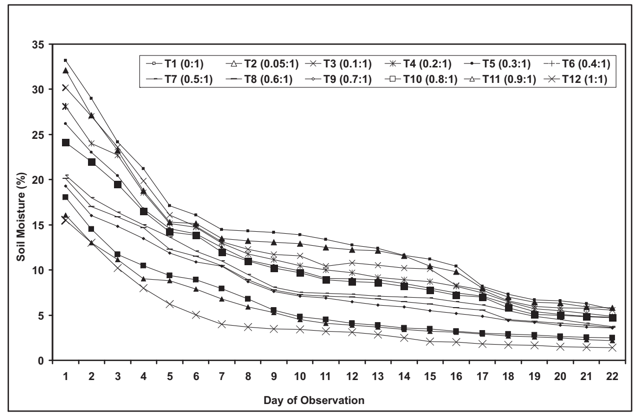

Fig. 6. Temporal depletion pattern of soil moisture under different sand and soil ratios in an arid Vertisol

T9 (0.7:1) to 2.31% under T2 (0.05:1). The regression models indicating depletion pattern of soil moisture under different treatments during the 22 days of study period are given in Table 3.

Among different treatments, T6 (0.4:1) which was superior for different soil physical, hydraulic and chemical parameters examined in the study was also found to retain soil moisture for a maximum period of about 6 days and subsequently became asymptotic. Although the treatments T1 (0:1) to T5 (0.3:1) which had a higher clay content retained higher soil moisture for almost the same period, they are unsuitable from soil aeration and drainage point of view. The regression models of sand and soil ratios below 0.4:1 indicated a significantly higher daily soil moisture depletion rate for different mixtures of sand and soil. The regression model of T6 (0.4:1) indicated that the sand and soil mixture had a lower soil moisture depletion rate compared to T1 to T5. The treatments of sand and soil ratios above 0.4:1 viz., T7 to T12 maintained a significantly lower soil moisture during all the 22 days of study. Thus based on an assessment of depletion pattern of soil moisture under different sand and soil mixtures also, addition of sand to soil in the ratio of 0.4:1 was found to be superior compared to other ratios.

4. CONCLUSIONS

In the present study, sand was added to an arid Vertisol in 12 different mixtures of sand and soil in order to optimize the hydraulic conductivity without significantly affecting available water, nutrient content and bulk density. Apart from these parameters, the dispersion ratio could be improved for reducing the soil erosion. Based on the study, there was a significant decrease in the field capacity from 32.6 to 16.4%; wilting point from 16.3 to 7.7%; available water from 16.2 to 8.7%; plastic limit from 23.2 to 7.8%; liquid limit from 55.5 to 30.1%; and dispersion ratio from

Table: 2
Effect of different sand and soil mixtures on soil moisture (%) on 22 days of observation in a black Vertisol

Day	Soil moisture (%) at different sand : soil mixtures												
	T1 (0:1)	T2 (0.05:1)	T3 (0.1:1)	T4 (0.2:1)	T5 (0.3:1)	T6 (0.4:1)	T7 (0.5:1)	T8 (0.6:1)	T9 (0.7:1)	T10 (0.8:1)	T11 (0.9:1)	T12 (1:1)	Mean	CV
1	32.00	32.10	30.20	28.10	26.20	24.10	20.50	20.10	19.30	18.03	16.10	15.5	23.6	26.4
2	27.14	29.00	27.00	24.00	23.00	22.00	18.00	17.00	16.00	14.50	13.00	13.0	20.3	28.4
3	23.22	24.14	23.57	22.72	20.42	19.50	16.37	15.88	14.81	11.74	11.15	10.2	17.8	28.8
4	18.77	21.21	19.88	18.54	16.75	16.50	14.97	14.69	13.50	10.50	9.00	8.00	15.2	28.2
5	17.13	15.28	16.07	15.15	14.58	14.20	13.62	12.29	11.90	9.40	8.80	6.20	12.9	25.5
6	16.05	15.12	14.82	14.75	13.98	13.87	12.10	11.50	10.90	8.90	7.90	5.02	12.1	28.0
7	14.49	13.49	13.12	12.98	12.50	12.00	11.00	10.50	10.40	7.92	6.80	4.00	10.8	28.8
8	14.30	13.22	12.30	11.75	11.10	11.00	9.50	8.90	8.70	6.80	5.92	3.70	9.8	32.2
9	14.14	13.09	11.70	11.16	10.50	10.20	8.10	7.80	7.60	5.53	5.30	3.50	9.1	36.3
10	13.88	12.92	11.57	10.50	9.90	9.70	7.50	7.25	7.10	4.80	4.50	3.40	8.6	39.3
11	13.40	12.49	10.41	9.99	9.07	8.90	7.42	7.10	6.90	4.50	4.10	3.20	8.1	39.6
12	12.73	12.24	10.79	9.70	9.00	8.70	7.30	7.00	6.50	4.10	3.90	3.10	7.9	40.3
13	12.37	12.15	10.51	9.20	8.90	8.60	7.10	6.80	6.10	3.90	3.70	2.87	7.7	41.4
14	11.62	11.55	10.20	8.90	8.50	8.20	7.00	6.50	5.90	3.60	3.40	2.50	7.3	42.1
15	10.40	11.20	10.10	8.70	8.00	7.80	6.90	6.20	5.50	3.50	3.20	2.10	7.0	42.6
16	8.32	10.35	9.77	8.20	7.45	7.20	6.50	5.80	5.20	3.20	3.10	2.00	6.4	41.4
17	8.02	8.23	7.76	7.46	7.10	7.00	6.10	5.55	4.90	3.00	2.90	1.80	5.8	38.0
18	6.55	7.30	6.59	6.49	6.20	5.80	5.50	4.50	4.40	2.90	2.70	1.70	5.1	35.8
19	7.01	6.45	5.98	5.72	5.40	5.10	4.90	4.30	4.20	2.80	2.60	1.65	4.7	35.0
20	6.67	6.35	5.83	5.49	5.10	5.00	4.50	4.10	3.90	2.65	2.50	1.50	4.5	36.0
21	5.91	6.34	5.73	5.20	4.90	4.80	4.10	3.90	3.70	2.55	2.30	1.45	4.2	36.2
22	5.66	5.83	5.53	4.90	4.75	4.70	3.73	3.65	3.58	2.50	2.20	1.40	4.0	35.8

CV: Coefficient of variation (%)

Effect	Standard error of mean (±)	Least significant difference (at $P < 0.01$ level)
Days	0.010	0.035
Treatments	0.007	0.026
Days x Treatments	0.033	0.123

Table: 3
Regression models indicating changes in soil moisture on different days as influenced by 12 mixtures of sand and soil in a black Vertisol

Treatment	Sand : Soil	Regression model	R^2	SE
T1	0 : 1	SM = 31.05** – 2.318** (D) + 0.056** (D^2)	0.92**	2.16
T2	0.05 : 1	SM = 29.24** – 2.212** (D) + 0.055** (D^2)	0.90**	2.31
T3	0.1 : 1	SM = 29.61** – 2.440** (D) + 0.064** (D^2)	0.94**	1.83
T4	0.2 : 1	SM = 27.61** – 2.254** (D) + 0.059** (D^2)	0.95**	1.44
T5	0.3 : 1	SM = 25.76** – 2.097** (D) + 0.055** (D^2)	0.96**	1.29
T6	0.4 : 1	SM = 24.36** – 1.921** (D) + 0.049** (D^2)	0.97**	1.06
T7	0.5 : 1	SM = 20.88** – 1.637** (D) + 0.042** (D^2)	0.97**	0.86
T8	0.6 : 1	SM = 20.24** – 1.629** (D) + 0.042** (D^2)	0.97**	0.79
T9	0.7 : 1	SM = 19.28** – 1.563** (D) + 0.040** (D^2)	0.98**	0.61
T10	0.8 : 1	SM = 17.51** – 1.707** (D) + 0.049** (D^2)	0.97**	0.75
T11	0.9 : 1	SM = 15.69** – 1.507** (D) + 0.043** (D^2)	0.97**	0.69
T12	1 : 1	SM = 14.78** – 1.643** (D) + 0.050** (D^2)	0.92**	1.15

SM: Soil moisture (%) ** indicates significance at $p < 0.01$ level D : Day
R^2 : Coefficient of determination SE: Standard error of estimated soil moisture (%)

0.75 to 0.51 with an increase in the sand level in the mixture. There was a significant increase in the bulk density from 1.28 to 1.48 Mg m^{-3} and hydraulic conductivity from 0.25 to 3.63 cm hr^{-1}. Increase in sand content in the mixture significantly decreased the available N from 267 to 125 kg/ha; available P_2O_5 from 20.7 to 8.4 kg/ha; and exchangeable K_2O from 544 to 291 kg/ha. The changes in soil parameters were predicted by best–fit regression model calibrated through sand and soil mixtures. The analysis of scores of different soil physical, hydraulic and chemical parameters based on linear scoring method indicated that sand application to soil in the ratio of 0.4:1 was superior for improving the soil environment in arid Vertisols. Based on the soil moisture depletion pattern observed over 22 days, addition of sand to soil in the ratio of 0.4:1 was superior for retaining soil moisture for a maximum period of 6 days compared to other sand and soil mixtures.

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