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Studies on Soil Conditions under the Stand of Palmyra Palm (*Borassus flabellifer*) – A Climate Resilient Multipurpose Tree Species in Odisha

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ABSTRACT

The investigation was carried out in different locations of 7 agro-climatic zones of Odisha, 3 villages in each, during January 2016 to July 2017. The experiment was laid out in Nested Design with 3 replications. The soil status under the stands of *B. flabellifer* was found significantly different in different locations. The organic carbon in soil differed from 0.05 to 1.38%, pH from 4.65 to 8.36, available N from 62.50 to 287.50 kg ha^{-1}, available P from 7.60 to 88.46 kg ha^{-1} and available K from 59.13 to 955.60 kg ha^{-1}. The OC, available N, P and K went on decreasing with increase in depth of soil whereas pH showed the reverse trend in all locations under study. Alluvial soil with high moisture content, high organic carbon, more available N, P and K, nearly neutral pH and moderate temperature helped this palm to excel in growth and yield.

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INTRODUCTION

Palmyra palm– *Borassus flabellifer* Linn. (Syn. *B. flabelliformis* Roxb. or *Borassus flabelliformis* Murr.) is an important palm species of tropical and sub-tropical parts of the world. Mahatma Gandhi called this palm "an antidote to poverty". In India, the fruits are hung in doorways and at the corners of marriage "shamianas" as symbol of happiness and prosperity (Benthall 1946). This splendid tree belongs to family Arecaceae. Other colloquial names for the Palmyra include fan palm, since the specific epithet is derived from word *flabellum* (Latin meaning is fan), *tar*, *brab*, *char* or *desert palm*, *patoo-tody* (male), *nama-tody* or *peuty* (female) in India ; *tal-gas* or *panna-maram* in Ceylon; *dtan* or than in Thailand ; *mak tan kok* in Laos ; *thot-not* in Cambodia ; *thot-not* in Vietnam.

The genus *Borassus* has seven species, although present day taxonomists recognize not more than four (Uhl and Dransfield 1987). Whatever the true number of species, the genus *Borassus* is one of the most widely distributed of the Palmae, with a range extending in a broad belt from Western Africa to Eastern Indonesia ; it is a genus of tropical wet and dry climates. The three most important economic species are : *B. aethiopum* Mart. occurring in Africa ; *B. flabellifer* L. found in coastal areas of India, Northern Sri Lanka and mainland South-Eastern Asia and *B. sundaicus* Becc. restricted to Indonesia. In each of these geographic areas *Borassus* palms are of significant value to local population. *Borassus* is most abundant in areas of low sandy plains or open savannahs and secondary forest. In some mountainous portions of India it occurs at elevations of 500–800 m. Attention has recently been drawn to *Borassus* because of global assessments of the potential of under developed tropical plant resources.

The different parts of Palmyra palm have economic value. Palm sap is stimulant, antiphlegmatic and cures dropsy. The sap can be concentrated to prepare jaggery. Its leaves and stalks are used for extraction of fiber and for brush making.

The Palmyra palm is cultivated in India and Sri Lanka. 'Neera' a special kind of liquor is prepared from the adult palm by tapping the sap from new inflorescence in Asian countries. It is collected by hanging earthen pots below the stabbed inflorescence having maximum sap flow. The fresh 'Neera' has large population of beneficial bacteria and yeast, and therefore considered good for health. The pulp of the fruit is also eaten raw or after roasting in India.The most valuable product of the tree is the sweet sap which runs nom the peduncles, cut before flowering and is collected in bamboo tubes or in earthen pots tied to the cut peduncle. The sap is also fermented into toddy and distilled.

The chief product of the Palmyra is the sweet sap (toddy) obtained by tapping the tip of the inflorescence, as is done with the other sugar palms and to a lesser extent, with the coconut. The sap flows for 5-6 months and each male spadix producing 4-5 lit per day; the female gives 50% more than the male. The toddy ferments naturally within a few hours after sunrise and is locally popular as a beverage. It is distilled to produce the alcoholic liquor called palm wine, amuck, or arak. Rubbing the inside of the toddy-collecting receptacle with lime paste prevents fermentation and there after the sap is referred to as sweet toddy, which yields concentrated or crude sugar (gur in India; jaggery in Ceylon); molasses, palm candy and vinegar As the extraction methods are destructive, palm stands are locally threatened by extinction. This could have serious consequences not only for the nutritional situation of the population but also for their income.

Palmyra palm jiggery (*gur*) is much more nutritious than crude cane sugar, containing 1.04% protein, 0.19% fat, 76.86% sucrose, 1.66% glucose, 3.15% total minerals, 0.1461 % calcium and 0.052% phosphorus. Also contains 11.01 mg iron and 0.767 mg copper per 100 g. The fresh sap is reportedly a good source of vitamin B complex.

The peeled seedlings are eaten fresh or sun-dried, raw, or cooked in various ways. They also yield starch, which is locally made into gruel with rice, herbs, chilli peppers, fish or other ingredients added. It has been proposed for commercial starch production. Small fruits are pickled in vinegar. During April and May, in India, the shell of the seed is punctured with a finger and the sweetish liquid is sucked out for refreshment like coconut water. Immature seeds are often sold in the markets. The kernels of such young seeds are obtained by roasting the nods and then breaking them open. The half-grown, soft-shelled seeds for the hollow jelly-like kernels are sliced longitudinally to form attractive loops, or rings and these, as well as the whole kernels, are canned in clear, mildly-sweetened water and exported. Tender fruits that fall prematurely are fed to cattle.

There are innumerable medicinal uses of all parts of the Palmyra palm. Briefly, the young plant is said to relieve biliousness, dysentery and gonorrhoea. The bark decoction with salt is used as a mouth wash and charcoal made of the bark serves a dentifrice. Sap from the flower stalk is prized as a tonic, diuretic, stimulant, laxative and anti-phlegmatic and amebicide. Efforts have also been made to explore the aero biologic and allergenic significance of the pollen of Palmyra palm (*Borassus flabellifer* Linn.), one of the important and common palm trees in India, with a view to isolate and purify its major allergenic components particularly from the pollen. Sugar made from this sap is said to counteract poisoning and it is prescribed in liver disorders. Candies of Palmyra palm are remedy for coughs and various pulmonary complaints. Fresh toddy, heated to promote fermentation, is bandaged onto all kinds

Table 1. Selected agro-climatic zones and villages of Odisha.

Agro-climatic zone	Villages
North Western Plateau Zone (Z_1)	Gohira (V1)
	Kolimati (V2)
	Medinpur (V3)
North Eastern Coastal Plain Zone (Z_2)	Kushadiha (V1)
	Nuagaon (V2)
	Singhpur (V3)
East and South Eastern Coastal Plain Zone (Z_3)	Pipili (V1)
	Talabania (V2)
	Bankhuala (V3)
North Eastern Ghat Zone (Z_4)	Dangapathar (V1)
	Raemal (V2)
	Kansar (V3)
South Eastern Ghat Zone (Z_5)	Pastikudi (V1)
	Utkela (V2)
	Gaigaon (V3)
Western Central Table Land Zone (Z_6)	Sutpara (V1)
	Puitala (V2)
	Madmada (V3)
Mid Central Table Land Zone (Z_7)	Nuagaon (V1)
	Khaliabandha (V2)
	Mundapal (V3)

of ulcers. The cabbage, leaf petioles and dried male flower spikes all have diuretic activity. The pulp of the mature fruit relieves dermatitis.

According to N. Bhol (Supervisor of the above investigation), Orissa University of Agriculture and Technology, Bhubaneswar, *Borassus flabellifer* is a climate resilient species in coastal areas of Odisha, India. He observed that it was found resistant to drought, flood and cyclone. It was one of the most resistant species to extremely severe cyclones happened in Odisha like the Super cyclone -1999, Phailin – 2013 and Hudhud – 2014. It is found growing in good number in coastal districts of Odisha which are frequently affected by cyclones, flood and sometimes with very high temperature. It also found in Bolangir district where temperature is high. Titilagarh area of this district in well-known place as one of the summer hotspots in the country where temperature goes to very high in summer and *B. flabellifer* is growing normally. It recorded 48^o C in April 2016, 48.1^o C in April 1999 and 50.1^o C in June 2003.

MATERIALS AND METHODS

The above investigation was carried out in different locations of 7 agro-climatic zones of Odisha during January, 2016 to July, 2017. The experiment was conducted in 7 agro-climatic zones of Odisha. In each agro-climatic zone, 3 villages were selected. The laboratory works were carried out at College of Forestry and College of Agriculture, Orissa University of Agriculture and Technology, Bhubaneswar. The experiment was laid out in Nested Design with 3 replications. It involved 7 agro-climatic zones of Odisha and in each agro-climatic zone 3 villages having more concentration of *Borassus flabellifer* trees. The name of the 7 agro-climatic zones and villages are given in Table 1.

Climate, weather and soil

The study areas fall in sub-tropical zone. The average weather and soil characteristics of the study areas are given in Table 2.

The observations were recorded on soil OC, pH, available N, available P and available K. For soil chemical analysis composite samples were collected from 4 depths such as 0–25 cm, 25–50 cm, 50–75 cm and 75–100 cm from surface level under the canopy of *Borassus flabellifer*. The soil samples were air dried under shade, finely ground and passed through a 2 mm sieve. The following methods were used in the laboratory for determining different chemical characteristics of soil. The methods used were mentioned below.

a) *Organic carbon* : Organic carbon content of the soil was determined by Walkley and Black's rapid titration method (Piper 1966).

b) *pH* : The pH was determined in 1 : 2 soil and water suspension by using glass electrode pH meter (Jackson 1973).

c) *Available nitrogen* : Available nitrogen was determined by the method described by Subbiah and Asiji (1956). Nitrogen released as ammonia during distillation of 20 g soil with 100 ml 0.32 % of $KMnO_4$ and 100 ml of 2.5 % NaOH was received in 2%

Table 2. Average weather conditions and soil characteristics of different agro-climatic zones under study.

Sl. No.	Agro-climatic zone	Weather	Mean annual rainfall (mm)	Mean maximum summer temp temp (ºC)	Mean minimum winter (ºC)	Broad soil groups
1.	North Western Plateau	Hot and moist sub-humid	1600	38.0	15.0	Red, Brown forest, Red and yellow, mixed Red and Black
2.	North Eastern Coastal Plain	Moist sub-humid	1568	36.0	14.8	Red, Lateritic, Deltalc alluvial, Coastal alluvial and Saline
3.	East and South Eastern Coastal Plain	Hot and Humid	1577	39.0	11.5	Saline, Lateritic, Alluvial, Red and Mixed red and Black
4.	North Eastern Ghat	Hot and moist, sub-humid	1597	37.0	10.4	Brown forest, Lateritic Alluvial Red, Mixed Red and Black
5.	South Eastern Ghat	Warm and humid	1710	34.1	13.2	Red, Lateritic, Black
6.	Western Central Table Land	Hot and moist sub-humid	1614	40.0	12.4	Red and Yellow, Red and Black, Black, Brown forest, Lateritic
7.	Mid Central Table Land	Hot and moist sub-humid	1421	38.7	14.0	Alluvial, Red, Lateritic, Mixed Red and Black

boric acid containing mixed indicator and ammonia against standard 0.02 NH_2SO_4.

d) *Available phosphorus* : It was determined by Bray's–I method with shaking 2 g of soil in 20 ml of extracting solution (0.03 N NH_4AF in 0.025 N HCL) for 5 minutes. The filtrate was estimated by spectrometer for phosphorus after development of color by $SnCl_2$ and measured at 660 nm (Jackson 1973).

e) *Available potassium* : It was determined by equilibrating 5 g of soil in 25 ml neutral ammonium acetate (Jackson 1973) and reading of extract was taken in flame photometer.

The quantitative data from various observations were analyzed as per the procedure described by Gomez and Gomez (1984). Attempt was taken to find out the possible relationship between different parameters. The critical differences were worked out at 5% probability level where the results varied significantly.

RESULTS AND DISCUSSION

The experimental results and discussion of the investigation are presented establishing the cause and effect relationship, wherever necessary and feasible, in light of available literature.

Organic carbon

The depth pertaining organic carbon in soil demonstrated remarkable variation under different zones irrespective of villages and soil depth. It ranged from 0.33–0.53 %. Z_7 showed highest organic carbon while Z_3 and Z_4 registered minimum value. The

Table 3. Organic carbon content under stands of Palmyra palm.

	V1					V2				
Villages zones	D_1 0-25 cm	D_2 25-50 cm	D_3 50-75 cm	D_4 75-100 cm	Mean of depth	D_1 0-25 cm	D_2 25-50 cm	D_3 50-75 cm	D_4 75-100 cm	Mean of depth
Z_1	0.62	0.36	0.27	0.18	0.36	0.62	0.44	0.33	0.24	0.41
Z_2	0.76	0.36	0.26	0.05	0.36	0.47	0.34	0.31	0.09	0.30
Z_3	0.80	0.54	0.41	0.27	0.51	0.89	0.45	0.43	0.12	0.47
Z_4	0.68	0.62	0.43	0.21	0.49	0.60	0.41	0.14	0.12	0.32
Z_5	1.38	0.54	0.50	0.21	0.65	0.50	0.12	0.12	0.06	0.20
Z_6	0.45	0.45	0.38	0.29	0.39	0.54	0.45	0.45	0.20	0.41
Z_7	0.58	0.54	0.51	0.20	0.46	0.45	0.33	0.27	0.18	0.31
Mean of villages	0.75	0.49	0.39	0.20	0.46	0.58	0.36	0.29	0.14	0.35

Table 3. Continued.

	V3					
Villages zones	D_1 0-25 cm	D_2 25-50 cm	D_3 20-75 cm	D_4 75-100 cm	Mean of depth	Mean of zones
Z_1	0.73	0.71	0.69	0.45	0.65	0.47
Z_2	0.70	0.53	0.48	0.30	0.50	0.39
Z_3	0.43	0.36	0.31	0.28	0.35	0.44
Z_4	0.31	0.29	0.12	0.05	0.19	0.33
Z_5	0.68	0.32	0.23	0.11	0.34	0.40
Z_6	0.45	0.44	0.36	0.36	0.40	0.40
Z_7	1.22	0.82	0.69	0.60	0.83	0.53
Mean of villages	0.65	0.50	0.41	0.31	0.47	0.42

trend of organic carbon under the stand of Palmyra palm was in the order of $Z_7>Z_1>Z_3>Z_5=Z_6>Z_2>Z_4$.

The accumulation of organic carbon under different villages was found remarkably different ranging from 0.35–0.47%. Villages under V_3 registered maximum value while under V_2 the minimum value irrespective of agro-climatic zones and soil depth.

A wide variation was also found under different depths. In all stands the organic carbon (%) was maximum in 0–25 cm depth followed by 25–50 cm, 50–75 cm and 75–100 cm.

With regard to interaction of agro-climatic zones, villages and soil depth, remarkable variation was noticed in soil organic carbon. It ranged from 0.05% to 1.38%. $Z_5V_1D_1$ (Western Undulating Zone × Pastikudi × 0–25 cm) registered the highest accumulation of organic carbon under the stand of Palmyra palm while $Z_2V_1D_4$ (North Eastern Coastal Plain × Kushadiha× 75–100 cm) and $Z_4V_3D_4$ (North Western Plateau × Kansar × 75–100 cm) recorded the lowest organic content in soil.

The data in Table 3 showed variation in organic carbon accumulation under different zones, villages, depths as well as interaction of these three. The variation among zones, villages and interactions may be due to difference in the edaphic condition in different locations. The higher value of Z_7 (Mid Central Table Land) may be because of the fact that in this zone soil is alluvial and black. The gradual decrease of organic carbon content towards higher depth may be because of reduction in accumulation of litter. The continuous addition of plant litter in the soil surface might have resulted in higher organic content in surface soil than lower depth. The results are in line with

Table 4. Soil pH content under stands of Palmyra palm.

Villages zones	V_1 D_1 0-25 cm	D_2 25-50 cm	D_3 50-75 cm	D_4 75-100 cm	Mean of depth	V_2 D_1 0-25 cm	D_2 25-50 cm	D_3 50-75 cm	D_4 75-100 cm	Mean of depth
Z_1	6.43	6.89	6.90	6.95	6.79	6.13	6.28	6.33	6.36	6.28
Z_2	6.22	6.56	7.09	7.63	6.88	5.99	6.38	6.65	6.88	6.48
Z_3	5.91	6.21	6.25	6.31	6.17	6.09	6.09	6.42	6.45	6.26
Z_4	5.67	5.72	5.72	5.73	5.71	6.09	6.12	6.19	6.33	6.18
Z_5	5.30	5.32	5.63	5.91	5.54	6.12	7.39	7.50	7.61	7.16
Z_6	7.36	7.55	7.57	7.69	7.54	7.99	8.06	8.09	8.36	8.13
Z_7	5.85	5.89	5.89	6.10	5.93	5.96	5.98	5.99	6.10	6.00
Mean of villages	6.11	6.31	6.44	6.61	6.37	6.33	6.14	6.74	6.87	6.64

Table 4. Continued.

Villages zones	V_3 D_1 0-25 cm	D_2 25-50 cm	D_3 50-75 cm	D_4 75-100 cm	Mean of depth	Mean of zones
Z_1	5.26	6.05	6.06	6.46	5.96	6.34
Z_2	6.24	6.30	6.53	6.70	6.44	6.60
Z_3	4.65	4.93	4.98	5.53	5.02	5.81
Z_4	5.57	5.67	5.71	6.12	5.77	5.88
Z_5	6.53	6.79	7.14	7.39	6.96	6.56
Z_6	7.69	7.72	7.93	7.99	7.83	7.83
Z_7	6.50	7.02	7.02	7.05	6.89	6.28
Mean of villages	6.06	6.35	6.48	6.74	6.41	6.47

the findings of Bhol (1995), Saralch (1994), Gupta *et al*. (1991), Kaushal (1992), Routaray (2015).

Soil pH

The data in Table 4 reflects variation in soil pH among agro-climatic zones irrespective of villages, depths and combinations of zone, village and depth. Among the zones it varied from 5.81 to 7.83 with maximum value in Z_6 and minimum in Z_3. Among villages the mean value varied from 6.37 to 6.64. Among interactions it varied from 4.65 to 8.36. In all zones and villages it increased progressively towards higher depth. It ranged from 4.65 to 8.36.

The variation in pH level was observed with respect to agro-climatic zones, depths and their interactions. Variation among agro-climatic zones may be variation in agro edaphic condition. The highest pH of Z_6 irrespective of villages and depths may be because of relatively drier situation. On the other hand the lower pH of Z_3 may be ascribed to moist condition of the soil.

The pH steadily increased towards higher depth of soil irrespective of agro-climatic zones and villages. This may be because of leaching of bases and their deposition in higher depth. The increase of soil pHwith increase of soil depth was also reported by Murthy *et al.* (1985) for Pine forest in GarwalHimalay, Soni (1991) for deodar forest of Himachal Pradesh, Sharma and Singh (1991) for chirpine forest, Kaushal (1992) for dry zone deodar, Saralch (1994) for Eucalyptus plantation, Routaray (2015) for mangium plantations. Among interaction, the lowest pH (4.65) in $Z_3V_3D_1$ (East and South Eastern Coastal Plain × Bankhuala × 0–25 cm) may be because of moist condition of soil and upper depth of soil. The highest pHunder $Z_6V_2D_4$ (Western Central Table Land × Puitala ×75–100 cm) may be ascribed to dry

Table 5. Available N (kg ha^{-1}) content under stands of Palmyra palm.

Villa-ges zones	D_1 0-25 cm	D_2 25-50 cm	D_3 50-75 cm	D_4 75-100 cm	Mean of depth	D_1 0-25 cm	D_2 25-50 cm	D_3 50-75 cm	D_4 75-100 cm	Mean of depth
	V_1					V_2				
Z_1	175.00	75.00	75.00	62.50	96.88	150.00	150.00	112.50	87.50	125.00
Z_2	125.00	100.00	100.00	62.50	96.88	125.00	112.50	100.00	100.00	109.38
Z_3	212.50	187.50	162.50	112.50	168.75	225.00	200.00	187.50	112.50	181.25
Z_4	212.50	200.00	200.00	87.50	175.00	287.50	200.00	175.00	75.00	184.38
Z_5	200.00	187.50	178.50	112.50	169.63	212.50	187.50	162.50	112.50	168.75
Z_6	87.50	87.50	75.00	62.50	78.13	150.00	112.50	112.50	100.00	118.75
Z_7	162.50	137.5	125.00	75.00	125.00	137.50	125.00	100.00	75.00	109.38
Mean of villa-ges	167.86	139.29	130.86	82.14	130.04	183.92	155.36	135.71	94.64	142.41

Table 5. Continued.

Villazes zones	D_1 0-25 cm	D_2 25-50 cm	D_3 20-75 cm	D_4 75-100 cm	Mean of depth	Mean of zones
			V_3			
Z_1	187.50	137.50	125.00	125.00	143.75	121.88
Z_2	214.00	176.00	143.00	114.00	161.75	122.67
Z_3	201.00	178.50	138.00	125.00	160.63	170.21
Z_4	187.50	162.50	162.50	150.00	165.63	175.00
Z_5	225.00	200.00	187.50	162.00	193.63	177.34
Z_6	112.50	100.00	100.00	62.50	93.75	96.88
Z_7	200.00	187.50	187.50	162.50	184.38	139.59
Mean of villages	189.64	163.14	149.07	128.71	157.64	143.37

situation of the locality and higher depth (75–100cm).

Available N

The perusal of data in Table 5 revealed a wide variation among agro-climatic zones irrespective of villages, depths ranging from 96.88 kg ha^{-1} – 177.34 kg ha^{-1}. Z_5 registered the maximum value while Z_6 recorded the lowest value. Among villages the mean value varied from 130.04 kg ha^{-1} – 157.64 kg $ha^{-1.}$ With regard to depths, in all agro-climatic zones as well as villages, the availability of Nitrogen went on decreasing towards higher depth. Among the interactions of agro-climatic zones, villages and depths, an appreciable variation was noticed ranging from 62.50 kg ha^{-1} - 287.50 kg ha^{-1}. $Z_4V_2D_1$ (North Western Plateau × Reamal × 0–25 cm) possessed maximum value while Z_1, Z_2, Z_6 under V_1D_4 registered the lowest value (62.50 kg ha^{-1}).

The variation of available N in different agro-climatic zones, villages, depths and in their combinations may be because of difference in agro edaphic conditions. Among the zones irrespective of villages and depths, the highest value under Z_5 may be because of black heavy soil where leaching of nitrogen is less. On the other hand the lowest value of Z_6 may be due to poor condition of soil with relatively high temperature. The quality of available N of decreased with increase of soil depth irrespective of agro-climatic zones and villages which may be due to continuous deposition of plant litter in soil surface and their mineralization might have resulted the higher content of nutrients in upper layer of soil. Similar findings are reported by Minhas (1986), Sharma and Singh (1991), Mallick (1992), Bhol (1995) and Routaray (2015).

The highest quantity of available N in $Z_4V_2D_1$ may be because of closeness of the site to forest and

Table 6. Available P (kg ha^{-1}) content under stands of Palmyra palm.

Villa-ges zones	V_1 D_1 0-25 cm	D_2 25-50 cm	D_3 50-75 cm	D_4 75-100 cm	Mean of depth	V_2 D_1 0-25 cm	D_2 25-50 cm	D_3 50-75 cm	D_4 75-100 cm	Mean of depth
Z_1	58.19	43.29	29.81	19.47	37.69	36.91	27.45	19.66	11.90	23.98
Z_2	50.95	47.95	37.55	11.45	36.98	49.70	35.70	28.19	21.50	33.77
Z_3	46.77	35.99	21.97	21.41	31.54	21.41	20.28	18.59	17.46	19.44
Z_4	37.75	36.62	20.28	14.08	27.18	45.08	28.17	26.48	23.66	30.85
Z_5	88.46	28.17	25.35	23.52	41.38	44.51	25.92	24.70	20.28	28.85
Z_6	33.24	31.55	28.17	26.48	29.86	29.30	27.61	27.04	23.10	26.76
Z_7	62.10	56.29	47.19	33.79	49.84	47.29	34.60	23.44	17.48	30.70
Mean of villages	53.92	39.98	30.05	21.46	36.35	39.17	28.53	24.01	19.34	27.76

Table 6. Continued.

Villages zones	V_3 D_1 0 -25 cm	D_2 25-50 cm	D_3 20-75 cm	D_4 75-100 cm	Mean of depth	Mean of zones
Z_1	45.43	37.08	23.47	16.63	30.65	30.77
Z_2	36.19	33.45	27.41	23.60	30.16	33.64
Z_3	17.50	11.20	10.10	7.60	11.60	20.86
Z_4	45.64	25.92	23.10	21.97	29.16	29.06
Z_5	55.22	43.08	23.66	21.10	35.77	35.33
Z_6	29.86	28.73	26.48	25.92	27.75	28.12
Z_7	45.64	42.82	36.62	33.81	39.72	40.09
Mean of villages	39.35	31.75	24.41	21.52	29.26	31.12

upper depth of soil (0–25cm). The lower value of $Z_1V_1D_4$, $Z_2V_1D_4$ ascribed to more leaching of the soil and higher depth. The lower value in $Z_6V_1D_4$ may be due to poor soil condition, high temperature and lower depth.

Available P

The perusal of data in Table 6 revealed that available P was influenced under different agro-climatic zones, villages, soil depths and their combinations. It varied from 20.1 kg ha^{-1} 40.09 kg ha^{-1} among agro-climatic zones irrespective of villages and depths. The highest value was registered under Z_7 and lowest in Z_6. Among villages irrespective of agro-climatic zones and depths, it varied from 27.76 kg ha^{-1} to 36.35 kg ha^{-1}. So far the depth is concerned it progressively reduced towards higher depth irrespective of agro-climatic zones and villages. So far as the interaction of agro-climatic zones, villages, depths is concerned, it varied from 7.60 to 88.46 kg ha^{-1}. This was highest in $Z_5V_1D_1$ and lowest in $Z_3V_3D_4$.

The variation of available P among agro-climatic zones, villages, depths and their interaction may be variation in agro edaphic condition of different locations. Among agro-climatic zones irrespective of villages and depth, the highest value under Z_7 (40.09 kg ha^{-1}) may be because of better edaphic condition as soil is alluvial and black whereas the lowest value under Z_6 (28.12 kg ha^{-1}) may be due to degraded soil. The decrease of available P with increase of soil depth may be because of reduction in accumulation of plant litter in the upper soil layer. These findings are in line with the findings of Saralch (1994) for Eucalyptus plantation, Bhol (1995) for different NTFs, Routaray (2015) for mangium plantations. The highest value under combination of $Z_5V_1D_1$ may be due to black soil and upper layer.

Table 7. K (kg ha^{-1}) content under stands of Palmyra palm.

Villa-ges zones	V_1 D_1 0-25 cm	D_2 25-50 cm	D_3 50-75 cm	D_4 75-100 cm	Mean of depth	V_2 D_1 0-25 cm	D_2 25.50 cm	D_3 50-75 cm	D_4 75-100 cm	Mean of depth
Z_1	955.60	573.80	299.70	167.20	499.08	330.62	278.20	264.00	184.10	264.23
Z_2	143.80	73.92	69.88	59.13	86.68	213.70	208.30	202.90	147.80	193.18
Z_3	366.91	221.76	219.07	196.22	250.99	380.35	372.28	338.68	127.61	304.73
Z_4	697.53	598.08	584.64	362.88	560.78	569.85	494.59	366.91	329.28	440.16
Z_5	243.91	235.20	232.51	220.41	232.91	833.28	438.14	206.97	192.19	417.65
Z_6	251.32	237.88	181.44	162.62	208.32	368.25	202.94	186.81	170.68	232.17
Z_7	294.30	259.40	238.40	237.80	257.48	185.47	141.10	131.70	137.10	148.84
Mean of villages	421.85	314.29	260.81	200.89	299.46	411.65	305.08	242.57	184.11	285.85

Table 7. Continued.

Villages of zones	D_1 0-25 cm	D_2 25-50 cm	V_3 D_3 50-75 cm	D_4 75-100 cm	Mean of depth	Mean of zones
Z_1	267.50	201.60	134.40	119.60	180.78	314.69
Z_2	278.00	206.00	189.19	154.02	206.80	162.22
Z_3	199.00	197.00	177.07	163.08	184.038	246.59
Z_4	384.38	192.19	174.72	154.56	226.46	409.135
Z_5	840.80	638.11	584.01	461.70	631.16	427.24
Z_6	547.00	440.83	393.79	387.07	442.17	294.22
Z_7	440.83	267.45	216.38	190.84	277.53	227.95
Mean of villages	421.73	306.17	267.08	232.98	306.99	297.43

Available K

The available K in soil under stands of *Borassus-flabellifer* varied remarkably among agro-climatic zones irrespective of villages (Table 7). It varied from 162.22 to 427.24 kg ha^{-1}. Z_5¬ (Western Undulating Zone) exhibited highest quantity of available K while Z_2 (North Eastern Coastal Plain) recorded the lowest quantity. The order of available K content was: $Z_5>Z_4>Z_1>Z_6>Z_3>Z_7>Z_2$. Among villages irrespective of zones, it differed from 285.85 to 306.99 kg ha^{-1}. In all villages and zones, it decreased with increase of depth of soil. In different combination of agro-climatic zones, villages and depths, an appreciable variation was found ranging from 59.13 kg ha^{-1} to 955.60 kg ha^{-1}. $Z_1V_1D_1$ (North Central Plateau Gohira× 0–25 cm) registered the maximum value while $Z_2V_1D_4$ (North Eastern Coastal Plain × Kushadiha × 75–100 cm) recorded the lowest value.

The variation in available K content in different agro-climatic zones irrespective of villages and depths may be due to variation in edaphic condition which has been given in Table 2. The higher quantity of available K in upper depth of soil may be due to continuous deposition of leaf litter in surface soil and their mineralization. Similar findings were also reported by Sharma and Singh (1991), Mallick (1992) for chirpine forest, Banarjee and Nath (1991) for forest soil of Sikkim, Kaushal (1992) for Deodar forest, Routaray (2015) for mangium plantations. Among the interactions, the maximum value of $Z_1V_1D_1$ (North Central Plateau × Gohira× 0–25 cm) may be because of the location of site near forest and upper layer of soil where accumulation of litter is maximum.

CONCLUSION

The organic carbon in soil differed under different zones from 0.33 (Z_7) to 0.52% (Z_4), 0.35–0.47% among villages and 0.05% to 1.38% among interaction of agro-climatic zones, villages and soil depth (highest accumulation in $Z_5V_1D_1$ while and lowest in $Z_4V_3D_4$ and $Z_2V_1D_4$). The variation in soil pH was 5.81 (Z_6) to 7.83 (Z_3) among agro-climatic zones, 6.37 to 6.64 among villages and 4.65 to 8.36 among the interactions.The available N varied 96.88 – 177.34 kg ha^{-1} among agro-climatic (highest in Z_5 and lowest in Z_6), 130.04 – 157.64 kg ha^{-1} among villages, 62.50–87.50 kg ha^{-1} among the interactions (maximum in $Z_4V_2D_1$ and minimum in $Z_1V_1D_4$, $Z_2V_1D_4$ and $Z_6V_1D_4$). The available P differed 20.1– 40.09 kg ha^{-1} among agro-climatic (maximum in Z_5 and minimum in Z_6), 27.76 to 36.35 kg ha^{-1} among villages, 7.60 to 88.46 kg ha^{-1} among the interactions (highest in $Z_5V_1D_1$ and lowest in $Z_3V_3D_4$). Among agro-climatic zones the available K varied 162.22 to 427.24 kg ha^{-1} (highest in Z_5 and lowest in Z_6), 285.85 to 306.99 kg ha^{-1} among villages and 59.13 to 955.60 kg ha^{-1} among the interactions (maximum in $Z_1V_1D_1$ and minimum in $Z_2V_1D_4$). Alluvial soil with high moisture content, high organic carbon, more available N, P and K, nearly neutral pH and moderate temperature helped this palm to excel in growth and yield.

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