



Jatropha (*Jatropha curcas*) based intercropping systems: An alternate land use for rehabilitation of degraded sodic lands

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ABSTRACT

A field study was conducted to evaluate the performance of jatropha based intercropping model as an alternate land use for rehabilitation of degraded sodic lands. Cultivation of *Jatropha curcas* L. as monocropping has not been proven economically viable because of its late fruiting and poor yield. A small and resource poor farmer having sodic soils can't wait for at least five years to get income. Therefore, the present study was conducted to replace monoculture of *jatropha* with intercrops in between jatropha plantation in sodic soils to optimize land use efficiency. Study revealed that the plantation of jatropha at 3 m apart and inter- cultivation of sweet basil - matricaria cropping sequence for four years was highly economical than the planting at 3×2m spacing and other tested crop rotations. Soil physico-chemical and biological properties in sweet basil - matricaria with jatropha L. as main crop were better than rest of the cropping sequences evaluated. Soil microbial biomass carbon (MBC) was also higher with sweet basil-matricaria cropping sequence followed by sorghum –wheat and maize-linseed. The study shows that inter cultivation of *Jatropha* in sodic soils encouraged biological activities in the rhizosphere. Inter-cultivation of medicinal and aromatic crops under *Jatropha* plantations for four years was found to be an alternate land use sequence to obtain higher income than the sole plantation of *Jatropha* in sodic soils. Soil health improvement due to intercropping can provide a better environment for cultivation of highly remunerative crops in future.

Key words: Alternate land use, Degraded sodic lands, Intercropping, *Jatropha curcas*, Rehabilitation

In the 21st century, the world is facing multiple challenges with the ever-growing population. At the same time issues related to food and energy security in the developed as well as developing countries is increasing, because of uncertainties to meet the growing demand for food and fuel. *Jatropha* (*Jatropha curcas* L.) being highly drought tolerant and well suited to semiarid conditions is the most potential and promising biodiesel plant that can be grown under degraded lands including sodic lands which are not suitable for growing food crops (Wani *et al.* 2007). However, barriers include insufficient knowledge on suitability of *jatropha* for various regions, unavailability of salt-tolerant *jatropha* genotypes, limited agronomic and input response studies have triggered to explore the feasibility of crops which can be grown under *jatropha* to fetch some income for livelihood security of resource poor farmers having salt-affected soils and to rehabilitate these degraded lands through bioremediation. The monoculture of *jatropha* either in good land or in degraded lands is not an economically viable proposition therefore, this practice

has been replaced by poly-culture by that time the tree could not attain full canopy. Most of the farmers preferred growing *jatropha* together with maize, cowpea, common beans and greengram in normal soils. *Jatropha* had been successfully intercropped with groundnuts in India during the dry periods when *jatropha* has shed all the leaves (Brittaine and Litaladio (2010). Rejila and Vijayakumar (2011) also reported on intercropping of *jatropha* with sesame, green chilli, green-gram and sunflower in normal soils where they found that *jatropha* - sesame intercrop was a success.

Out of 6.73 million ha degraded salt-affected soils in India nearly 3.8 million ha are sodic soils (Mandal *et al.* 2009). Part of the sodic land have been reclaimed by government support and put under agriculture and forestry (Singh *et al.* 2012). Pandey *et al.* (2011) proposed some diverse land use sequence to harness the productivity potential of these soils and plantation of *J. curcas* is one of the important land uses for sustainable development of this land and improving livelihood of resource poor farmers who cannot afford the reclamation of these lands through chemical amendments. Despite the several advantages of growing *jatropha*, there is no scientific data showing the effect of intercropping with *jatropha* on amelioration of sodic soils. Therefore, the present study was undertaken to (i) identify optimum plant density of *jatropha* for suitable

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intercropping in degraded sodic soils, (ii) find out suitable crops and cropping sequence for inter-cultivation with jatropha and (iii) to determine the effect of plant density and intercropping on amelioration of degraded sodic lands.

MATERIALS AND METHODS

A field experiment was conducted at ICAR-Central Soil Salinity Research Institute, Regional Research Station, Lucknow (26° 47' 45" N and 80° 46' 32" E). The climate of experimental site is semi-arid, sub-tropical and monsoonal receiving an average annual rainfall of 817 mm. The mean maximum temperature of 39.0°C in May and mean minimum temperatures of 7.1°C in January indicate a seasonal climate. The mean annual temperature during the study period was recorded as 24.6°C, whereas mean annual soil temperature (MAST) and the mean winter soil temperature (MWST) was 31.0°C and 18.0°C, respectively. Tube well water used for irrigating the jatropha plants as well as intercrops was having pH 8.2 and EC 63.0 µS/m, Na 3.2 m mol/l, Ca + Mg 3.5 m mol/l, K 0.1 m mol/l with residual sodium carbonate (RSC) of 2.8 m mol/l.

The soil pH₂ (1:2 w/v soil: water) of the surface layer (0-15 cm) determined with digital meters was 9.46 and it increased to 9.86 at 90 cm soil depth. Electrical conductivity (EC₂) determined with digital meter decreased from 1.77 dS/m to 0.62 dS/m accordingly. Exchangeable sodium percentage (ESP) was estimated from exchangeable sodium ratio (ESR) and sodium adsorption ratio (SAR) drawn from the concentration of soluble Na⁺, Ca²⁺ and Mg²⁺. The soil organic carbon content was analyzed using chromic acid titration method (Wang *et al.* 1996). The bulk density of soil was determined using a core sampler (Wilde 1964). Available N was estimated by the method given by Subbiah and Ashija (1956). Available P and K were determined by the Olsen extraction (Olsen and Dean 1965) and ammonium acetate extraction, respectively. Infiltration rate was measured using, double concentric infiltrometer (Yadav and Vasistha 1989). Soil microbial biomass carbon (MBC) was estimated by fumigation and extraction method of Vance *et al.* (1987). To analyze the microbial population, soil samples were collected from 0 m and 1 m away from the trunk respectively at 0-15 cm soil depth. Dehydrogenase activity was analyzed using method given by Dick *et al.* (1996). The initial soil properties of the experimental site are given in Table 1.

Six month old seedlings of jatropha genotype BTP 1-K raised in normal soil were planted in 40 cm diameter at the top, 20 cm at the bottom and 120 cm deep auger holes. The experiment consisted of two plant spacing, i.e. 3 × 3 m and 3 × 2 m as main plot treatments and three intercropping sequences, viz. control (no intercropping), sorghum-wheat (S-W), maize-linseed (M-L) and sweet basil-matricaria (SB-M) as sub plot treatments. The experiment was conducted with four replications under split plot design. Each auger holes was filled with a mixture of original soil + 4 kg gypsum + 10 kg farmyard manure (FYM). The jatropha plants were irrigated immediately after planting and subsequently

Table 1 Initial soil properties of the experimental site

Soil parameters	Soil depth (cm)			
	0-15	15-30	30-60	60-90
pH ₂	9.6 ± 0.13	9.63 ± 0.16	9.82 ± 0.20	9.86 ± 0.20
EC ₂ (dS/m)	1.77 ± 0.10	1.43 ± 0.08	0.86 ± 0.14	0.64 ± 0.07
ESP	40 ± 1.43	50 ± 2.12	65 ± 3.56	70 ± 2.45
OC (g/ kg)	1.04 ± 0.02	1.0 ± 0.03	0.8 ± 0.05	0.6 ± 0.02
Bulk density (g/cm ³)	1.56 ± 0.03	1.50 ± 0.04	1.51 ± 0.01	1.53 ± 0.02
Available N(kg/ ha)	93.8 ± 112	62.7 ± 2.12	54.3 ± 1.40	45.02 ± 2.45
Available P (kg/ ha)	24.8 ± 1.86	21.5 ± 1.63	18.3 ± 0.84	17.02 ± 1.12
Available K (kg/ ha)	388.6 ± 2.43	383.9 ± 2.62	321.2 ± 1.79	238.5 ± 1.32
Infiltration rate(mm/ day)	8.62 ± 0.12			
MBC (Mg/kg)	96.4 ± 3.23			
GR (Mg/ha)	10.5 ± 0.63			

ESP: Exchangeable sodium percentage, OC: Organic carbon, GR: Gypsum requirement, pH₂ and EC₂: refers to soil and water suspension ratio of 1:2.

at monthly interval during first year of planting through furrow irrigation method. Subsequent irrigations were given once in a year during June. Sorghum (*Sorghum vulgare*), maize (*Zea mays*) and sweet basil (*Ocimum basilicum*), were grown during (June to October) and wheat (*Triticum aestivum*), linseed (*Linum usitatissimum*) and matricaria (*Matricaria chamomilla*) during *rabi* (November to May) seasons for four years till jatropha developed full canopy. Recommended packages and practices were followed for all the crops. Plant mortality was recorded after every six months. Sorghum yield was estimated on the basis of green fodder yield, maize and wheat yields in terms of grain and straw, sweet basil as dry biomass yield and in case of matricaria flower yield was recorded.

The observation on plant growth and biomass yield were recorded periodically. Plant girth was measured at 130 cm above the ground as described by Achten *et al.* (2010). To measure the air dried pruned biomass, jatropha plants were pruned every year during February (dormancy period) and air dried. To measure total biomass, three representative plants were uprooted from each treatment, roots and shoots were separated and air dried to measure air dry biomass after five years of study. Litter collectors of 100 cm × 100 cm size, with 0.5 mm mesh steel net were used to measure annual litter fall yield and estimate total litter fall added to the soil during the five years of study. The collected data

were statistically analyzed using MSTAT-C software version 2.1 developed by Russell (1994).

RESULTS AND DISCUSSION

Plant growth and biomass yield

Plant spacing plays an important role in growth and development of jatropha plants. Data revealed that seedlings planted at wider spacing attain more plant height than closer spacing under all the cropping sequences (Fig 1). This is due to increasing plant population, competition for nutrients, sunlight and water. Maximum plant height (205.6 cm) was recorded with SB-M cropping sequence in all the consecutive years followed by S-W (185.0 cm) and minimum (165.8 cm) with control. The annual increment in plant height was significantly higher ($P \leq 0.05$) in SB-M (45.63 cm) cropping sequence than that of S-W, M-L and control under both the plant spacing. During initial two years, plant girth was

not significantly affected due to spacing and intercrops but, maximum plant girth (24.3 cm) was attained in SB-M cropping sequence and minimum (19.6 cm) with control. From third year onwards, spacing poses a significant effect on plant girth in all the cropping sequences (Fig 1).

Number of branches, an important biomass attributing character did not show much difference due to plant spacing at one year growth stage but from second year onwards, it increased significantly with $3\text{ m} \times 3\text{ m}$ spacing as compared to $3\text{ m} \times 2\text{ m}$ spacing. Highest number of branches in all the years was recorded with SB-M cropping sequence as compared to control, S-W and M-L (Fig 2). Annual increment in number of branches in jatropha was higher with $3\text{ m} \times 3\text{ m}$ spacing as compare to $3\text{ m} \times 2\text{ m}$. Maximum increment to the level of 13.25 and 13.12 was recorded with SB-M cropping sequence at $3\text{ m} \times 3\text{ m}$ and $3\text{ m} \times 2\text{ m}$ plant spacing respectively and minimum (7.50 and 6.00) with control where no understory crop was grown.

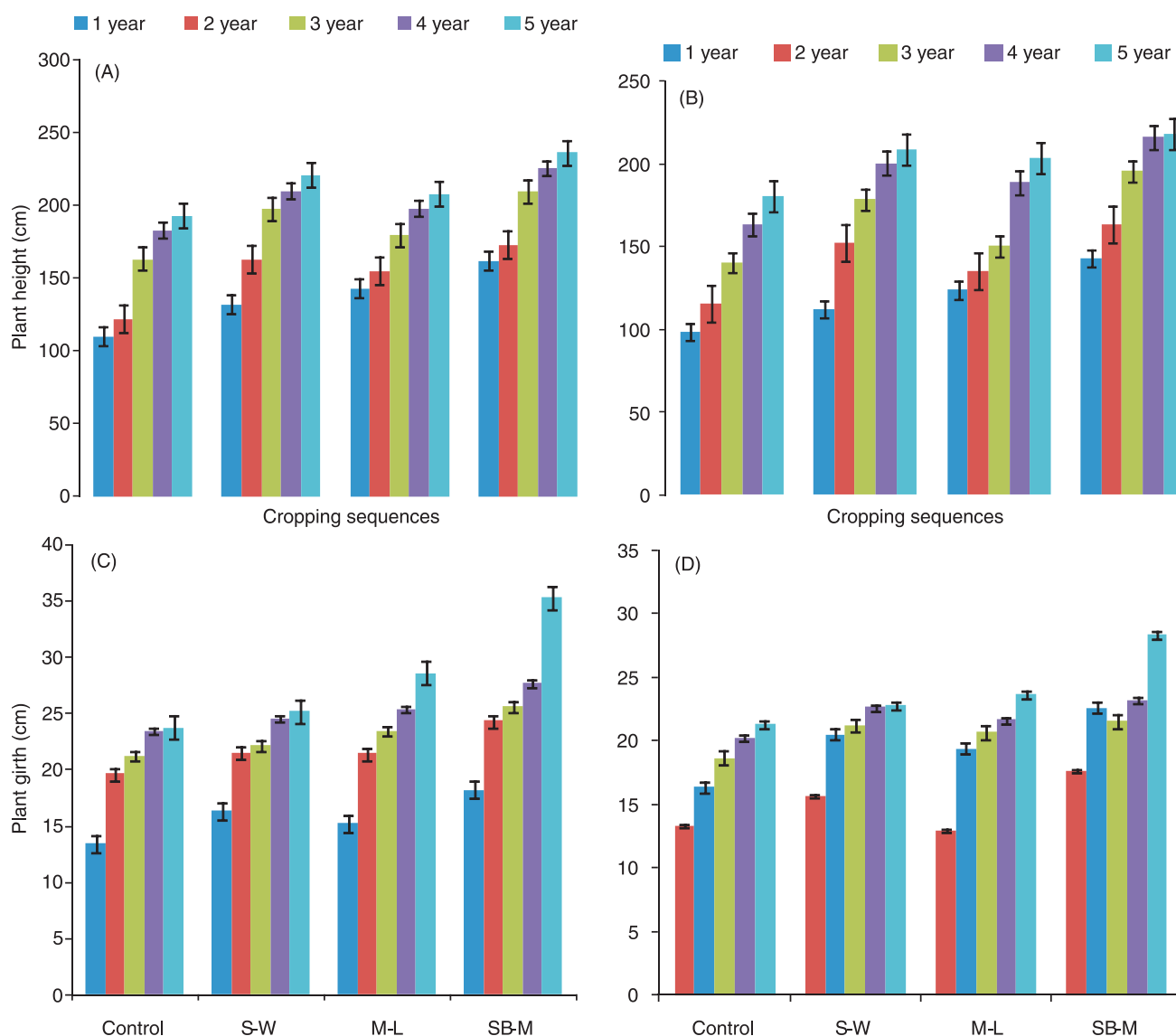


Fig 1 Effect of plant density and intercropping sequences on plant height (A) at $3 \times 3\text{ m}$ (B) at $3 \times 2\text{ m}$ and plant girth (C) at $3 \times 3\text{ m}$ and (D) at $3 \times 2\text{ m}$ spacing.

Average pruned biomass yield (2.36 and 3.77 t/ha) was significantly ($P \leq 0.05$) higher under $3 \text{ m} \times 2 \text{ m}$ spacing than $3 \text{ m} \times 3 \text{ m}$ spacing in all the cropping sequences. It is because of more number of plants per unit area. During the initial years, when the soil was highly sodic, the plant growth was poor resulting in low pruned biomass yield at both the spacing. After two years of planting, pruned biomass yield increased significantly. This may be due to ameliorative effect of soil and addition of nutrients to the intercrops. Maximum pruned biomass (3.77 t/ha) was recorded with SB-M cropping sequence, whereas minimum with control.

Tree biomass yield as well as total biomass (tree+pruned) yield after five years of planting were significantly ($P \leq 0.05$) higher in $3 \text{ m} \times 2 \text{ m}$ plant spacing as compared to $3 \text{ m} \times 3 \text{ m}$ because of more number of plants per unit area. The share of pruned biomass to total biomass under $3 \text{ m} \times 3 \text{ m}$ spacing ranges from 5.31 to 5.98% however, under $3 \text{ m} \times 2 \text{ m}$ spacing it ranges from 4.64 to 6.13%. Maximum total dry biomass (73.26 t/ha and 66.27 t/ha) was observed with SB-M cropping sequence in both the plant spacing and it was significantly higher over control, S-W and M-L rotations. This may be because of higher availability of moisture and nutrients applied to SB-M cropping sequence (Kagamebga *et al.* 2011, Singh *et al.* 2015).

Soil physico-chemical properties

There was significant improvement in physico-chemical

properties of the soil due to combined effect of jatropha plants and intercropping. Significantly higher bulk density was recorded in control plot where only jatropha plants were grown over the plantation of jatropha and cultivation of crops in between the trees. Planting of jatropha at of $3 \text{ m} \times 2 \text{ m}$ spacing recorded maximum reduction in bulk density and increase in soil porosity and cumulative infiltration rate because of addition of maximum litter fall and biomass yield of jatropha (Fig 3). This is due to the shallow root system of jatropha plants and the intercrops, which enhances the proportion of macropores to micropores (Wani *et al.* 2012). Soil infiltration rate increased from 8.62 mm/day to 22.1 mm/day due to improvement in the soil surface over the years (Ogunwale *et al.* 2008, Singh *et al.* 2011). Highest infiltration rate (22.10 mm/day) was recorded with SB-M cropping sequence followed under jatropha planted at $3 \text{ m} \times 2 \text{ m}$ spacing. However, no significant difference was observed in infiltration rate between $3 \text{ m} \times 3 \text{ m}$ and $3 \text{ m} \times 2 \text{ m}$ plant spacing.

Improvement in soil chemical properties like pH, EC, organic carbon and available NPK was also observed due to cultivation of jatropha alone or with intercrops. The degree of improvement was linked with annual leaf litter fall, total biomass production, tree root spread and management practices of intercrops. Results indicated that, the highest improvement in soil properties was recorded under plantation of jatropha at $3 \text{ m} \times 2 \text{ m}$ spacing and growing of SB-M

Table 2 Effect of plant spacing and intercropping sequences on annual increments in plant growth parameters of jatropha

Cropping sequences	Annual increment in plant height (cm)		Annual increment in stem girth (cm)		Annual increment in number of branches/plant	
	3×3 m	3×2 m	3×3 m	3×2 m	3×3 m	3×2 m
Control	31.69±1.12	31.06±0.56	3.43±0.21	1.99±0.08	7.50±0.64	6.00±0.46
S-W	37.06±0.62	33.66±0.48	2.96±0.19	2.36±0.10	8.25±0.58	8.10±0.52
M-L	33.47±1.02	31.65±0.54	4.45±0.17	2.21±0.12	12.25±0.60	9.00±0.51
SB-M	45.63±0.83	35.38±0.43	5.69±0.20	2.73±0.08	13.25±0.66	13.12±0.55
Mean	36.96	32.93	4.13	2.32	10.31	9.05
LSD ($P=0.05$) for cropping sequence	3.12	2.13	0.63	0.42	2.17	1.62
LSD ($P=0.05$) for spacing	3.26		1.24		1.63	

S-W: Sorghum-wheat, M-L: Maize-linseed and SW-M: Sweet basil-matricaria

Table 3 Total biomass yield of jatropha as affected by plant spacing and intercropping (mean of 5 years)

Cropping sequences	Pruned biomass (t/ha)		Tree biomass yield (t/ha)		Total biomass (t/ha)	
	3×3 m	3×2 m	3×3 m	3×2 m	3×3 m	3×2 m
Control	1.49±0.21	2.36±0.06	26.54±1.16	36.08±1.20	28.03±1.20	38.44±1.52
S-W	2.60±0.16	2.98±0.10	46.42±1.23	61.16±1.16	49.02±1.05	64.14±1.61
M-L	2.66±0.13	3.09±0.12	44.33±1.35	62.58±1.26	45.99±1.41	65.67±1.53
SB-M	3.03±0.12	3.77±0.08	63.24±1.24	69.49±1.43	66.27±1.23	73.26±1.42
Mean	2.44	45.13	47.32	3.05	57.32	60.37
LSD ($P=0.05$) for cropping sequences	0.32	0.24	1.12	1.32	2.22	1.62
LSD ($P=0.05$) for spacing	0.14	0.14	0.23	0.26	0.21	0.12

S-W: Sorghum-wheat, M-L: Maize-linseed and SW-M: Sweet basil-matricaria

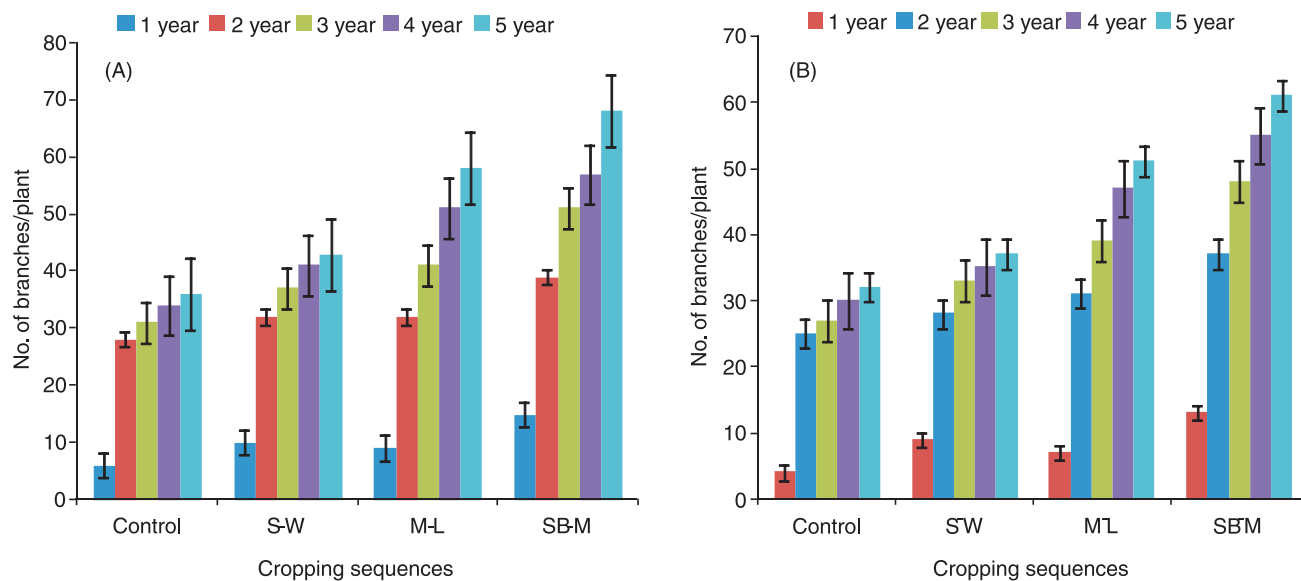


Fig 2 Effect of plant density and spacing on number of branches at (A) 3×3 m and (B) 3×2 m spacing.

as intercrops (Table 4). This is because of matricaria helps to improve sodic soils through its exceptionally higher sodium uptake and CO₂ emission through root respiration, organic matter decomposition and root exudation (Singh *et al.* 2013). Organic matter added through leaf litter and fine root mortality produces organic acids (humic and fulvic) that reduce soil pH. The winter months accounted for 80% of total litter fall that was composed of about 75-80% foliage which in turn helps in increasing organic carbon and reducing soil pH (Singh *et al.* 2014). The organic carbon content of the surface soils was increased about three folds in intercropping with jatropha and about twofolds in sole

plantation of jatropha. This is due to addition of litter fall of jatropha plants and decomposition of crop residues left in the soil. Wani *et al.* (2012) and Baumert *et al.* (2015) reported that soil carbon content increased by 19% and 84% during 4 years of jatropha cultivation. Singh *et al.* (2016) have also reported a significant increase in organic carbon from a *Prosopis* based silvipastoral sequence. Growing of SB-M under the jatropha trees significantly ($P \leq 0.05$) improved fertility status (available NPK) of sodic soils in comparison to barren sodic soils over five year period because of production of more biomass added to the soils and less nutrient uptake. Plantations of *J. curcas* on degraded sodic lands are supposed to offset the degraded soil properties at varying extents corresponding to their growth and age (Abhilash *et al.* 2010, Garg *et al.* 2011).

Microbial properties

Soil microbial biomass plays an important role in managing nutrient cycling and availability to plants (ITAB 2002). The highest populations of bacteria, fungi, actinomycetes as well as dehydrogenase activity were recorded in the rhizosphere soil as compared to non-rhizosphere soil (Fig 4). The number of bacteria in the rhizosphere soil was about 40% higher than the non-rhizosphere soils. This is because of high mineralization in the canopy area of jatropha plants than outside the canopy and quality of C: N ratio. The microbial biomass, temperature and humidity favored the microbial activity involved in the rate of the mineralization. Anbalagan *et al.* (2012), Chaudhary *et al.* (2007) and Ogunwole *et al.* (2007) also reported that the microbial biomass is always higher under canopy than outside of the canopy. This indicates more biological activities in the rhizosphere zone which increased microbial biomass carbon. Similarly, fungal population in the rhizosphere zone was more than the non-rhizosphere soils. Plant spacing does not have a significant role in microbial activities in rhizosphere soil. However,

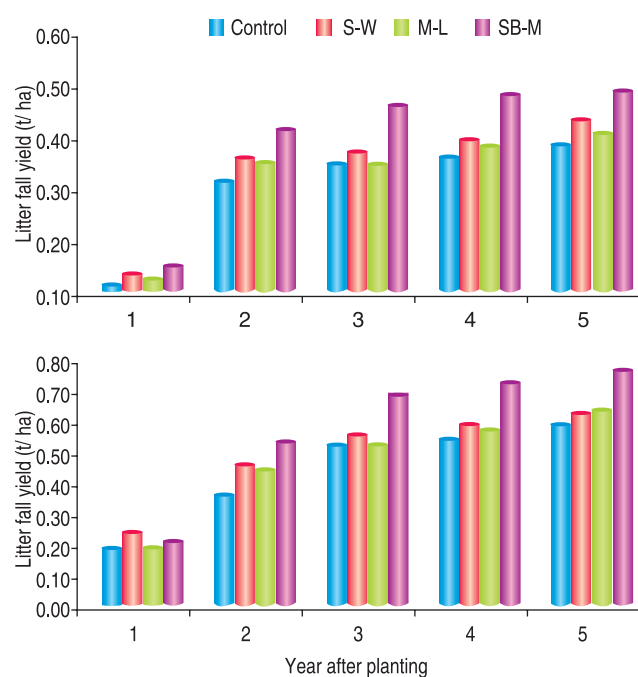


Fig 3 Litter fall yield under different intercropping sequences at (a) 3 m × 3 m and (b) 3 m × 2 m spacing.

Table 4 Ameliorative effect of jatropha intercropping on physico-chemical properties of soil 5 years after plantation

Soil parameters	Initial	After 5 years								LSD (P=0.05)
		Control		S-W		M-L		SW-M		
		3 × 3m	3 × 2m	3 × 3m	3 × 2m	3 × 3m	3 × 2m	3 × 3m	3 × 2m	
Bulk density (g/cm ³) (0-75 mm)	1.60 ± 0.04	1.57 ± 0.03	1.56 ± 0.02	1.54 ± 0.14	1.52 ± 0.12	1.56 ± 0.08	1.53 ± 0.12	1.48 ± 0.14	1.48 ± 0.11	0.08
Soil porosity (%)	48.6 ± 0.42	50.2 ± 0.34	51.2 ± 0.42	52.8 ± 0.32	53.41 ± 0.30	51.30 ± 0.28	52.20 ± 0.33	54.3 ± 0.30	54.8 ± 0.28	2.34
Infiltration rate (mm/day)	8.62 ± 0.12	14.2 ± 0.14	15.4 ± 0.21	18.75 ± 0.16	21.20 ± 0.18	16.62 ± 0.20	18.40 ± 0.16	21.2 ± 0.13	22.1 ± 0.14	4.23
Soil pH ₂	9.46 ± 0.15	9.22 ± 0.11	9.34 ± 0.21	9.12 ± 0.15	9.13 ± 0.16	9.13 ± 0.21	9.11 ± 0.14	9.05 ± 0.17	8.92 ± 0.21	0.03
EC ₂ (dS/m)	1.77 ± 0.10	0.21 ± 0.09	0.45 ± 0.10	0.67 ± 0.10	0.21 ± 0.09	1.30 ± 0.08	0.62 ± 0.09	0.45 ± 0.10	0.30 ± 0.09	0.008
ESP	40 ± 2.23	36.2 ± 1.15	32.4 ± 1.68	32.4 ± 1.85	35.4 ± 2.12	32.5 ± 2.21	35.2 ± 2.10	30.2 ± 2.13	35.3 ± 2.43	3.2
OC (g/kg)	1.0 ± 0.02	1.8 ± 0.03	2.0 ± 0.12	2.4 ± 0.20	2.5 ± 0.14	2.5 ± 0.13	2.5 ± 0.16	2.7 ± 0.20	2.7 ± 0.08	0.002
Available N (mg/kg)	41.9 ± 1.12	103.6 ± 1.15	110.1 ± 1.16	95.2 ± 1.23	107.8 ± 1.42	95.9 ± 0.86	114.8 ± 1.12	103.6 ± 1.21	111.9 ± 1.32	34.2
Available P (mg/kg)	11.1 ± 0.26	9.6 ± 0.23	10.1 ± 0.26	12.3 ± 0.31	13.5 ± 0.22	10.9 ± 0.25	12.1 ± 0.26	13.6 ± 0.30	14.5 ± 0.26	1.12
Available K (mg/kg)	173.5 ± 22.50	137.6 ± 17.62	146.9 ± 16.50	166.9 ± 18.10	171 ± 18.21	148.9 ± 16.42	199.2 ± 17.52	171.8 ± 16.16	189.7 ± 18.21	13.6
MBC (mg/kg)	96.4 ± 3.23	96.4 ± 2.56	100.1 ± 2.48	112.2 ± 3.12	119.3 ± 3.22	102.5 ± 2.86	111.2 ± 3.10	120.5 ± 2.80	124.5 ± 3.10	2.32

S-W: Sorghum-wheat, M-L: Maize-linseed, SW-M: Sweet basil-matricaria, EC: Electrical conductivity, ESP: Exchangeable sodium percent. pH₂ and EC₂: refers to soil and water suspension ratio of 1:2.

maximum microbial biomass carbon was recorded in soils under SB-M cropping sequence followed by S-W and M-L and minimum in control (Table 4). This study shows that plantation of jatropha in sodic soils stimulated soil microbial population, which in turn recorded high biological activities due to rhizosphere activities.

Conclusion

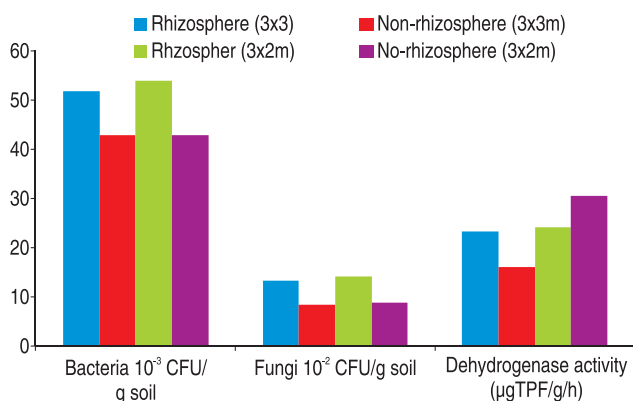


Fig 4 Combined effects of plant density and spacing on microbial population and enzyme activities of rhizosphere and non-rhizosphere soils.

Five years study revealed that plantation of *J. curcas* at 3 m × 3 m spacing and inter cultivation of sweet basil - matricaria cropping sequence found highly ameliorative alternate land use for sodic soils. Improvement in soil physico-chemical properties was also higher under sweet basil-matricaria cropping sequence. Thus, the growing of medicinal and aromatic crops in between jatropha rows for four years is highly remunerative jatropha based cropping sequence for sodic soils. By evolving, promoting and adopting jatropha-based intercropping sequences, it is possible to improve the socio-economic conditions in rural areas and transform the national energy scenario and the ecological landscape especially in degraded sodic areas. Inter-cultivation of sweet basil-matricaria also increased land use efficiency and improved livelihood security by getting some income to the resource poor farmers who cannot wait for such a longer period without getting any income from their land.

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