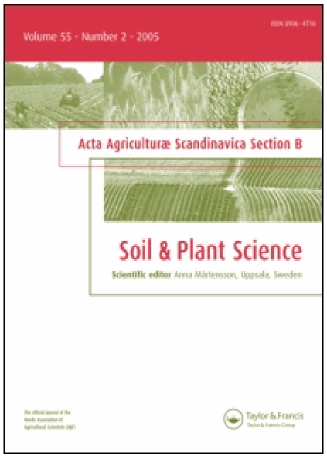

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Contribution of **Jatropha curcas** to soil quality improvement in a degraded Indian entisol

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ORIGINAL ARTICLE

Contribution of *Jatropha curcas* to soil quality improvement in a degraded Indian entisol

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Abstract
Soil quality improvement is critical to any rehabilitation programme in dry land degraded ecosystems. This study reports on the impact of cultivation of *Jatropha curcas* with or without soil amendments on the structural stability, and carbon and nitrogen content of a degraded Entisol under rehabilitation in western India. Cultivation of *Jatropha curcas* resulted in 11% average increase in mean weight diameter of the soil and 2% increase in soil macro-aggregate turnover. Cultivation of *Jatropha curcas* with nitrogen and phosphorus- or without any-amendment improved macro-aggregate stability relative to nearby native vegetation. Regression analysis showed a significant correlation between organic carbon and mean weight diameter. The cultivation of *Jatropha curcas* appeared to have also contributed to the quality of these soils as it maintained organic carbon and nitrogen stock and displayed a potential to increase carbon sequestration rate. Soil structure recovery under cultivation of *Jatropha curcas* implies a sustainable improvement in the surface integrity of these soils, which will ensure more water infiltration rather than runoff and erosion.

Keywords: *Aggregate stability, carbon sequestration, soil quality, soil rehabilitation.*

Introduction

Land degradation remains one of the most serious environmental problems which continue to threaten the livelihoods of many people worldwide. In the Indian subcontinent, about 187 Mha of land is degraded (Ramasamy, 2005), and soil erosion due to wind and water accounts for 40% of this degradation (Sehgal & Abrol, 1994). Generally, land productivity declines rapidly when soils lose vegetation cover or when inappropriate cultivation practices are adopted (Lal, 1997) leading to soil organic matter depletion and reduction in number and stability of soil aggregates. Overgrazing and indiscriminate removal of green cover, particularly in the semi-arid areas of western India, have resulted in rapid erosion of topsoils and ultimately converted cultivable land into degraded wastelands. As a result of erosion, most of the soils of these wastelands are generally low in organic matter, nutrient poor and structurally weak (Tomar, 2005). The predominant land use of these wastelands is free grazing by ruminant animals like cattle, buffaloes, sheep and goats. While the native pastures are principally *Prosopis juliflora*, *Acacia nilotica* and *Zizyphus mauritiana*. Entisols and inceptisols are the most predominant soil types in most parts of these wastelands. As a result of degradation, these areas are usually sparsely populated in a densely populated Indian subcontinent. In the past, efforts towards soil rehabilitation and improvement for agricultural productivity and poverty reduction have concentrated in areas with favourable ecosystems. However, the current interests in long-term sustainability and reduction of environmental costs of agricultural ecosystems have made management and restoration of fragile (degraded) ecosystems a serious challenge. For any rehabilitation programme to be successful on these degraded ecosystems in India, it must promote income-generating activity in such a way

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as to reduce or alleviate poverty. The economic viability of such a rehabilitation programme is a condition to its adoption by the resource-poor inhabitants.

Jatropha curcas (hereafter referred to as Jatropha) is a multipurpose perennial shrub, of which the seeds are rich in oil. When extracted, the pure plant oil can be used directly or, after trans-esterification, as biodiesel in engines. As a result of this, Jatropha is an attractive crop whose cultivation is being introduced rapidly in many rural programmes in India and the rest of the world, as it may contribute to rural development by income generation. Furthermore, since Jatropha has the ability to grow wild and may not compete with conventional agricultural crops for land, it may serve environmental functions in degraded ecosystems. The potential of using woody perennials has often been encouraged for conservation as well as production on degraded land (Narain et al., 1998). This is because perennial vegetation guarantees organic matter and nutrient additions from the litter and roots of plants (Salako et al., 2001), which can significantly improve soil structure.

Aggregate dynamics and their relationship with soil organic matter are key factors that influence structural stability of soils. Increased aggregation and stability of the aggregates, along with carbon sequestration, is a key indicator for evaluating soil quality improvement (Reeves, 1997). Increased soil disturbance through cultivation of crops has been reported to increase soil structural deterioration. Taser and Metinoglu (2005) reported a 68% increase in mean-weight diameter (MWD) of soil under no-tillage relative to conventional tillage. Haynes and Beare (1997) suggested crop root mass, root length density and root exudates as vital to aggregate stability in soils. Soils amended with cattle manure over a long time have been reported to increase MWD (Ogunwole & Ogunleye, 2004), and improve wet aggregate stability (Darwish et al., 1995). In glacially deposited soils, Smucker et al. (2004) reported a preferential carbon concentration in macro-aggregates of no-tilled soil. Carbon and nitrogen enrichments have also been reported in aggregate fractions between 0.25 mm and >2 mm when organic waste was used to ameliorate a degraded tropical ultisol (Adesodun et al., 2005). In order to develop agricultural practices for sustainable maintenance of soil organic matter and improvement of soil structure, information regarding the effects that cultivation and growth of crop plants have on these soil properties is required. However, such information is surprisingly sparse. Here, we hypothesize that cultivation of Jatropha can serve environmental functions in degraded ecosystems. Hence, this present study was initiated to determine aggregate stability and dynamics of carbon and nitrogen in water-stable aggregates of a degraded entisol under Jatropha cultivation at Chorvadla in Gujarat State, India.

Materials and methods

Description of the study area

Experiments were conducted at the Jatropha Experimental Farm of Central Salt and Marine Chemicals Research Institute (CSMCRI) at Chorvadla (21° 40′ N, 71° 46′ E; 120 m a.s.l.) in Gujarat State, India. There are two distinct climatic seasons in the area: a rainy season from May to September, and a dry season from October to the third week of May. Annual long-term rainfall and temperature average 539 mm and 27.8 °C, respectively. Before the commencement of the Jatropha plantation, the area was under native savanna vegetation. Physiographically, the area has an undulating landscape, but a flat to slightly sloping area (<5%) was chosen as the site for the experimental farm. The soils of the area are generally shallow and well drained sandy loam entisols, classified according to the United States Department of Agriculture (USDA) soil taxonomy as isohyperthermic mixed-loamy kaolinitic lithic ustorthents.

Experimental design and treatments

The trial was a nitrogen+phosphorus fertilizer study, laid out factorially in a randomized complete block design with three replications. The trial that was started in June 2004 had four nitrogen rates (0, 30, 45, 60 kg ha^{-1}) and four phosphorus rates (0, 10, 20, 30 kg ha^{-1}) applied to Jatropha planted (in the same year, 2004) at a spacing of 2 m × 2 m. Soils were, however, sampled from the top horizon (0–10 cm) of five selected treatments (bearing semblance to farmers' cultural practices for agricultural crops) and nearby native vegetation (Table I).

Soil sampling and analysis

Surface soil samples were collected from each of the selected treatment plots in November 2006. Soils were sampled from four cardinal points beneath a Jatropha canopy with the aid of a traditional hoe. For each replicate treatment, soils were sampled from three Jatropha canopies. These soil samples were bulked (2–4 kg) to produce fifteen composite samples. For the native site, the area was partitioned into three subplots and each subplot was considered a replicate. The eighteen composite samples were

Table I. Description of selected treatments (Jatropha Experimental Farm, Chorvadla).

Treatment Name	Treatment description	Rates of organic/Inorganic amendment
BBA	Native vegetation site adjacent to experimental area on which *Zizyphus mauritiana* is the predominant plant	-NIL-
NPO	Control plot, cultivated to Jatropha with no amendment	-NIL-
NPI	Phosphorus amended plot, cultivated to Jatropha. Jatropha cake and single super phosphate (SSP) are the amendments	Jatropha cake at 2.25t ha^{-1}. SSP at 62 kg ha^{-1}
NIP	Nitrogen amended plot, cultivated to Jatropha. Jatropha cake and urea are amendments	Jatropha cake at 2.25t ha^{-1}. Urea at 65 kg ha^{-1}
NIPI	Nitrogen+Phosphorus amended plot, cultivated to Jatropha. Jatropha cake and SSP are amendments	Jatropha cake at 2.25t ha^{-1}. Urea at 65 kg ha^{-1}. SSP at 62 kg ha^{-1}
NIIP	High nitrogen amended plot, cultivated to Jatropha. Jatropha cake and urea are amendments	Jatropha cake at 2.25t ha^{-1}, Urea at 98 kg ha^{-1}

passed through a 2 mm sieve before air-drying, after which 200 g of air-dried soil was dry sieved through three nests of sieves (2-, 0.25- and 0.053-mm size) for 3 minutes with a vertical motion of 20 amplitudes at 30 ± 3 movements per minute. The amount of aggregate in each sieve size range was determined as a fraction of the initial air-dried samples weight. MWD was calculated as the sum of multiplication of the mean diameter of each size fraction and the proportion of the sample weight occurring in the corresponding size fraction (Van Bavel, 1950). The MWD served as an index of soil structural stability to wind erosion (Unger, 1997).

The dry aggregate fraction collected on the various sieve sizes were wet sieved by presoaking in water for 60 seconds before oscillating in water at 30 oscillations per minute. The resultant water-stable aggregates on each sieve were oven dried at 105 °C for 24 h before the mass was determined. The mass of the <0.053 mm (silt and clay) fraction was obtained by difference. Aggregated silt and clay (ASC) that is defined as the difference between silt and clay in calgon- and water-dispersed samples of whole soil (Mbagwu & Bazzoffi, 1998) was used as an index of micro-aggregate stability. Organic carbon and total nitrogen concentration in whole soil and water-stable aggregates were analysed by the Walkley-Black wet oxidation (Nelson & Sommers, 1982) and the Kjeldahl digestion (Bremner & Mulvaney, 1982) procedure respectively.

Statistical analysis

To compensate for variance heterogeneity, values for aggregate stability were arc sin-transformed while those of carbon and nitrogen concentrations were logarithm-transformed before data analysis. To determine the effects of Jatropha cultivation on soil structure, carbon and nitrogen distribution data were subjected to analysis of variance for randomized complete block design and the least significant difference (LSD) test was used to separate the means. Mean values that differed at $p \leq 0.05$ were considered significant. Correlation analysis was carried out using treatment means. The GENSTAT computer package was used for these analyses.

Results and discussion

Aggregation and aggregate stability

There was a significant difference in dry aggregate size distribution (DASD) among the treatments (Table II). The NPO (control) treatment recorded the highest proportion of dry aggregate in the 2–0.25 mm size range. This aggregate fraction is usually referred to as macro-aggregates (Six et al., 2004). The BBA (native) and the NIIP (high nitrogen amended) treatments recorded similar proportions of macro-aggregates distribution. The lowest fraction of macro-aggregate was realized in those plots that received phosphorus amendment with or without nitrogen. The various treatments in this study had no significant effect on the micro-aggregate (0.25–0.053 mm) fraction of the soil (Table II). However, the NIPI (nitrogen+phosphorus amended) treatment produced the highest silt and clay (<0.053 mm) fraction, which was significantly higher that those of the other treatments.

The observed increase in the proportion of macro-aggregate under Jatropha cultivation is a clear indication that cultivation of Jatropha increases macro-aggregate turnover in degraded soils. Jatropha plants are deciduous xerophytes that shed their leaves at particular periods of the year (dry season). As a result of this deposition of organic material, a large active microbial biomass could develop beneath the canopy, which in turn exudes (microbial) products that act as binding and gluing agents, thus improving aggregation (Haynes & Beare, 1997). Many workers have reported correlation of varying

Table II. Dry aggregate fraction, particle size distribution and mean weight diameter as influenced by Jatropha cultivation at Chorvadla, western India.

Treatment	2–0.25 mm. (macro-aggregates)	0.25–0.053 mm (micro-aggregates)	>0.053 mm (silt and clay)	Mean weight diameter (mm)	Clay	Silt	Sand
BBA	0.62ab	0.41	0.023b	0.68b	11.3b	31.8a	52.5d
NPO	0.72a	0.26	0.017b	0.84a	9.6b	20.2c	68.3a
NPI	0.58b	0.38	0.017b	0.71b	15.1a	30.6a	53.9cd
NIP	0.64ab	0.33	0.02b	0.77ab	13.7ab	22.6bc	63.0ab
NIPI	0.57b	0.44	0.09a	0.68b	13.4ab	30.5ab	55.5bcd
NIIP	0.65ab	0.31	0.02b	0.79a	11.5b	25.8abc	61.6abc
LSD (0.05)	0.101	0.125	0.047	0.103	0.612	0.30	0.156
Significance	*	NS	*	*	*	*	*

Values within the same column having same letter are similar. *Significant at $p < 0.05$.

degrees between aggregation and microbial biomass or microbial products (Six et al., 2004; Denef et al., 2001) in soils. The absence of any significant change in micro-aggregate turnover in this study signifies that Jatropha cultivation does not dictate micro-aggregation in these soils. Jatropha-induced macro-aggregates were more stable than those from the native vegetation. High values of MWD signify the ability of soils under Jatropha to resist wind erosion. Among treatments under Jatropha cultivation, high MWD values were associated with soils that received only nitrogen fertilizer- or no-amendment, while phosphorus-amended soils, with or without nitrogen fertilizer, recorded lower MWD values (Table II). Hadas et al. (1990) observed that nitrogen and zero fertilizer addition affect and stabilize the size of larger soil structural units at air dryness. However, phosphorus fertilizers cause aggregation of soil structural units into smaller aggregates.

When averaged across Jatropha cultivation treatments, MWD value increased over that of native vegetation by 11% while macro-aggregate turnover increased by 2%. Addition of nitrogen or zero amendment increased MWD by 15 and 24% respectively. One probably reason for reduction in macro-aggregate turnover and MWD with amended treatments compared with control (NPO) under Jatropha cultivation is the disruptive forces that result from annual incorporation of Jatropha cake and inorganic fertilizers. Macro-aggregates are highly susceptible to disruption thereby, making them more dependent on cultural practices.

When the various dry aggregate fractions were wet sieved, significant differences were observed in the stability of the various aggregate sizes to water erosion. The NPO (control) treatment recorded the highest proportion of water-stable macro-aggregate, while the NPI (phosphorus-amended) treatment recorded the lowest value (Table III). Stability of macro-aggregates, estimated by dividing water-stable macro-aggregate fraction by dry macro-aggregate (Franzluebbers, 2006), showed NPO as the most stable and the order of diminishing stability as:

$$\text{NPO} > \text{NIPI} > \text{BBA} > \text{NIIP} > \text{NPI} > \text{NIP}$$

Calcium, usually present in phosphorus fertilizers (Hadas et. al. 1990), may have contributed to improve macro-aggregate stability in soils amended with phosphorus fertilizer. The process of calcium bridging is a dominant factor and a positive effect of calcium addition to soil structural stability. Across Jatropha treatments, 17–30% of the dry macro-aggregate fraction disintegrated into micro-aggregate, while 15–25% reduced to silt and clay fraction (Table III). There was no significant treatment difference in the stability of dry micro-aggregates. Hence, micro-aggregate stability is higher and less affected by cultural practices under Jatropha.

The ASC is an index of micro-aggregate stability (Mbagwu and Bazzoffi, 1998). The phosphorus-amended (NPI and NIPI) treatments, due to indirect calcium addition, recorded significantly higher values of ASC while the NPO treatment recorded the lowest value (Table III). When calcium, through complexation with organic matter, forms clay–polyvalent cation–organic matter complexes, it exerts a stabilizing effect at the level of micro-aggregate (Clough and Skjemstad, 2000).

Carbon and nitrogen concentrations

Total carbon (C) concentration of whole soil and water-stable macro-aggregate fractions were not affected by Jatropha cultivation treatments. Highest carbon concentration was recorded in the NPO treatment in whole soil (9.6 g kg^{-1}) and macro-aggregates (10.8 g kg^{-1}). The values of total C content are further confirmation of the low organic carbon content of these soils (Table IV). Total nitrogen (N) in whole soil and all water-stable aggregate fractions was influenced by the treatments. Significantly high N values were recorded for NPO

Table III. Water stable dry aggregate fraction and aggregate silt and clay (ASC) as influenced by Jatropha cultivation at Chorvadla, western India.

	Macro-aggregate			Micro-aggregate		
Treatments	2–250 mm	0.25–0.053 mm	<0.053 mm	0.25–0.053 mm	<0.053 mm	ASC
BBA	0.52ab	0.29a	0.19ab	0.82	0.18	3.91a
NPO	0.68a	0.17b	0.15b	0.83	0.17	3.30b
NPI	0.47b	0.28ab	0.25a	0.79	0.21	3.99a
NIP	0.50ab	0.30a	0.20ab	0.77	0.23	3.49a
NIPI	0.52ab	0.27ab	0.21ab	0.78	0.232	3.93a
NIIP	0.55ab	0.25ab	0.20ab	0.80	0.20	3.72ab
LSD (0.05)	0.166	0.1143	0.096	0.081	0.081	0.152
Significance	*	*	*	NS	NS	*

Values within the same column having same letter are similar. *Significant at $p < 0.05$.

treatment relative to others. The minimal soil disturbance witnessed in the NPO treatment must have favoured the heavy concentration of C and N at the surface soil layer (Mrabet et al., 2001). However, heavy soil mixing (through annual incorporation of soil amendments) would facilitate the distribution of C and N throughout the profile of amended soils. A greater portion of the increase in whole-soil organic C and total N occurred in micro-aggregate fraction than in macro-aggregates (Table IV), particularly in soils cultivated to Jatropha. This is an indication that most of the soil organic matter C and N lost is derived from the mineralization of macro-aggregate-associated soil organic matter. The high correlation ($p < 0.01$) between dry macro-aggregates and water-stable micro-aggregate-associated C and N (Table V) is further proof of this assertion. When macro-aggregate disintegrates, nutrients are released (as their binding agents also degrade). The carbon and nitrogen in the micro-aggregate fractions were more resistant to decomposition and may have longer turnover time compared with C and N in macro-aggregates. Micro-aggregates have been reported to physically protect organic matter C from decomposers in soil (Six et al., 2002), thus enhancing carbon sequestration in such soils. Estimates of soil carbon sequestration rates calculated from total organic soil C differences (in micro-aggregates) between treatments and dividing by duration of treatment (Conant et al., 2003) showed that Jatropha cultivation in degraded soil could sequester an average of 1.33 g C kg^{-1} $year^{-1}$.

The fraction of dry macro-aggregates accounted for more than 80% of the variation in MWD, a further indication that the proportion of macro-aggregates in soil dictates the resilience or otherwise of that soil to resist erosion by wind. The MWD was significantly related with whole soil organic carbon content ($p < 0.05$), accounting for 23% of variation (Table V). This further strengthens the fact that soil organic carbon has an effect on MWD and is important with respect to maintenance of soil structural stability. Hence any practice that improves soil organic carbon at a higher level will stabilize dry soil aggregates.

Table IV. Carbon and nitrogen concentrations (g kg^{-1}) of whole soil and water stable aggregates as influenced by Jatropha cultivation at Chorvadala, western India.

Treatments	BBA	NPO	NPI	NIP	NIPI	NIIP	LSD (0.05)	Significance
Whole soil Carbon	5.06	9.55	5.33	4.19	5.96	4.50	3.29	NS
Nitrogen	1.17ab	1.56a	0.72b	1.04ab	1.04ab	0.70	0.29	*
C: N	4.36	6.12	7.50	4.11	6.04	7.06	2.98	
Macro (2–0.25 mm) aggregates								NS
C	10.19	10.79	4.78	8.77	5.38	7.26	2.665	NS
N	1.02a	1.19a	0.73ab	1.14a	0.48b	0.73ab	0.343	*
Micro (in macro-aggregates) aggregates								
C	2.20b	4.47ab	7.03a	4.64ab	3.73ab	4.17ab	2.702	*
N	0.69ab	1.44a	0.86ab	0.68ab	0.60b	0.96ab	0.484	*
Micro (0.25–0.053 mm) aggregates								
C	4.92b	9.18a	4.36b	6.01ab	3.96b	4.66b	1.676	*
N	0.45b	1.24a	0.40b	0.53b	0.43b	0.39b	0.463	*

Values within the same row, having the same letter are similar. *Siginificant at $p < 0.05$.

Table V. Relationship between mean weight diameter (MWD, mm), dry macro-aggregates, whole soil and micro-aggregate associated carbon and nitrogen.

Variables				
Dependent	Independent	Equation	$R^{2\star}$	P level**
MWD	Dry macro-aggregate fraction	$Y=0.09+1.04\,X$	0.822	<0.001
MWD	Whole soil organic carbon	$Y=0.64+0.016\,X$	0.23	0.025
MWD	C/N ratio	$Y=0.697+0.007\,X$	0.102	0.101
MWD	Water stable micro-aggregate associated organic carbon	$Y=0.58+0.029\,X$	0.505	<0.001
MWD	Water stable micro-aggregate associated nitrogen	$Y=0.63+0.13\,X$	0.422	0.002
Dry macro-aggregate fraction	Whole soil organic carbon	$Y=0.54+0.014\,X$	0.214	0.03
Dry macro-aggregate fraction	Water stable micro-aggregate associated organic carbon	$Y=0.49+0.025$	0.509	<0.001
Dry macro-aggregate fraction	Water stable micro-aggregate associated nitrogen	$Y=0.53+0.113\,X$	0.407	0.003

*Coefficient of correlation. **Level of significance of coefficient of correlation.

This method of estimating soil C sequestration has been referred to as a 'surrogate for potential C sequestration rate' (Conant et al., 2003). This is because it has a tendency to overestimate sequestration rates, particularly in this study where soil analysed was only the top 10 cm and only micro-aggregates enriched carbon was used in the estimation. Carbon sequestration rate estimated for NPO treatment was 2.61 g C kg^{-1} $year^{-1}$, which was the highest of all the treatment, while the NIPI recorded the lowest C sequestration rate (0.23 g C kg^{-1} $year^{-1}$).

Soil conditions reflected the effect of Jatropha cultivation practices on a degraded soil. From the perspective of both soil structure and carbon and nitrogen sequestration, Jatropha cultivation under minimal soil disturbance can serve 'environmental functions'. Jatropha cultivation improved soil resistance to wind erosion and enhanced macro-aggregate stability to water erosion. Under Jatropha, increased potential carbon sequestration rates are possible as stable micro-aggregates can offer protection to organic carbon. Jatropha cultivation programmes therefore will not only serve as a source of income-generation to resource-poor farmers but will improve the quality of their soils in the long run.

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