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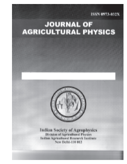

Research Article

Nutrient Mining Potential of Rainfed Jatropha Plantations under Different Density in Semi-Arid Regions of North-West India

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ABSTRACT

Jatropha (*Jatropha curcus* L.) is a very hardy plant, requires minimum inputs and is a good candidate for reclamation of degraded land. Eight years aged established Jatropha plantations under different densities with minimum managements and rainfed conditions, were assessed for nutrient mining potential. Despite of lesser chlorophyll content in low density (LD) plants, net photosynthesis was higher with better nutrient uptake. In High Density (HD) plantations, eight years aged Jatropha plants effectively recharged the soil surface with 59.4-67.3 kg/ha Nitrogen, 3.1-3.77 kg/ha Phosphorus and 24.2-28.6 kg/ha Potassium nutrients through leaf litter and fruit drop followed by their further decomposition in soil which recommends Jatropha plantation as a potential option for nutrient recharge with very low attention and inputs in degraded lands. Although in LD plantations, the nutrient recharge/ha is comparatively low but while considering for agroforestry systems, our findings suggest that LD Jatropha plantations can serve dual purpose with nutrient recharging and intercropping with other agricultural crops as well.

Key words: Nutrient mining, Jatropha, Density of plantation

Introduction

Jatropha is a biofuel plant and also considered as 'Carbon neutral crop'. About 70% of petroleum and 40% of diesel requirement of India is fulfilled through importing from outside (Outlook magazine, 2021). Jatropha is a poten-tial candidate for large scale plantation on marginal lands as it presents several ecological services and thus considered for a dual purpose of biodiesel production and land reclamation (Behera *et al.,* 2010). *Jatropha curcas L.* has immense adaptability and are grown in wide range of areas including tropical and subtropical regions. The plant can also grow in wastelands on almost any terrain including on gravelly, sandy and saline soils. Especially under semi-arid condition, Jatropha has the possibility to reclaim marginal and degraded lands and concepts of reclamation of marginal soil by Jatropha are well reported (Spaan *et al*., 2004). Jatropha is deciduous in nature. Mass shedding of leaves coincides with dry winter season from December onwards and completes by January. This process adds huge organic matter to the soil and also return back a good load of nutrients that was uplifted from deeper layer of soil by deep root systems (Jongschaap *et al*., 2007). Apart from biodiesel application, Jatropha has relatively high efficiency of carbon sequestration and mining of nutrients from deep layer of soil and can sufficiently improve soil quality (Jongschaap *et al*., 2007). A large tract of 14 million ha of marginal waste land is already identified in India for plantation with biofuel crops like Jatropha (Wani *et al.,* 2009a). In India, many Jatropha researcher

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focused their research especially on feasibility of growing Jatropha at waste/degraded lands, while concomi-tantly addressing the issues of renewable biodiesel production. Also a few studies focused on C sequestered in the above and belowground plant parts and few studied on soil quality parameters like aggregate stability, soil organic matter content under long term Jatropha cultivation practices.

Jatropha plantations of 3-5 years age, added around 4000 kg plant biomass or 1450 kg ha^{-1} equivalent organic C to soil per year through leaf fall, pruned twigs and de-oiled cake (Wani *et al*., 2012). Along with C additions, 4000 kg ha^{-1} $year^{-1}$ plant biomass which gets recycled into the soil also added 85.5 kg nitrogen (N), 7.67 kg phosphorus (P), 43.9 kg potassium (K), 5.20 kg sulphur (S), 0.11 kg boron (B), 0.12 kg zinc (Zn) and other nutrients (Wani *et al.,* 2012). Such benefit would help in reclamation of the degraded lands. Thus dual purpose of reducing the atmospheric CO_2 concentration and increasing the soil organic carbon, which plays a crucial role in soil quality improvement and the availability of plant nutrients, may be achieved with Jatropha plantations (Srinivasa Rao *et al.,* 2009). Till date many studies are available focusing on multiple ecosystem services by Jatropha. But there is need for better understanding on temporal variations on growth and physiological aspects of Jatropha plants along with nutrient mining potential from deeper layer of soil under different plantation densities. Comprehensive studies to evaluate ecosystem level benefits of Jatropha under different population densities and seasons under rainfed northwest Indian condition are rare. Thus, in present study we focused on the effects of different planting densities on nutrient mining potential in north-west India under minimum management practices to prescribe with best planting density option with maximum nutrient mining potentials for agroforestry system as a potent forest candidate.

Materials and methods

Experimental site and Jatropha Plantation details

A field experiment was conducted at research farm of ICAR-Indian Agricultural Research Institute (IARI), New Delhi, India (28°35′N latitude and 77°12′E longitude). Jatropha (*Jatropha curcus* L.) was planted under three different population densities where distance between plants was kept constant at 2 m but altering the distance between rows to 1.5, 2 and 3 m, resulting in high (HD), medium (MD) and low (LD) plant population density plots, respectively. The total number of plants/ha were 3333, 2500 and 1666 in HD, MD and LD, respectively. But for convenience in monitoring, 40 plants were selected from each population plot and were divided into 5 blocks of 8 trees in each category. Experimental field was maintained as rainfed and without addition of external fertilizers and avoided any other management practices. In general, experimental area is characterized as semi-arid sub-tropical with a mean annual precipitation of ~670 mm, and mean monthly maximum and minimum air temperatures of 40.5°C in May to June and 6.5°C in December-January, respectively.

Physiological responses in Jatropha plantation

Net photosynthetic rate (P_N), stomatal conductance (gs), leaf intercellular CO_2 concentration (C_i) transpiration rate (E) were measured during September 2012 using an Infra-Red Gas Analyser (LICOR-6400XT (USA) portable Infra-Red Gas Analyzer (IRGA) at fixed light level (PAR) of 1000 ìmol m^{-2} s^{-1} on mature leaves selecting 10 trees per treatments. Observations were taken between 9.30 am to 11 am on bright sunny day. Mature leaves used in gas exchange measurement were sampled for measuring chlorophyll pigment content. The content of chlorophyll *a*, chlorophyll *b* and total chlorophyll were calculated as per the method of Arnon (1949).

Nutrient parameter analysis

Three trees were randomly sampled from each treatment for quantifying aboveground biomass by destructive method. Trees were cut to the ground level during November, 2011, March, 2012 and September, 2012. Green leaves and stem parts were separated and dried to get leaf and stem dry weight. A net was tied surrounding each tree to prevent litter loss and dried leaf litter from each treatment was collected in regular intervals. Jatropha fruits were harvested at maturity to get the yield. Nutrients (NPK) status in stem, litter, green leaf and fruits of Jatropha were measured to examine their movement in different plant parts before and after leaf shedding. Total N, P and K contents in plant tissues were estimated as per the standard methods and procedures given by Yoshida and co-workers (1976).

Nutrient recharging/ recycling potential analysis

Nutrient recycling was estimated based on dry matter production. N, P and K contents quantified as percentage in each parts of the Jatropha tree and finally the N, P, K recycled converted to g/ tree. Nutrient recharging to the surface soil from individual tree was calculated as summation of total nutrient in total leaf litters (Kg) and total nutrients in total fruits.

Nutrient recharged (g/plant) on top soil = Σ(Nutrients present in total green leaves and litters + Nutrients present in total fruits)/plant …(i)

Where, plant weight is on dry weight basis

Results and Discussions

Physiological responses under different plantation densities:

Concentration of photosynthetic pigments varied significantly in plants under different population densities. During September, when the plants were with full canopy, results indicate that chlorophyll-*a* pigment concentration was least in LD plants and highest in plants of HD plants and intermediate in MD plants. However, variations in chlorophyll *b* contents of all treatments were not significant (Table 1). Total chlorophyll pigment concentration was 2.16, 2.04 and 1.89 mg/g fresh leaf tissue in HD, MD and LD plants, respectively (Table. 1). Similarly, carotenoids contents varied significantly ($p<0.05$) among the treatments. Net photosynthetic rate was highest

Table 1. Photosynthetic pigments and gas exchange parameters such as net photosynthesis rate, stomatal conductance, leaf internal CO_2 concentration and transpiration rate in Jatropha grown in three plant population densities of high (HD), medium (MD) and low (LD)

Treatments*	Chlorophyll a (mg/g leaf tissue)	Chlorophyll b (mg/g leaf tissue)	Total Chlorophyll (mg/g leaf tissue)	Carotenoids (mg/g leaf tissue)	Chlorophyll a/b	Net photosynthesis rate (µmol/m^2/s)	Stomatal conductance (mol/m^2/s)	Ci (ppm)	Transpiration rate (mmol/m^2/s)
HD	1.65±0.01	0.51±0.01	2.16±0.01	0.11±0.01	3.22±0.02	7.40±0.30	0.08±0.01	201±12	2.64±0.24
MD	1.55±0.02	0.48±0.03	2.04±0.04	0.10±0.01	3.26±0.20	7.39±0.26	0.07±0.01	194±6	2.45±0.16
LD	1.43±0.01	0.46±0.01	1.89±0.01	0.09±0.01	3.12±0.01	8.38±0.28	0.07±0.01	177±5	2.38±0.12
CD at 5%	0.02**	NS	0.03**	0.01*	NS	0.25*	NS	NS	NS

*HD: High Density; MD: Medium Density, LD: Low Density; NS: Non Significant in plants of LD plants and no significant differences observed in MD and HD plants. Declined N content might have influenced the chlorophyll pigment concentration as well which was reduced in plants under LD plots. However, the reduction in chlorophyll pigment did not influence net photosynthetic rate, which was recorded more in plants growing in LD plants indicating increased efficiency in resources such as light, water and nutrient utilization. However, stomatal conductance, transpiration rate and leaf internal CO_2 concentration did not change significantly in plants of all three different densities (Table 1).

Nutrient parameter responses under different densities

Quantitative analysis of major nutrients in different plant parts indicates significant variations in treatments and with the season. Leaves collected during September and November corresponding to an active and partially senescing stage. Leaves had more N content during September compared with November (Table 2). This may be because of progressive senescence of leaves which would go for mass senescence by December during dry winter condition. During senescence, nutrients from senescing leaves were partially translocated to stem, which is evident

Table 2. Nitrogen, phosphorus and potassium concentration in green leaves, stem, fruit and leaf litter in Jatropha plantation grown under three plant population densities

Treatments*	Green leaves		Stem			Fruit (kg/plant/year) (Harvested at maturity)	Leaf litter (kg/plant/year) (Collected throughout year in the wrapped net surrounding each plant)
	Nov	Sept	Nov	Mar	Sep		
				Nitrogen (%)			
HD	2.51	3.07	1.41	3.87	1.15	2.23	1.43
MD	2.48	2.97	1.41	3.42	0.98	2.21	1.39
LD	2.45	2.91	1.34	3.29	0.85	2.14	1.34
				CD at 5%			
Treatments (T)	NS			0.04**		T: NS	T: 0.02**
Months (M)	0.03**			0.03**			
TxM	NS			0.08**			
				Phosphorus (%)			
HD	0.13	0.16	0.14	0.23	0.12	0.15	0.06
MD	0.13	0.15	0.11	0.21	0.11	0.14	0.06
LD	0.13	0.14	0.09	0.14	0.10	0.14	0.05
				CD at 5%			
Treatments (T)	NS			0.003**		T:NS	T: 0.004**
Months (M)	NS			0.002**			
TxM	NS			0.005**			
				Potassium (%)			
HD	1.89	2.14	1.60	2.49	0.32	0.85	0.62
MD	1.77	1.91	1.54	2.09	0.64	0.81	0.64
LD	1.76	1.87	1.23	1.53	0.50	0.79	0.71
				CD at 5%			
Treatments (T)	0.02**			0.02**		T: NS	T: NS
Months (M)	0.01**			0.01**			
TxM	NS			0.03**			

*HD: High Density; MD: Medium Density, LD: Low Density from higher NPK content in stem during March (Table 2). N content was lowest in leaves collected from LD plants in both September and November. Increasing concentration of nutrients with plant population densities indicate that competition factor among plants was taken over by dilution effect within plant. Analyses of nutrient concentrations in stems were made on three occasions correspond to the period of full canopy in September, initiation of mass senescence of leaves in November and a leafless period in March. Results indicate a significant variation within the treatments as well with the seasons (Table 2). Nitrogen content in standing stem was lowest during September while it was highest in March and intermediate during November. Nitrogen content in leaves was highest in plants of HD, while it was lowest in plants grown under LD condition. Similarly, N content in fruits and leaf litter collected by the end of November were lowest in plants od LD plots. However, the change in fruit N content was not significant (Table 2). Phosphorus content also varied similarly as N in leaves under different plant population densities and season. However, the response was not significant. A significant variation was observed in stem P content during November, March and September with similar trends to N content. Similar to N concentrations, fruit and litter P concentrations were lowest in LD plants. Potassium content in different plant parts varied in similar lines as N and P with exception for stem potassium content during September and potassium concentration in leaf litter. Slightly higher K concentration was observed during these months in these plant parts under LD condition. However change in leaf litter K concentration was not significant (Table 2).

Nutrient accumulation in plants under different densities

Based on total biomass and nutrient concentration in different plant parts such as stem, green leaves, leaf litter and fruits; total N, P and K uptake was calculated. Concentration of nutrients (%) was less in LD plants. Lavish growth of individual tree in LD plots as indicated by higher stem, leaf, seed yield and total aboveground biomass in LD plants (data not shown), resulted in this dilution effect. Although concentration of nutrients was lowest in LD plots, total accumulation of NPK in stem, leaves and fruits per plant were more in LD plants compared with HD and MD plots. Total N content was 261.1, 378.2 and 489.9 g per tree in HD, MD and LD, respectively. Whereas P content was ~52% more in LD than HD plants and surprisingly K concentration was ~3.5 times more in LD plants as compared to HD plants (Table 3). Accumulation of NPK during a period of the whole year (2010-11, at 8^{th} year age of plantations) calculated based on biomass production per year indicated variation with the treatment wherein more N accumulation observed compared to other two nutrients (P and K). The NPK accumulated more per plant basis, in plants grown under LD plots. Overall production and recycling of leaves in the form of dry litter and fruits were more in plants growing in LD plots and subsequently the total nutrients recycled, although the concentration of individual nutrients were more in majority of the plant parts in HD plots, plants of LD plots were more lustuorous and with more biomass and thus observed dilution effects of NPK nutrient concentration in LD plants. Nitrogen recycled through leaf litter and fruits were 20.2, 27.4 and 35.6 g/plant in HD, MD and LD plots, respectively. An amount of 1.13, 1.36 and 1.86 g of P was recycled per plant in HD, MD and LD plots, whereas it was 7.3, 11.6 and 17.1 g in case of K (Table 2). However, the quantum of N and P recycled/ha land was highest under HD followed by MD and lowest under LD plots as total number of plants/ha accommodated under different densities are HD:3333>MD:2500>LD:1666. In the present study fruits produced were not processed further for biodiesel and other by products, instead were allowed to go to soil along with leaf litter. Thus leaf litter and fruits constitute the plant parts which recycled the nutrients to the soil. Large number of plants which could be accommodated in high and medium density plots (3333 and 2500 per ha, respectively) compared to low density plots (1666 per ha) resulted in to higher amount of leaf litter and higher nutrient recycling in top

Table 3. Accumulation of major nutrients in different plant parts calculated based on biomass production and nutrient concentration

Treatments*	Nutrients in stem (g/tree)	Nutrients in leaves (g/tree)	Nutrients in fruits (g/tree)	Total amount of nutrients (g/tree)	Nutrients in litter (g/tree)	Amount of nutrient recycled from each tree (g)	Amount of nutrient recycled (kg/ha)
				Nitrogen			
HD	227.0	26.9	7.3	261.1	12.9	20.2	67.3
MD	332.9	35.6	9.8	378.2	17.6	27.4	68.5
LD	430.0	47.3	12.5	489.9	23.2	35.6	59.4
				Phosphorus			
HD	23.7	1.4	0.48	25.6	0.66	1.13	3.77
MD	37.3	1.7	0.61	39.7	0.75	1.36	3.39
LD	50.3	2.2	0.79	53.3	1.07	1.86	3.10
				Potassium			
HD	64.1	18.8	2.8	85.7	4.5	7.3	24.2
MD	216.5	22.9	3.6	243.0	8.0	11.6	29.0
LD	252.6	30.5	4.6	287.7	12.5	17.1	28.6

*HD: High Density; MD: Medium Density, LD: Low Density

soil and similar line of findings reported by Wani *et al.* (2012). Recycled amount of K/ha under different plant density, however, increased with decrease in plant population density. While comparing all three nutrients i.e., N, P and K, among these, Nitrogen was recycled more effectively compared with P and K. However, previous study of our team reported that, LD Jatropha plantation supported growth of wheat plants in a system of agroforestry better than high and medium density plots (Mahmoud *et al*., 2016a). This may be because of more sunlight availability, additional amount of N, P and K as bonus amount added to soil. Apart from these, several soil biological properties like Microbial Biomass Carbon (MBC), Microbial Biomass Nitrogen (MBN) gets improved under Jatropha plantation as reported by Mahmoud and his coworkers (2016b) which suggests Jatropha as a poten-tial candidate for large scale plantation on marginal lands (Behera *et al.,* 2010). Thus, LD plants can serve dual purpose with enough nutrients recharging to the surface soil and as a companion candidate in agro-forestry cropping systems to allow other agricultural crops to grow simultaneously.

Conclusion

The findings of present study show that Jatropha under rainfed condition with minimum inputs and negligible management can recharge huge amount of nutrient into the surface soil. Huge foliage produced during rainy season serve as a potential source for recharging nutrients in upper soil surface following their shedding during winter season. The whole process in turn is expected to improve the soil fertility and enhance growth and productivity of intercrops under Jatropha-based agroforestry systems. Thus, Jatropha is a potent candidate with minimum attentions, management for degraded land reclamation/ improving soil quality and the LD plantation of Jatropha can be prescribed as a potential forest component under agro-forestry systems of rainfed north-west India.

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