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Identifying plantation density of *Bambusa balcooa* for marginal ecology through agronomical and farmers field trials addressing economic feasibility

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Abstract: Bamboo plantation on marginal land may provide opportunity for short and long-term investments allowing land owner for spreading financial risks. Financial advantages and economic viability are possible if grown under suitable agro climatic conditions with appropriate planting densities. *Bambusa balcooa* growth and productivity was studied on marginal wasteland of Gujarat in India using four planting densities. On-farm trials were established at densities ranging from 1112 plants/ha, 2223 plants/ha, 2964 plants/ha and 6175 plants/ha (D1, D2, D3 and D4) in Aravali district of Gujarat. Growth data like survival per cent, clump girth at base and height at 3rd internode, culms/clump, harvestable culms/ha, fresh and dry matter yield were collected and subjected to statistical analysis using various statistical tools. Survival and biomass yield was significantly higher ($p<0.000$) in D1 density and therefore same density was used for on-farm field trials. D1 density plantation showed lowest production cost @ 25 USD/Mg biomass as against other densities of *B. balcooa* plantation. Gujarat state accounts for 2.01Mha of wasteland with dry climate. Bamboo plantation with 1112 plants/ha has potential for maximum economic returns besides advantages in soil- reclamation and other ecological benefits.

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Introduction

Carbon dioxide emissions from industrial and transportation fossil fuel consumption causes global warming through accumulation of carbon dioxide in the atmosphere. Bioenergy as a source of fuel is been considered globally to reflect on energy security, oil price volatility and environmental pollution (IEA, 2011).

Bamboo's ability for providing environmental services through carbon sequestration is receiving high levels of interest which also confirms that bamboo outstrips its rate of carbon accumulation as against some fast growing trees (Lou *et al*., 2010). Further Bamboo thrives on nutrient poor soils with less silvi-cultural requirement yielding higher biomass besides having versatile diverse uses, surface root structure that improves soil ecosystem, absorb more CO_2 and produce more oxygen. Looking at these benefits, to meet the requirement of enhanced quality planting material (QPM) especially for bioenergy, we at Abellon Agrisciences Ltd have established bamboo tissue culture protocols for *Bambusa balcooa* species (Patel *et al*., 2015).

Taxonomically bamboo is a grass comprising of more than 1400 species with properties of fast growth and rejuvenation after cutting, known to thrive in diverse climatic and soil conditions (Gami *et al*., 2015). This makes it a quick and reliable source of biomass for bioenergy (Scurlock *et al*., 2000). Bamboo also shares a number of anticipated fuel characteristics such as low ash content, alkali index with high calorific values with other bioenergy feedstock (Patel *et al*., 2017). The composition of bamboo culms in terms of bioenergy properties like calorific value was found to be superior to other grasses used for biofuel purposes (e.g. switch grass, Miscanthus) (Scurlock *et al*., 2000).

Bamboo is proficient in providing environmental, monetary and employment security to societies. India has 13.96-million-hectare area under bamboo cultivation and is the second richest country, after China, in terms of bamboo diversity with 136 species (Bystriakova *et al*., 2003; National Bamboo Mission, 2019). However, its production and exports are negligible as compared to other countries like Indonesia, China and European Union (Bystriakova *et al*., 2003). The annual production of bamboo in India is about 14.6 m Mg and annual productivity varies from 1 to 3 Mg ha^{-1} (National Bamboo Mission, 2019). India is considered to be a net importer of bamboo which implies that there are greater opportunities to harness the market potential by increasing its production.

National biofuel policy promotes use of wasteland for cultivation of non-food biomass crops. Gujarat has 2.01 mha of wasteland which is 10.26% of the total geographical area (TGA) and wasteland in India account for 46.7 mha (14.91% of TGA) (Ministry of New & Renewable Energy- Government of India, 2009; MRD, 2011). However agronomic practices need to be standardized to cultivate bamboo based on agro climatic conditions on such marginal lands to maximise cost effective biomass production. Planting densities are an important aspect which requires optimization for enhancing productivity of biomass through canopy development, retention of soil moisture and competition with weeds (JaingHua and XiaoSheng, 2001). Therefore, this study was carried out;

(i) To know optimum planting density of tissue culturally raised *Bambusa balcooa* Roxb. at marginal land type with different densities to determine best productivity as against cultivation cost

(ii) To validate economics of selected plantation densities and agronomy practices based yield in on-farm trials

Materials and Methods

Plantation density

Tissue culturally raised *Bambusa balcooa* plants were established on one hectare with four different planting densities (D1-1112 plants/ha, D2-2223 plants/ha, D3-2964 plants/ha and D4-6175 plants/ha) in three replications at a spacing of 4.57 X 1.98 m, 4.57 X 1.0 m, 3.65 X 0.91 m and 1.52 X 0.91 m respectively as shown in Fig1. The trials were performed in 2011 at Aravali district, Gujarat, India. Geographically Aravali district is located in the foothills of Aravali mountain range in north Gujarat and the agronomical trials were located at 23˚33"35.19' N (latitude), 73˚17"7.95' E (longitude) at 163.98 meters of altitude above mean sea level. The soil of experimental sites is rocky, porous and has less water retention capacity and fall in marginal category of land.

Agronomy Practices

Hardened tissue cultured *B. balcooa* plants (Patel *et al*., 2015) were obtained from Abellon Agrisciences Ltd. Gujarat and planted following the guidelines recommended by Mehra and Mehra (2007). Before planting, the land was prepared through rotavator and pits of 45cm × 45 cm × 45cm were prepared manually for planting. Organic manure @ 2 kg and 250 gm fertilizer-mixture (Urea-100g, DAP-100g, Potash-50g) were added to each of the pits. Insecticides (Monocrotophos 0.05%) @1.24 litres/ha and fungicides (Dithane M 45 at 0.2 %) @ 16.67 kg/acre were applied. Weeding was performed as per requirement twice a year while pruning was performed second year onwards @ one per year with the onset of monsoon. Plants were irrigated as per the recommended practices (Aseri *et al*., 2012) and irrigation schedule was modified depending upon season and plant growth stage.

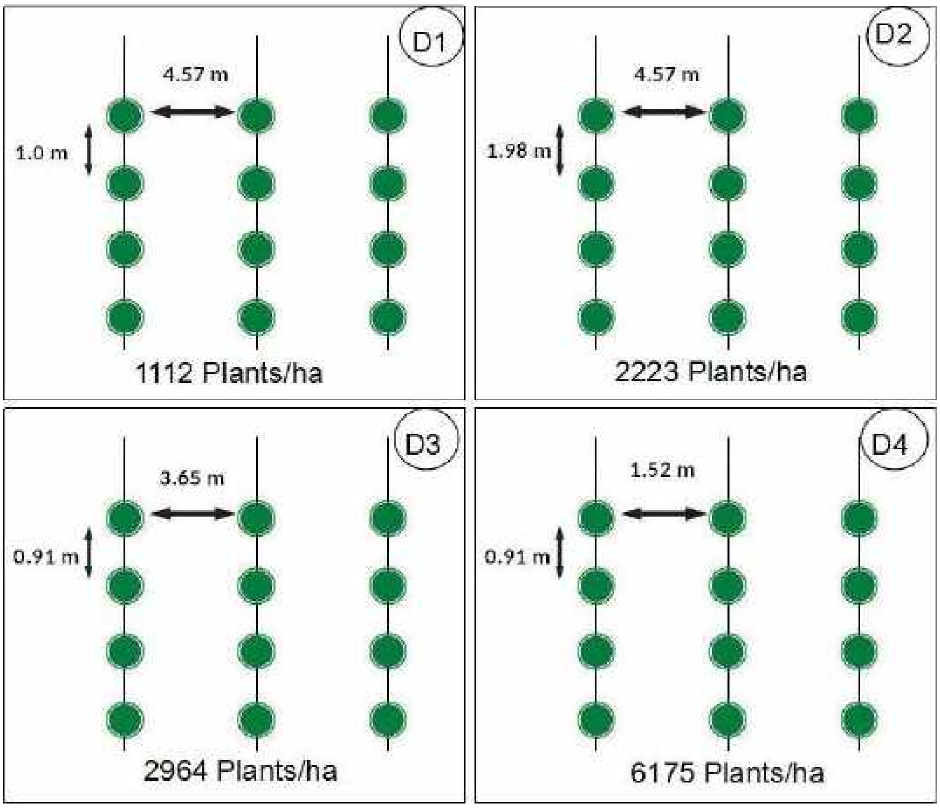

Fig 1. Four different Bamboo cultivation densities in experimental plots in Aravali, Gujarat, India

Growth parameters recorded

Plant growth parameters like survival per cent, number of culms per clump, clump girth (at base and at 3rd internode height), average height of clumps, fresh weight and dry weight per clump were recorded annually for four years. Every year, from each plantation density, 10 bamboo clumps were selected for fresh weight and dry weight estimation. Selected clumps were cut near to ground (5cm from ground) and measured fresh weight quickly at farm itself with electronic balance operated with battery. From the same clumps 5 numbers of samples of 100 g -500 g from the base, middle and top were taken in sealed plastic bags for dry weight estimation and subjected to oven drying till constant weight was obtained at 75°C. Similarly, at the end of fourth year, fresh and dry weight yields for culms, leaves, and offshoots were recorded for 100 clumps from each of the cultivation densities and biomass yield per hectare for all the parameters were calculated.

On-farm Trials in farmers' fields

On-farm trials for bamboo cultivation for selected density of 1112 plants/hectare (D1) were conducted at Surendranagar, Aravali and Bhavnagar district of Gujarat state following the guidelines recommended by Mehra and Mehra (2007). Surendranagar district is located in the north western part of Saurashtra Peninsula of Gujarat State. The district covers an area of 10,489 sq. km and is situated between north latitude 22.77˚ N and east longitudes 71.66˚ E. A major portion of the district is drought prone with medium black and silty type of soil. Mean annual rainfall in this district is 555 mm. Aravali district is located in east of Gujarat and has an area of 3210 sq. km. It has a sub - tropical climate with moderately low humidity and comes under normal rainfall areas. Goradu type of soil is found predominate in Aravali district. It lies between north latitude 23.520˚ N and east longitudes 73.370˚ E. Mean annual rainfall in Aravali district is 856 mm. While, Bhavnagar district is 9980.9 sq. km and is located in southern part of the Saurashtra Region of Gujarat between 21.509˚ N and 71.857˚ E coordinates. The district is characterized by tropical climate with medium black type of soil. Mean annual rainfall in Bhavnagar district is 584 mm.

Biomass Yield and Economic returns

Biomass yield per hectare for *B. balcooa* for all four densities was calculated from average fresh and dry weight values of culms, leaves, and off-shoots from the 100 clumps from each of the cultivation densities at the end of fourth year of cultivation. Cost of cultivation of *B. balcooa* per hectare was calculated by computing the expenses of all farm inputs, labour costs, electricity and fuel consumed during land preparation and irrigation throughout the span of four years (Abraham, 2017).

SPSS Statistical software, version 20 (IBM, 2017), was used to analyse mean and standard deviation for plant growth parameters. Correlation analysis was performed to study correlation among different plant growth parameters. ANOVA test was performed to analyse the variation in yield and growth parameters between densities. Tukey's posthoc test was performed to estimate difference in specific group means when compared with each other. The test compares all possible pairs of means to reveal which parameter is significantly influenced under which group. Regression analysis was performed to examine the relationship and influence of one or more independent variables on a dependent variable. The dry weight of bamboo biomass was taken as the dependant variable.

Results

Growth and biomass yield at different planation densities in initial trials in Aravali, Gujarat is given in Fig 1 and 2. *Bambusa balcooa* plants were successfully cultivated under marginal ecological conditions at Aravali district, North Gujarat at four different densities, D1-1112 plants/ha, D2-2223 plants/ha, D3-2964 plants/ha and D4-6175 plants/ha (Fig 1, Fig 2) to identify suitable plantation densities for *B. balcooa.*

Plant growth parameters were recorded annually up to four years for *B. balcooa* plants in all cultivation densities (D1, D2, D3 and D4) as shown in Table 1. Survival rate for the *B. balcooa* at all densities were close to 100% except D4 (97.66%) at the end of fourth year. All the parameters except the total number of culms/ha decreased with respect to increase plant densities for all four years. All the parameters increased with increase in age post planting for all plant densities. D1 had the highest fresh and dry weight (159.87±0.061 kg/

Fig 2. Bamboo growth at different densities of agronomical plantation plots

Labels: D1=1112 Plants Per Hectare, D2=2223 Plants Per Hectare, D3=2964 Plants Per Hectare and D4=6175 Plants Per Hectare

Table 1. Growth performance and biomass yield of *Bambusa balcooa* Roxb. under different cultivation densities

Sl. No	Parameters	Bamboo Cultivation Densities															
		D1 (1112 plants/ha)				D2 (2223 plants/ha)				D3 (2964 plants/ha)				D4 (6175 plants/ha)			
1.	**Years after Planting**	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
2.	**Survival ratio (%)**	100	100	100	100	100	100	100	100	100	99.33	99	99	100	98	97.66	97.66
3.	**Clump girth at base (m)**	0.97± 0.001	1.75± 0.002	2.71± 0.001	2.80± 0.002	0.94± 0.001	1.68± 0.001	2.52± 0.001	2.52± 0.001	0.92± 0.001	1.46± 0.001	2.29± 0.001	2.31± 0.001	0.66± 0.001	1.06± 0.001	1.42± 0.001	1.42± 0.001
4.	**Clump Girth at Chest height (m)**	1.51± 0.004	2.38± 0.004	3.43 ± 0.004	3.50± 0.004	1.45± 0.002	2.30± 0.002	3.01± 0.003	3.05± 0.003	1.39± 0.002	1.92 ± 0.002	2.73± 0.002	2.78± 0.002	1.17± 0.001	1.56± 0.002	1.94± 0.001	1.96± 0.001
5.	**Total No. of culms/ha**	3385± 2.167	8734± 1.351	13563 ±1.400	14760± 1.790	6829± 0.981	1141± 0.972	17735 ± 0.998	18781± 1.282	8782± 0.872	15139± 1.150	22722± 1.297	22786± 1.357	16145± 0.804	28404± 0.661	41940± 0.659	42205± 0.818
6.	**Culms/ Clump**	3.04± 0.014	7.85± 0.015	12.20± 0.014	13.26 ± 0.014	3.07 ± 0.010	5.13± 0.010	7.97± 0.010	8.44 ± 0.010	2.96± 0.009	5.16 ± 0.009	7.67± 0.009	7.79± 0.009	2.61± 0.006	4.60 ± 0.006	6.79± 0.006	6.83± 0.006
7.	**Height (m)**	2.08± 0.001	4.11± 0.002	8.33± 0.001	8.74± 0.002	2.07± 0.001	4.12± 0.001	7.61± 0.001	7.98± 0.002	1.90± 0.001	3.48± 0.001	5.60± 0.001	5.95± 0.002	1.84± 0.001	3.23± 0.001	4.50± 0.001	4.88± 0.001
8.	**Fresh weight (kg/clump)**	12.52± 0.015	37.83± 0.022	73.99± 0.047	159.87± 0.061	11.31± 0.014	33.18± 0.012	53.35± 0.013	62.89± 0.013	17.73± 0.010	28.02± 0.010	35.88± 0.010	41.02 ± 0.009	6.36± 0.006	9.36 ± 0.006	12.27± 0.006	13.36± 0.006
9.	**Dry weight (kg/clump)**	6.88± 0.011	19.29± 0.023	37.67± 0.024	82.59± 0.027	6.67± 0.015	14.33± 0.015	25.53± 0.015	32.91± 0.015	7.28± 0.013	13.43± 0.013	19.85± 0.013	21.33± 0.014	3.17± 0.006	4.52± 0.009	6.10± 0.009	6.84± 0.009

clump and 82.59±0.027 kg/clump respectively) among all the densities after the end of four years.Tukey's Post Hoc test was performed when ANOVA test showed significant difference to find out mean difference with specific group for each growth parameter. Total culms/clump per hectare significantly decreases as density increases showing negative mean difference (Table 2).

While rest of the parameters showed positive mean difference with each density of plant showing statistical significance p=0.0001 (Table 2). The results show that as density increases, clump productivity decreases even though plant height and other parameters show good growth indication which is required for biomass yield. Therefore, correlation analysis to study the strength of a relationship between two numerically measured continuous growth related variables was done (Table 3). This was used to establish if there are possible relations between variables. Plant density was negatively correlated with clump girth at bottom and 3rd culm height, culms per clump, height, fresh and dry weight showing significance level p=0.0001 (Table 3).

It means as density of bamboo plantation increases all of the growth related parameters (clump girth at bottom and 3rd culm internode height, culms per clump, height, fresh and dry weight), decreases

Table 2. Tukey's Post Hoc Test of growth parameters & cultivation density of *Bambusa balcooa* Roxb.

Parameters	Density		Mean Difference	Std. Error	p-value	Parameters	Density		Mean Difference	Std. Error	p-value
Year	D1	D2	0.000	0.021	1.0000	Culms per Clump	D1	D2	2.9338*	0.041	0.0001
		D3	0.000	0.020	1.0000			D3	3.1940*	0.039	0.0001
		D4	0.000	0.018	1.0000			D4	3.8803*	0.036	0.0001
		D3	0.000	0.016	1.0000		D2	D3	0.2602*	0.031	0.0001
	D2	D4	0.000	0.014	1.0000			D4	0.9466*	0.028	0.0001
	D3	D4	0.000	0.012	1.0000		D3	D4	0.6863*	0.025	0.0001
Clump girth at base(m)		D2	-0.11852*	0.009	0.0001	Height (m)	D1	D2	0.37269*	0.033	0.0001
	D1	D3	0.04973*	0.009	0.0001			D3	1.58148*	0.031	0.0001
		D4	0.65716*	0.008	0.0001			D4	2.20005*	0.029	0.0001
	D2	D3	0.16825*	0.007	0.0001		D2	D3	1.20879*	0.025	0.0001
		D4	0.77568*	0.006	0.0001			D4	1.82736*	0.022	0.0001
	D3	D4	0.60743*	0.006	0.0001		D3	D4	0.61858*	0.020	0.0001
Clump Girth at Chest height (m)		D2	0.25375*	0.010	0.0001	Fresh weight (kg/ clump)	D1	D2	30.86972*	0.353	0.0001
	D1	D3	0.49967*	0.009	0.0001			D3	40.39319*	0.338	0.0001
		D4	1.04935*	0.009	0.0001			D4	60.71896*	0.313	0.0001
	D2	D3	0.24592*	0.007	0.0001		D2	D3	9.52346*	0.270	0.0001
		D4	0.79560*	0.007	0.0001			D4	29.84923*	0.238	0.0001
	D3	D4	0.54968*	0.006	0.0001		D3	D4	20.32577*	0.215	0.0001
Total culms per ha		D2	-3578.865*	155.780	0.0001	Dry weight (kg/ clump)	D1	D2	16.74704*	0.184	0.0001
	D1	D3	-7246.640*	149.146	0.0001			D3	21.13621*	0.176	0.0001
		D4	-22063.289*	138.163	0.0001			D4	31.44812*	0.163	0.0001
	D2	D3	-3667.774*	118.997	0.0001		D2	D3	4.38917*	0.141	0.0001
		D4	-18484.424*	104.903	0.0001			D4	14.70108*	0.124	0.0001
	D3	D4	-14816.650*	94.772	0.0001		D3	D4	10.31191*	0.112	0.0001

* The mean difference is significant at the 0.05 level
D1=1112 Plants Per Hectare, D2=2223 Plants Per Hectare, D3=2964 Plants Per Hectare and D4=6175 Plants Per Hectare

Table 3. Correlation Analysis of growth parameters, plantation years and plantation densities of *Bambusa balcooa* Roxb.

Parameters		Density code	Year	Clump Girth at bottom (meter)	Clump girth at Chest height (meter)	Total Culms/ ha	Culms per clump	Height (meter)	Fresh weight (kg/ clump)	Dry weight (kg/clump)
Density (Plants/ha)	r-value	1	0.000	-0.500**	-0.576**	0.683**	-0.383**	-0.413**	-0.682**	-0.672**
	p-value		1.000	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Year	r-value	0.000	1	0.737**	0.708**	0.620**	0.806**	0.829**	0.436**	0.451**
	p-value	1.000		0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Clump Girth(m)	r-value	-0.500**	0.737**	1	0.943**	0.040**	0.822**	0.913**	0.756**	0.759**
	p-value	0.0001	0.0001		0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Clump Chest height girth(m)	r-value	-0.576**	0.708**	0.943**	1	0.001	0.884**	0.941**	0.811**	0.812**
	p-value	0.0001	0.0001	0.0001		0.767	0.0001	0.0001	0.0001	0.0001
Total Culms/ha	r-value	0.683**	0.620**	0.040**	0.001	1	0.276**	0.217**	-0.274**	-0.258**
	p-value	0.0001	0.0001	0.0001	0.767		0.0001	0.0001	0.0001	0.0001
Culms/clump	r-value	-0.383**	0.806**	0.822**	0.884**	0.276**	1	0.924**	0.757**	0.766**
	p-value	0.0001	0.0001	0.0001	0.0001	0.0001		0.0001	0.0001	0.0001
Height(m)	r-value	-0.413**	0.829**	0.913**	0.941**	0.217**	0.924**	1	0.766**	0.770**
	p-value	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001		0.0001	0.0001
Fresh weight (kg/clump)	r-value	-0.682**	0.436**	0.756**	0.811**	-0.274**	0.757**	0.766**	1	0.996**
	p-value	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001		0.0001
Dry weight (kg/ clump)	r-value	-0.672**	0.451**	0.759**	0.812**	-0.258**	0.766**	0.770**	0.996**	1
	p-value	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	

**Correlation is significant at the 0.01 level (2-tailed)

Table 4. Regression analysis based on dry weight of bamboo as dependant variable while growth parameters as constant predictors

Model Summary									
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.997a	.993	.993	1.12815	.993	927154.007	8	49887	0.000

a. Predictors: (Constant), Fresh_weight, Total_Culms_per_hectare, Clump_Girth, Density, Culms_per_clump, Year, Height, Clump_Chest_height_girth
b. Dependent Variable: Dry_weight

Dependant variable : Dry weight

Parameter	Mean	SD	N	Person r	R2	p-value	S.E.	Constant (B)	B0
Constant (Dry Weight-Kg/Clump)	13.0321	13.80	49895		0.993	0.0001	0.049		-0.997
Density	3.14	1.005	49895	-0.672	0.993	0.0001	0.012	- 0.203	-0.997
Year	2.5	1.118	49895	0.451	0.993	0.0001	0.015	0.531	-0.997
Clump Girth at bottom (meter)	1.4798	0.60181	49895	0.759	0.993	0.0001	0.029	0.206	-0.997
Clump girth at Chest height (meter)	2.02	0.65581	49895	0.812	0.993	0.0001	0.037	0.573	-0.997
Total Culms/hectare	23392.23	12299.601	49895	-0.258	0.993	0.0001	0.000	-0.000038	-0.997
Culms/clump	5.885	2.4812	49895	0.766	0.993	0.0001	0.007	0.278	-0.997
Height (meter)	4.2838	1.95053	49895	0.770	0.993	0.0001	0.012	0.218	-0.997

significantly. Regression analysis was applied on growth data to understand how the typical value of the dependent variable (dry weight here) changes when any one of the independent variables is varied, while the other independent variables are held fixed (Table 4).

The R2 and Adjusted R2 were 0.993 and 0.993, respectively. The weighted combination of the predictor variables explained approximately 99% of the variance of dry weight of bamboo. The prediction model was statistically significant, F (8, 49887) =927154.00, p <0.001, and accounted for approximately 99% of the variance of dry weight bamboo biomass yield (R2= 0.993.607, Adjusted R2= 0.993). The zero-order correlation lists the Pearson r values of the dependent variable (Dry weight of Bamboo in this case) with each of the predictors.

The Y intercept of the model is labelled as the constant and has a value here of -0.997. The raw (B) and standardized (Beta) coefficients, and their significance levels determined by t tests (Table-4). All the predictors are statistically significant. As can be seen by examining the beta weights, clump girth at 3rd internode height followed by height, total culms per hectare, density, clump girth at bottom, culms per clump, fresh weight followed by year (of plant age) were making relatively larger contributions to the prediction model.

Statistical data suggested that as density of plantation increases, biomass yield decreases. Therefore, D1 density, that is 1112 plants/hectare, was selected since this density is suitable for the agro climatic condition of the geographic area to cultivate *Bambusa balcooa*.

Bamboo Farmers' field on- farm trials

On-farm field trials for *Bambusa balcooa* were conducted following D1 density (1112 plants/hectare) in 3 farmers fields at Surendranagar (B1), Bhavnagar (B2) and Aravali (B3) districts of Gujarat state in India (Fig 3). Agronomic practices followed as per the density in agronomical trials followed at Aravali district at captive plantation.

Total fresh and dry weight data for culms, were recorded for 100 clumps from all cultivated densities and farmers fields at the end of four years. Biomass yield per hectare of respective densities was calculated as shown in Table 5. Highest fresh and dry weight for the culms after the fourth year was found in D1 density. Similarly, highest estimated fresh and dry biomass weight for bamboo at the end of fourth year was found in D1 density as compared to D4 density. Biomass yield parameters for farmers field trials showed same yield data as per D1 density agronomy trials conducted as captive farming (Table 5).

Cost of cultivation of *B. balcooa* per hectare was calculated at the end of fourth year for all the plant densities for agronomical trials and farmers field trial considering land preparation, field maintenance, labour costs, plants & fertilizers, fuel and electricity costs consumed throughout the duration of 4 years. Cultivation density D4 showed the highest cost of cultivation (3333.07 USD/ha) despite the minimal farm inputs used. While density D1 (991.56 USD/MT/ha) showed the least cost of cultivation per hectare. Similarly, costs were derived for all three farmers field trials (Table 5) which showed almost same results as shown in D1 agronomic density trial for captive farming. Cost of cultivation of bamboo as against biomass yield was found to be lowest at D1 density at agronomic trial and farmers field trial (around 25 USD/million tons) (Table 5).

Discussion

Natural distribution of bamboo depends on soil properties and climatic conditions. However, bamboo has great adaptation capabilities (BTSG-KFRI, 2015) which make it as an alternative crop for cultivation on marginal land (Patil *et al.*, 1994). This study also cultivated and established agronomical density trials of bamboo at marginal ecology at Aravali district (D1 to D4), and farmers field on-farm trials at Surendranagar (B1), Bhavnagar (B2) and Aravali (B3) for *B. balcooa* plants.

Bamboo cultivation is known for soil reclamation (Desh, 1990; International Network for Bamboo & Rattan, 2014; Rao *et al.*, 1999) and can convert marginal land into fertile land (Yourmila and Bhardwaj, 2017; Zhou *et al.*, 2005) provided optimised cultivation density that account for biomass productivity. Therefore, identifying right plantation density to optimize biomass yield was one of the objective for bamboo plantation. Especially when Gujarat state holds 2.01 mha of wasteland out of 46.7 mha in India (MRD, 2011).

Survival rate for the *B. balcooa* for all densities at agronomical trials & farmers field on-farm trials were close to 100% except 6175 plants/hectare (D4) (97.66%) at the end of fourth year. The decrease in the survival rate of bamboo plants at higher densities may be caused due to higher competition for nutrients or water among the bamboo plants, as bamboo is known for faster absorbance of nutrient & water to sustain faster growth (Piouceau *et al*., 2014; Yourmila & Bhardwaj, 2017). It has also been reported that increase in number of clumps in higher plantation density leads to dearth of growth space as well as creates competition for light, space and nutrients which diminishes growth of new rhizome and culms (Kigomo & Kamiri, 1985) resulting into overall less biomass productivity (Kittur, Sudhakara, Mohan Kumar, Kunhamu, & Sureshkumar, 2016). Correlation analysis (Table 3) also confirms an inverse relationship as higher the plantation densities lower the biomass yield. At the end of fourth year, gradual decrease with increase in the plantation density of *B. balcooa* was noticed while for each individual cultivation density *B. balcooa* showed a significant increase in the clump girth at base & 3rd internode height. Standing culm density is also an important parameter to judge the biomass productivity in bamboo (Volkar & Devid, 2001). The number of culms in *B. balcooa* cultivation increased significantly ($p<0.0001$) for each density with respect to years after plantation (Table 1). Optimum standing-culm density in bamboo varies with species and geographic location. Bamboos with smaller diameter (1-4 cm) like species P. *nigra* and P. *niduaria* have much higher standing-culm density (Shen, Fan, Liu, Chen & Li, 1993), than bamboos with medium diameter (4-5 cm) like species P. *makinoi* (Yang & Huang, 1981) and lower in bigger diameter (8-18 cm) in P. *pubescens* (Dart, 1999; Liao, 1986).

Fig 3. Farmers' field bamboo cultivation
Labels: B1: Surendranagar, B2: Bhavnagar and B3: Aravali (districts of Gujarat state)

Table 5. Culm yield & cultivation cost of *Bambusa balcooa* Roxb. after four years of cultivation at different plantation densities & farmers field trials.

Parameters	**Plantation density (Plants/Ha)**				**Farmer's field trials**		
	D1(1112 plants/ ha)	**D2(2223 plants/ ha)**	**D3(2964 plants/ ha)**	**D4(6175 plants/ ha)**	**B1 (1112 plants/ ha)**	**B2 (1112 plants/ ha)**	**B3 (1112 plants/ ha)**
Culm yield (MT/Ha)							
Fresh weight of culms (MT)	105.05	84.47	78.34	60.51	103.64	102.97	108.53
Dry weight of culms (MT), a	62.60	48.61	40.30	32.31	61.97	62.64	63.19
Cost of cultivation (USD/Ha)							
Land Preparation Cost (USD/ha)	22.20	22.20	22.20	22.20	22.20	22.20	22.20
Plant Cost (USD/ ha)	546.09	1091.70	1455.60	3032.49	546.09	546.09	546.09
Fertilizer Cost (USD/ha)	71.32	91.37	0.00	234.06	71.32	71.32	71.32
Pruning Cost (USD/ha)	59.89	74.86	82.35	0.00	59.89	59.89	59.89
Rotavator Cost (USD/ha)	53.90	47.91	35.93	0.00	53.90	53.90	53.90
Weeding Labor (USD/ha)	112.29	112.29	112.29	0.00	112.29	112.29	112.29
Electricity Bill (USD/ha)	44.32	44.32	44.32	44.32	44.32	44.32	44.32
Organic Manure (USD/ha)	81.57	163.05	217.44	0.00	81.57	81.57	81.57
Total Cultivation Cost (USD/ha),b	991.56	1647.69	1970.13	3333.07	991.56	991.56	991.56
Harvesting Cost (USD/MT),c	9.21	9.21	9.21	9.21	9.21	9.21	9.21
Harvesting Cost (USD/ha), d = a*c	576.54	447.61	371.16	297.57	570.74	576.91	581.98
Production cost (cultivation + Harvesting) (USD/ ha) (b+d)	1568.1	2095.3	2341.29	3630.64	1562.3	1568.47	1573.54

B1: Surendranagar, B2: Bhavnagar and B3: Aravali (districts of Gujarat state)

The relative increase in the number of culms per clump gradually decreased with increase in plantation density from 3.04 culms/clump for D1 to 2.61culms/clump for D4 at the end of first year and 13.26culms/clump for D1 to 6.83culms/clump for D4 at the end of fourth year (Table 1) and correlation analysis confirms negative correlation between density of plantation with culms per clumps (Table 3). Thus, the growth parameters for bamboo plants showed increase with respect to time at every plantation density but showed gradual decrease with increase in plantation densities. Regression analysis conducted in present study (Table 5) also showed that increase in each unit of density of plantation reduces 0.203 unit of dry weight of bamboo. INBAR (Jaing Hua & Xiao Sheng, 2001) suggested that planting density depends upon site conditions along with the size of the species involved. Generally, higher densities are suitable for the establishment of small-sized bamboos. While too low density will suffer from canopy exposure to sun light, low soil moisture and strong competition from weeds resulting into poor productivity

Soil and agro-climatic conditions were poor in the present bamboo agronomical trials wherein D1 plantation density (1112 plants/hectare) showed greater biomass yield after 4th year with less density of plants. Patil *et al*., (1994) recommended for marginal land to have standing culm density of 15000-21000 per hectare (Patil *et al*., 1994). In our study too, the D1 density showed culms/ha of 14760±1.79 (Table 1).

Therefore, bamboo on-farm trials were conducted using D1 density at farmers' fields at Surendranagar district (B1), Bhavnagar district (B2) and Aravali district (D3) in Gujarat state. Cost of cultivation of bamboo was calculated for each density for agronomical trials conducted at Aravali district as well as for on farm farmers' filed trial (Table 5). D1 plantation density showed highest bamboo dry biomass production of 62 Mg resulting into cost of bamboo production and harvesting of around 25 USD/ Mg of dry biomass. This was almost similar for D1 density plantation at on farm farmers' field trial. Abraham (2017) also reported similar cost of production per Mg of biomass in south Indian region. In the current study, other densities D2, D3 and D4 showed higher cost of production per Mg of biomass due to lower biomass yield (Table-5). INBAR (JaingHua and XiaoSheng, 2001) reported 342.46 USD/ha/year as working capital to get 4500 culms as output. Pandey *et al.,* (2012), reported bamboo plantation cost of 192 USD/ha/year for 400 plants/ha density at Mahi ravine in India with output of 1500 poles/ha that accounted 0.13 USD/pole (Pande *et al*., 2012). Though various studies have worked out economics of bamboo plantation as per their need and objective (Abraham, 2017; Grow more biotech Ltd, 2018; Pande *et al*., 2012), this study has primarily focused on marginal land use and plantation density for *Bambusa balcooa* cultivation.

Conclusion

Agronomical trials carried out at Aravali district with four densities of *B. balcooa* plantation suggested that cultivation of 1112 plants/ha density is suitable for the agro-climatic region of Gujarat. The On-farm field trials carried out at Aravali, Bhavnagar and Surendranagar districts with 1112 plants/ha density showed similar biomass output yield of around 62 Mg of dry biomass per hectare with 25 USD/million tons of biomass cost of production. More than 46 m ha of waste land available in India, out of which 2.01 m ha occur in Gujarat state. This 2 m ha of waste land in Gujarat have potential to grow bamboo for economic, environmental and soil revival benefits.

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