A Study of Generation and Regulation of Crop Residue: Bioenergy

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ABSTRACT

Background: Agricultural residues are a significant part of the waste generated in India. It is challenging for farmers to manage surplus crop residue sustainably because of large production and limited options. Ultimately, most farmers burn crop residue without giving it a second thought. Besides affecting the environment, burning crop residues also reduces soil fertility, soil nutrient content and soil organic humus levels by releasing greenhouse gases.

Methods: This study was conducted to identify surplus crop residues available and their current uses. Vidarbha region in Maharashtra was selected for the study and cotton, tur and soybean crops were selected since these are the most commonly grown crops there. A man-to-man survey was conducted to determine the type and amount of crop residue available and how it is currently being used. Three farmlands in the Vidarbha region of Maharashtra were selected for the study. Four different varieties of cotton, tur and soybean were grown on three farms. The yield and crop residue generated were measured per unit area. Analysis of crop residue availability was conducted using statistical methods.

Result: Based on the study, it can be concluded that biomass waste is abundantly available and there is potential to generate bioenergy by utilizing agricultural waste effectively. Furthermore, the regression study shows that crop output is a major predictor of crop residue generated.

Key words: Bioenergy, Crop residue, Field study, Sustainable development.

INTRODUCTION

The problem of waste management is widespread throughout world, including in the agriculture sector. Globally, agriculture is one of most important resources and the backbone of every developing nation. It is estimated that the average global biomass waste generation is in order of 140 Gt annually (Tripathi *et al*., 2019). Almost 686 Mt of biomass waste is generated in India each year, of which 234 Mt is surplus for bioenergy production (Hiloidhari *et al.,* 2014). As a consequence, handling such huge volumes of biomass waste is difficult since burning and dumping can have harmful effects on the environment. This study examined local crop residue availability since limited local data is accessible to determine crop residue supply for planning decentralized bioenergy production units.

Need for renewable energy planning based on crop residues

In future, renewable energy will play a significant role in power generation as conventional sources of energy are depleting rapidly. Coal power plants supply 40% of the world's electricity and they can also run on biomass (Yang *et al*., 2019). Within a generation, coal will be phased out if global temperatures rise one and a half degrees above pre-industrial levels (Otsuki *et al*., 2023). Climate change is caused by greenhouse gas emissions, including carbon dioxide and switching to alternative fuels is considered a promising solution to problem. If bioenergy is consumed instead of fossil fuels, carbon neutrality can be achieved (Yang *et al*., 2019) (Paraschiv and Paraschiv, 2023). There has been an increase of interest in lignocellulosic feedstock due to the growing focus on bioenergy (Fusi *et al*., 2021); (Muazu *et al*., 2022). Biomass has advantages such as renewability and diversification, making it a potential source of primary energy having approximately 10^{11} Gt of supply potential (Majada *et al*., 2021). Biomass availability is essential for the bio economy. Sawdust, wood chips and forest wood are the main fuel sources used today, although doing so results in deforestation and health issues. Therefore, in future, only low-grade biomass will be available for fuel use. The need for fuels is increasing, so it is important to find new, locally available, sustainable resources like biomass that may be used to power small-scale appliances in remote areas. Crop biomass has substantial potential to generate bioenergy by using various thermochemical processes (Petlickaitė *et al*., 2022). Previously, surplus biomass from diverse crop residues such as cotton, sugarcane, soybean, maize, vineyard waste, reed plant,

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switchgrass and others were utilized to produce the biofuel (Al Afif and Pfeifer, 2021) (Mitchell *et al*., 2020) (Harun *et al*., 2018) (Petlickaitë *et al*., 2022) (Senila *et al*., 2020). It is vital to do research on locally accessible biomass material since the availability of crop biomass close to pelleting facility will lower transportation costs and partially resolve the handling issue.

Current scenario of crop residue usage

FAO predicts that 120 M hectares will become agricultural land in developing nation by 2030, while IEA predicts agricultural residues will increase to 6.8 Gt and forestry residues will increase to 0.7 Gt (Baruya, 2015a). The demand for all biomass wastes is expected to rise by 2050 globally, with a greater share of agricultural residues being used for energy production. The amount of crop residues that are currently available from agriculture is estimated to be 2.9 Gt p.a^{-1}., which indicates that there are ample crop residues available worldwide (Baruya, 2015b) (Raji and Sarode, 2019). More than 2 Gt of crop residues are burned globally, providing around 18% of all CO_2 and particulates emission (Devi *et al*., 2017). The majority of the poor and rural communities, which make up 38% of the world's population, use biomass as a cooking fuel (Baruya, 2015b). India's energy supply and demand are significantly out of balance and nation has restricted conventional fuel options (Hiloidhari *et al*., 2014) (Ram *et al*., 2022). Because of which India is looking for renewable and sustainable energy option. Emerging economies like India have access to the straw residue at a rate of around 368 Mt year^{-1} (Hiloidhari *et al*., 2014). India has 141 million hectares of arable land and annually produces 800 million tonnes of agricultural and horticultural products (Kaushik and Singh, 2016). Crop statistics from the Ministry of Agriculture (MoA), Government of India, are a major data source for estimating crop residue biomass availability. Given the country's insufficient crop level record, it was thought necessary to build a local biomass database for decentralized energy generation. In India, 585 million people use biomass, accounting for 58% of the population and 24% of the global population. India's biomass consumption is 198 Mt, with biomass accounting for 40% of the primary energy supply and 84% of household energy demand (IEA, 2002). The biomass generation density in Maharashtra is 265.6 MT km^{-2}, the biomass consumption density is 173 MT km^{-2} and the biomass surplus density is 92.6 MT km^{-2} (TIFAC, 2009). Each region has its own locally created biomass feed supplies derived from the agricultural, forest and urban sources, a resource that is adaptable and ubiquitous can be tailored to match local needs and aims. TIFAC has done zone-wise mapping of biomass residue availability but the local crop residue data is still unavailable. Therefore, this study has been carried out.

MATERIALS AND METHODS

India needs to estimate the availability of biomass at the district level and develop zone-level recommendations for implementing relevant biomass conversion technologies. Cropped area, cropping pattern, yield and surplus residue percentage are a few of the key factors that determine surplus residue potential (Purohit and Chaturvedi, 2018). This study has been conducted in three phases i) primary stage, ii) secondary stage and iii) tertiary phase. In primary stage, various reports by government organizations such as TIFAC, IARI, IEA, NITI Aayog, IEEJ and FAO statistics have been studied to learn about agricultural statistics. Following that in secondary stage, a local survey was conducted in the Vidarbha area of Maharashtra state to assess the availability of biomass waste and its utilization. A man-to-man survey was conducted to assess the biomass output from several crop cultivars. Tur, soybean and cotton crops create a large quantity of biomass and are often used by farmers in the Vidarbha area. As a result, in tertiary stage, tur, soybean and cotton crop residues are considered. To determine the optimal quantity of crop residues generated, field research was conducted by seeding multiple varieties of tur, soybean and cotton crop. Soil condition and characteristics were also analyzed by collecting the soil samples and testing it in government soil testing laboratory at Yavatmal district, Maharashtra. The weather conditions were also assessed by collecting rainfall and temperature data. Also, the entire life cycle of the different crops, from seeding to harvesting, has been investigated.

RESULTS AND DISCUSSION

Primary stage

Plant biomass is valuable feedstock used in wide range of businesses, most notably food and feed production, but also the chemical, pharmaceutical and power industries. As a result, several reports have been produced by various government and corporate organizations to investigate its global availability. India has the distinction of having the most cotton cultivation land, accounting for about 37% of world's cotton cultivation land between 12.5 million and 12.6 million hectares. According to the Cotton Corporation of India Ltd. current yield of cotton is 466 kg ha^{-1}. Table 1 compares cotton cultivation, production and consumption in India to the rest of the globe. This demonstrates India's enormous excess biomass potential from cotton.

At global level, India has the largest area under pigeon pea cultivation of 53.38 lakh hectares (64%) and produces the highest volume of pigeon pea of 48.73 lakh tonnes (57%). However, India has a comparatively lower crop yield of 913 kg per hectare as given in Table 2. From the data in Table 2 it can be concluded that India has huge potential to cultivate pigeon pea (Tur) crop. Similarly, Maharashtra has greatest proportion of Tur crop growth in India and its agricultural waste output is also huge according to (TIFAC Report, 2009).

Soybean plays a significant role in the world's oilseed agriculture scenario because of its high productivity, profitability and critical contribution to soil fertility (Ghosh, 2016). United States, Brazil and Argentina are the top three soybean-producing countries. The pool of edible oils in India is greatly augmented by soybeans. Currently, soybean accounts for 43% of all oilseed output and 25% of all oil production in the nation. India now holds the fifth place in the world for soybean output as shown in Table 3.

Secondary stage

A study from the Maharashtra Energy Development Agency States that India generates 22 Mt of cotton stalk and 4 Mt of tur stalk per year. This biomass waste is either burned or utilized as feed for animals. Farmers in the Vidarbha area of Maharashtra mostly cultivate the crops cotton, tur and soybeans; consequently, a data gathering survey was conducted by interviewing farmers about residue generated from their crops to learn more about biomass availability. The majority of 130 to 150 persons that were interviewed by visiting their houses were from Yavatmal, Akola and Nagpur districts. Information about crop residues generated from different varieties of tur, cotton and soybean crop and their current usage was gathered. Cotton waste in the Vidarbha region is an unidentified source of biomass energy since it is abundant and has the potential to create bioenergy. Farmers in Vidarbha region primarily burn cotton and tur residue. Also, many farmers are presently using soybean waste to feed cattle, with leftovers being burnt on the farm. Because large portion of agricultural residue listed above belongs to the Vidarbha region, it has been considered for survey and investigation.

From oral survey, it was found that proper use of crop residue has numerous benefits for farmers. However, the improper storage or use of crop residue can lead to drawbacks like breeding of insects and odour. Burning of crop residue in fields results in loss of organic fertilizers, soil erosion and reduction of soil fertility. Additionally, storing crop residue in houses and animal shelters can lead to fear of fire breakouts and it can become a breeding ground for pests and vermin, notably rats, mosquitoes and snakes leading to decrease of its efficacy as animal fodder or fuel. Moreover, when used as fuel in domestic cooking stoves, it can cause air pollution, leading to environmental and health concerns. All of these situations can become costly for farmers and lead to lack of crop production. Therefore, proper management of this biomass is required.

Table 1: Area under cotton cultivation, production and consumption of cotton in India.

Crop year 2019-20	World	India
Area in million hectares (Mha)	34.31	12.60
Production in million tonnes (Mt)	26.15	6.12
Consumption in million tonnes (Mt)	22.54	5.63

Source: ICAC journal "cotton this month", cotton advisory board.

Table 2: Major countries growing pigeon pea crop.

Country	Area (Lakh ha)	Production (Lakh tonnes)	Crop yield (kg ha^{-1})
India	53.38	48.73	913
Myanmar	6.68	6.28	939
Tanzania	2.68	2.72	1016
Malawi	2.46	3.71	1506
Kenya	1.19	1.91	1612
Others	16.43	21.98	1383
World	82.82	85.06	1027

Source: FAO Statistics (DPD/Pub./TR/29/2017-18).

Table 3: Major countries growing soybean crops in million metric tons.

Year	2021-2022	2020-2021	2019-2020	2018-2019	2017-2018
US	119.9	112.5	96.6	120.5	120.1
Brazil	144	137	128.5	119.7	123.4
Argentina	52	47	48.8	55.3	37.8
China	19	19.6	18.1	15.9	15.3
India	11.2	10.5	9.3	10.9	8.4
Paraguay	10.5	9.9	10.1	8.5	11
Canada	6.4	6.4	6.2	7.4	7.7
Mexico	0.3	0.23	0.23	0.33	0.43
European union	2.8	2.6	2.6	2.7	2.5
Others	19.4	18.4	18.9	19.9	17.5

Source: The soybean processors association of India, 2023.

The oral survey results of crop residue data are given in following Table 4.

Tertiary stage

In this stage Among these different varieties of tur, soybean and cotton crop four varieties of each crop has been selected by considering the surplus biomass production and frequency of varieties that have taken by the farmers. Three local farms in Yavatmal district have been selected for the experimentation. Yavatmal is also popularly known as cotton city. Four varieties of each crop were sown on each farm. Each variety was sown in 1000 square feet thrice on every farm. Factors affecting crop growth such as rainfall, temperature, soil parameters and fertilizers used were studied. Rainfall and temperature data for that region is shown in Table 5. Life cycle study of these crops was carried out for two cropping seasons in the years 2021 and 2022 to get complete information about the factors affecting production of biomass. Four varieties yielding maximum amount of biomass has taken for the study.

Soil properties and constituents largely affect crop production; therefore, soil testing was carried out using government guideline. The soil in the selected farms is mostly Alluvial and clayey. The data from Table 6 shows that soil contains low available phosphorus, low organic curb percentage and insignificant available nitrogen. As a result, fertilizers containing all three primary plant nutrients, namely nitrogen, phosphorus and potassium, are applied to the soil.

In June 2021 and 2022, *i.e.*, during the kharif seasons, four different varieties of cotton, tur and soybean were seeded. Tur and cotton were harvested in January of the next year, while soybean crop was harvested in October of the same year. To estimate the biomass produced from each crop variety, the quantity of crop residue generated per square meter was reported from three farms for each variety. Fig 1, Fig 2 and Fig 3 shows the average crop production and residue generated on selected field. The residue to product ratio were also calculated which gives the value of unused crop residue remained after harvesting (Daioglou *et al*., 2016). The residue to product ratios obtained for cotton crop varities Ankur-3028, RCH-659, RCH-779 and Ajeet-155 were 1.2, 1.1, 1.1 and 1.05 respectively. While the residue to product ratios obtained for soybean crop varities JS-335, Eagle, Ankur and Karishma were 2.4, 1.9, 2.7 and 2.5 respectively and the residue to product ratios obtained

Table 4: Average crop residue produced in kg/acre obtained from survey.

Cotton		Tur		Soybean	
Variety of cotton crop	Average crop residue (kg $Acre^{-1}$)	Variety of tur crop	Average crop residue (kg $Acre^{-1}$)	Variety of soybean crop	Average crop residue (kg $Acre^{-1}$)
Rasi-MAGNA	2250	Mahamandal	825	Eagle	1232
basant	3000	Maruti IPC-8863	1029	Vikrant	1366
RCH-659	2029	Shri Ganesh	926	JS-335	1202
RCH-779	2093	Daftari	1000	Karishma	1352
Money maker BG-2	1715	Munni	933	KSL-441	1201
RCH-773	2000	Charu-Ankoor	978	Narmada JS-9560	1382
Ankur-3028	2047	BSMR-736	1583	JS-9305	2333
Ajeet-155	1900	BDN 711	825	Phule Agrani	774
Shriram-6588	1500	-	-	Balaji Kuber	1667

Table 5: Rainfall and temperature data of two crop seasons.

Year	Month	Taluka normal rainfall (mm)	Total rainfall (mm)	Rainy days	Temperature ranges (°C)
2021	June	171.4	290.7	11	22-38
	July	276.9	180.4	14	23-37
	August	218.7	229.2	08	24-34
	September	295.7	306.6	20	23-33
	October	56.10	54.4	02	16-35
2022	June	171.4	81	07	24-44
	July	276.9	430.4	22	23-35
	August	253.9	241	11	23-34
	September	121.9	196.2	09	23-35
	October	55	137.8	03	18-37

for tur crop varities Daftari, Maruti IPC-8863, Ankur-Charu and BSMR-736 were 3.6, 3.7, 3.8 and 3.6 respectively.

Regression analysis of data

Regression analysis allows us to make predictions by determining the kind and strength of the relationship between two or more variables (Jhajharia *et al*., 2023). Therefore, correlation analysis was performed between crop production and crop residue generated assuming a linear regression model as shown in Fig 4, Fig 5 and Fig 6. We can predict the surplus biomass waste produced by agricultural activities by establishing the link between crop yield and residue formed since crop production data for all areas is readily available. For each farm values of crop residue generated were compared with values of crop yield considering crop production as an independent variable and crop residue as

Table 6: Properties of agricultural soil.

Properties	Observation		
Chemical properties	Farm 1	Farm 2	Farm 3
pH	7.63	7.74	7.42
Salinity (EC) mili seimens/cm	0.164	0.158	0.178
Organic curb percent	0.29	0.26	0.23
Available phosphorus P_2O_5 (kg/Ha)	36.12	24.38	28.90
Available potassium K_2O (kg/Ha)	360	325	308
Containing calcium percentage	62.78	59.34	67.08
Containing magnesium percentage	10.08	11.16	8.82
Containing sodium percentage	8.74	10.13	7.04
Percent free lime	5.47	5.43	5.43
Physical properties			
Maximum water holding capacity	81.30	59.48	73.88
Apparent density	0.76	0.68	0.89

Table 7: Model coefficients-cotton, soybean and tur crop residue.

Cotton	Predictor	β	t	p	r^2	F	p	r
	Production	0.947	17.21	<.001	0.897	296	<.001	0.947
Soybean	Predictor	β	t	p	r^2	F	p	r
	Production	0.912	12.935	<.001	0.831	167	<.001	0.912
Tur	Predictor	β	t	p	r^2	F	p	r
	Production	0.939	15.868	<.001	0.881	252	<.001	0.939

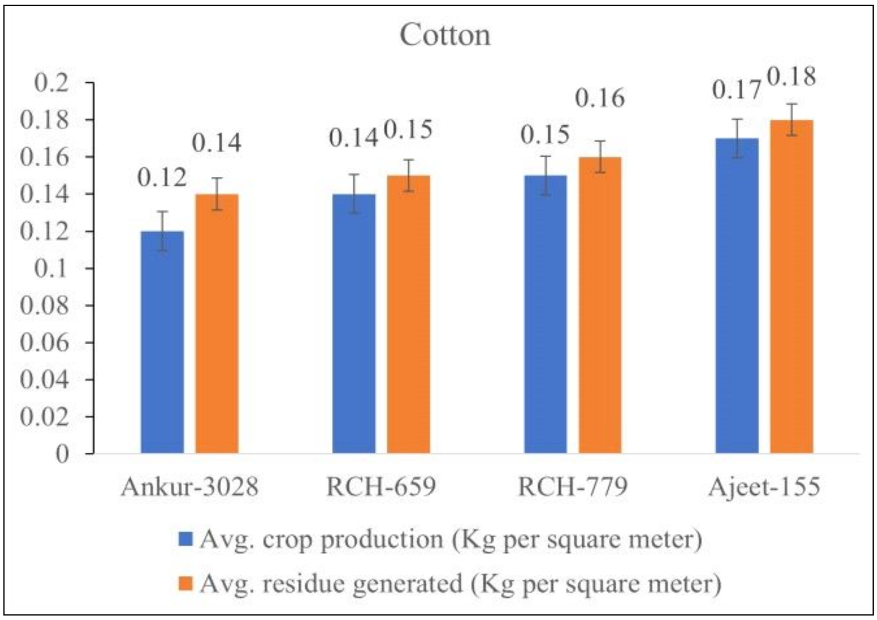

Fig 1: Average cotton crop production and residue generated.

a dependent variable. To analyze the performance of each relationship, the coefficients of determination R^2 were computed, along with the corresponding p-value to indicate its significance.

Regression analysis has indicated that crop production is a significant predictor of crop residue in cotton, soybean and tur crops (β=0.947, β=0.912, β=0.939, respectively). Coefficients of determination from Table 7 (r^2=0.897, r^2=0.8276, r^2=0.88, respectively) showed that variation of crop production can explain 89%, 83% and 88% variation in crop residue of each cotton, soybean and tur crop, respectively. The linear regression models are adequately fit since F=296, F=167 and F=252 for cotton, soybean and tur crop, respectively and all p values are <0.001. This shows that crop production is a reliable predictor for crop residue, with a high degree of accuracy.

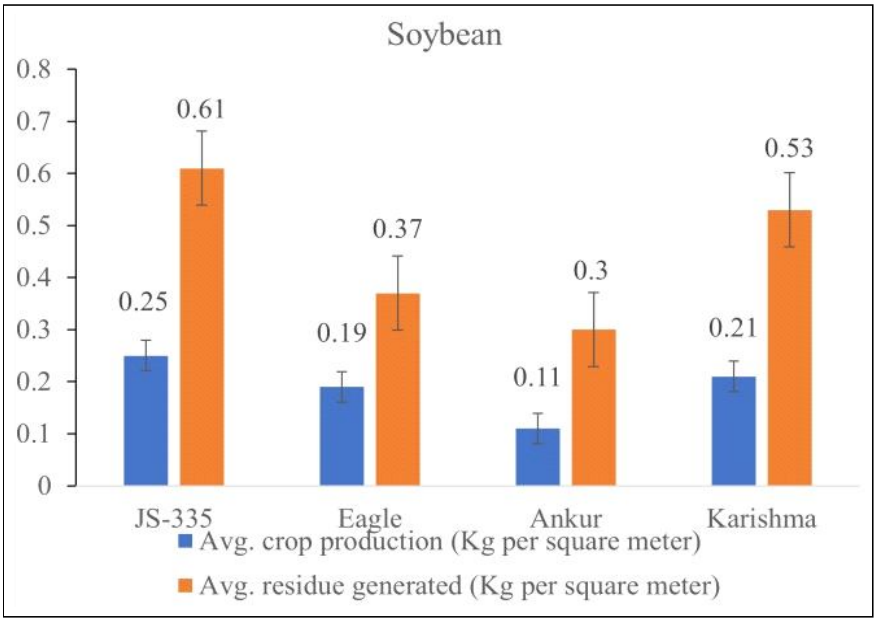

Fig 2: Average soybean crop production and residue generated.

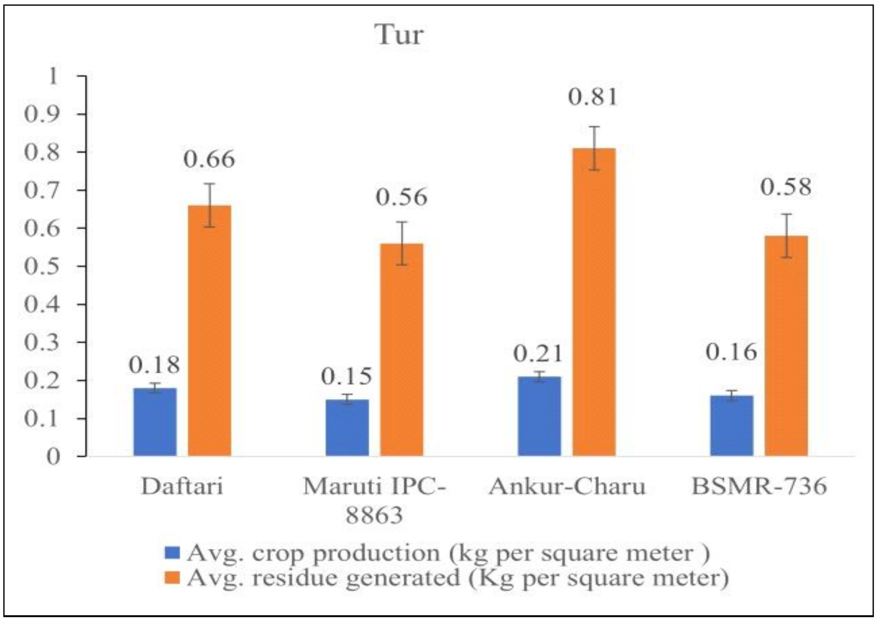

Fig 3: Average tur crop production and residue generated.

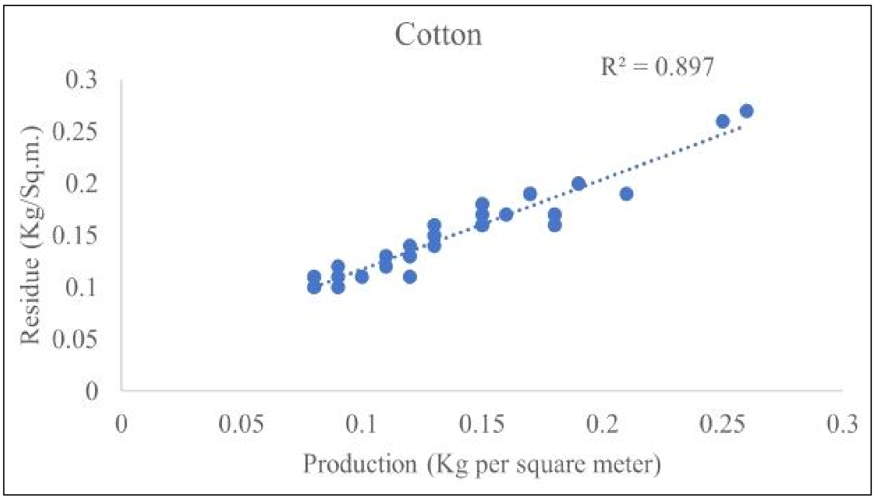

Fig 4: Linear regression model for cotton crop.

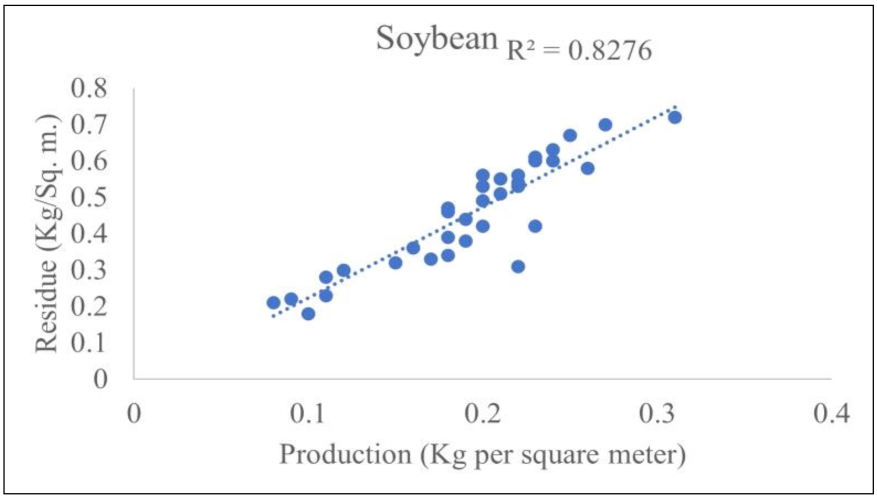

Fig 5: Linear regression model for soybean crop.

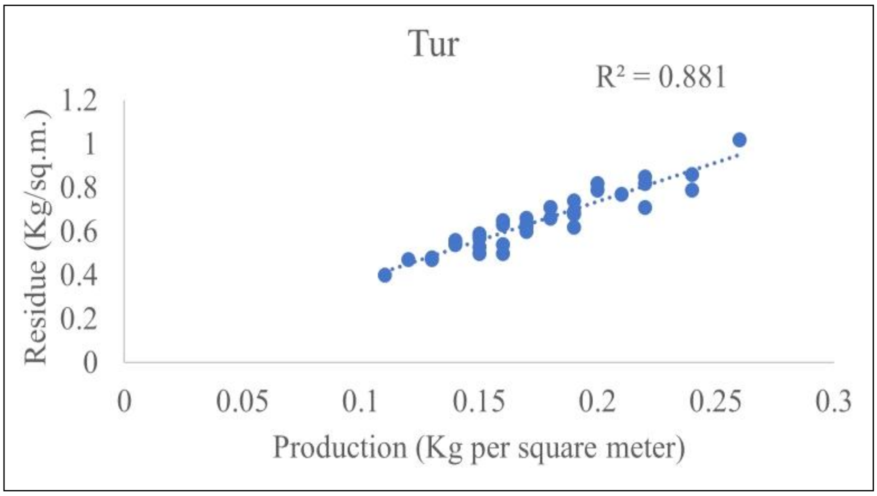

Fig 6: Linear regression model for tur crop.

Conclusion

In order to investigate local excess biomass, current study calculated the crop residue produced by cultivating four distinct cotton, soybean and tur crop varieties. The maximum residue to product ratios for cotton, soybean and tur crop were determined in order to gain an understanding of the surplus residue generated. It will facilitate the decision-making of farmers during crop cultivation. The highest yield and residue are produced by cotton variety Ajeet-155, soybean variety JS-335 and tur variety Ankur-Charu. Regression analysis indicates that crop production is a significant predictor of crop residue for each of these crops and linear regression models have been found to be a reliable predictor of crop residue with a high degree of accuracy. Overall, India could use its agricultural biomass to make a major contribution to the global biomass market.

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Conflict of interest: None.

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