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EXPLORING OPTIMAL CEREAL CROP SEQUENCE USING CULTIVATED LAND UTILIZATION INDEX AND YIELD IN KATIHAR DISTRICT, INDIA: A SUB DIVISION LEVEL ANALYSIS

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ABSTRACT

The present study attempts to identify the suitable crop sequences in an agriculturally productive district of Bihar, India. Rice-rice-vegetables, rice-maize-rice, rice-maize-maize, rice-maize-jute, rice-pulse-rice, rice-pulse-jute, rice-pulse-potato, and maize-maize-rice were found to be the suitable crop sequences in the area under study. Findings revealed that most of the blocks were found suitable for suggested crop sequences, while only two blocks (namely Balrampur and Barsoi) showed low potential in the rice-maize-rice sequence. Use of farm machinery, application of efficient farm inputs, and irrigation is required to maximize the yield and achieve long-term agricultural sustainability in this district.

Contribution/ Originality

This study intends to identify the suitable cropping sequence for achieving a long-term sustainability in agriculture, in the Katihar district of Bihar, India. This study tried to establish the relationship of yield with cultivated land utilization index (CLUI), soil bulk density, and NPK, for suggesting suitable crop sequence for sustainable agricultural development in the district.

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1. INTRODUCTION

Agriculture has always been an important source of livelihood to the rural masses in India. Increasing population pressure on resources has been a barrier to achieving agricultural sustainability, especially in rural areas. Identification of suitable crop sequence and efficacious measures to increase agricultural yield, is necessary for sustainable agricultural development. Agriculture has gone through many stages over time. It does not only provide livelihood, but also plays a key role in the manufacturing and industrial sectors (Sajjad *et al.,* 2014). Agriculture has made rapid strides over the years, and many countries like Russia federation, India, China, Brazil and Indonesia, have started participating in international agricultural markets. Export of agricultural commodities in these nations have increased from 9.4% to 20% between 2000 and 2015. A similar pattern was also observed in imports (FAO, 2018). However, at the same time agriculture has also been affected by urbanization, industrialization and climate change. The reducing level of GHGs, has also increased conflict for land and water resources (FAO, 2017). Nearly 33% farms in dry lands have been highly degraded affecting overall livelihood, health of the ecosystem, food security and impoverishment of farming communities, globally (FAO, 2014). Hence, achieving agricultural sustainability with less resource intensification is a great challenge, particularly for developing countries like India. Fulfilling the demand of 10 billion people for fibre, fuel and food by 2050 is a difficult task. For achieving long-term sustainability in agricultural production, it must be grown at an average rate of 1.75% by 2050 (Global Agricultural Productivity Index, 2018). It is also anticipated that food demands would reach 60% by 2050. Therefore, effectual farming practices are essential to make production sustainable (Liebisch *et al.,* 2014).

Characterization of farming system refers to the assessment of nature and traits of farming system, in terms of inputs like irrigation, fertilizers, high yielding variety of seeds, insecticides, pesticides, land use and quality of soils, etc. It is also essential to assess the cropping pattern, crop combination, crop intensity, crop diversification, utilization of cultivated land and yield, when suggesting long term sustainability of agricultural systems. Characterization of a farming system is significant, especially in a diversified farming system. Adoption of new techniques play an important role in achieving such characterization (Timler *et al.,* 2014). Indian agriculture has experienced tremendous changes in the previous century. Increase in food production exceeded the population growth since in the 1960s (Sajjad *et al.,* 2014). Earlier, the emphasis were laid on ensuring self-sufficiency in production, which was somehow achieved. This massive production resulted to various socio-environmental implications, ranging from social lamentation to degrading land and natural resources (Abrol and Sangar, 2006). The size of most of the landholdings in India are small, resulting to meagre income of the farmers. Of the total landholdings, nearly 86% of the farmers belong to the small and marginal farmers' category (Iqbal, 2018). Characterization of farming system requires assessment of land use/land cover modification. Land cover transformation affects fallow cycles, cropping pattern, crop rotation, etc. The main features of land cover modification are increasing land use production and intensification of land use. This land intensification has direct impact on cropping intensity which simultaneously helps in understanding the relationship between natural resources, people and sustainable land resource management (Zhang and Li, 2016). Agricultural sustainability at farm level can be helpful in creating a holistic perspective of ecological, social and economic development (Sajjad and Nasreen, 2016).

Cropping pattern, cropping system and cropping intensity are significant parameters of farming system characterization, determined by the climate, soil, nourishment and other farm level components (Das, 2006). Land holdings and regional characteristics, determine the cropping pattern as monoculture, mixed cropping, double cropping and sequential cropping. Farmers with less land holdings are vulnerable to climate change, fragmentation of land, and lesser earnings. Diversified mixed cropping can significantly minimize the vulnerability of farmers, by improving the crop yield and derived benefits (Amejo *et al.*, 2019). Cropping intensity is mainly defined as the ratio of output and input in an agricultural system (Ruiz-Martinez *et al.*, 2015). Assessment of cropping intensity will also help in attaining agricultural productivity, while maintaining the sustainability of the environment (Fan *et al.*, 2014). It is generally believed that agriculture may lead to environmental problems, which is not usually the case. Prudent agricultural activities can significantly provide solutions to various environmental problems, but monitoring has several implications. However, agricultural monitoring is more difficult than other economic sectors (Dumanski and Pieri, 2000). Various scholars have examined agricultural intensity in terms of single components like micronutrients (Kleijn *et al.*, 2008; Overmars *et al.*, 2014) and pesticides (Ruiz-Martinez *et al.*, 2015). Several consensuses among scientific studies were made to characterize the farming system (Hess and Hoskinson, 1996; Van *et al.*, 2010; Alemu, 2016). Bembridge (1987) analysed the various constraints of a farming system namely, unscrupulous inputs, technological barriers and small landholdings. Knowledge of crops with adequate technological support were identified as the two important determinants of a crop farming system.

Remote sensing data is playing an important role in identifying the cropping types, cropping intensity and plant phenology at various scales (Fan *et al.*, 2014). Geospatial techniques have emanated as significant tools to prepare spatial inventory of cropping pattern, land use characteristics, examining the biophysical characters and land resources (Choudhury *et al.*, 2006). Various indices obtained from high resolution satellite data as leaf area index (LAI), leaf water content (LWC), canopy cover (CC), plant chlorophyll content and normalized difference vegetation index (NDVI), etc. can help in identifying inherent cropping characteristics (Liebisch *et al.*, 2014). Chatterjee *et al.* (2015) characterized the farming system and farm typology, using multivariate statistical, cluster and principal component analyses. They emphasized that identification of farm typology may significantly reduce the problems of farmers and can be indelible to provide better livelihood opportunities. Assessment of soil and land use characteristics are indispensable for increasing the productivity. NDVI and assessment of ground cover derived from satellite data, provides empirical information regarding the land and soil quality (Sheffield and Morse-McNabb, 2015). Land suitability is carried out when assessing the sustainability of agriculture. It is focused on the assessment of the potentiality of land, for specific utilization (Jamil *et al.*, 2018a). Zhang and Li (2016) examined the agrarian land use intensity of varied characteristics using principal component and energy analyses in Beijing, China. Jamil *et al.* (2018b) examined the cropland suitability through GIS based multi-criteria decision-making, using site-specific parameters in the Bijnor district of Uttar Pradesh, India. Singh *et al.* (2013) characterized the farming system in southern arid lands of Rajasthan, using field derived samples. They identified that lack of farming techniques and planting methods hindered the farming efficiency. Sajjad *et al.* (2014) examined the spatial and temporal variability of agricultural sustainability in the Vaishali district, using sustainable livelihood security index (SLSI) at block level. Bio-intensive farming requires appropriate cropping pattern, techniques and agricultural inputs in order to maintain the output sustainability. Sajjad and Prasad (2014) evaluated the crop diversification in the Jalandhar district of Punjab, India using the Gibs and Martin index. They identified that, declining crop diversification may affect farmers' income, nutrients, natural resources and ground water, etc. Rajbhandari (2011) evaluated the efficiency and relationship among land utilization index (LUI), rotational intensity and yield efficiency for analysing the bio-intensive farming system.

Katihar is a district of Bihar in India, known for its agricultural productivity and yield. Agriculture is the mainstay of the economy, and provides livelihood to the rural masses. Analysis of present cropping pattern, is essential in suggesting alternate crop-based farming systems. Thus, this study intends to characterize crop farming, based on the land utilization index. This study also tried to examine the relationship between cultivated land utilization index (CLUI), soil bulk density, NPK and yield, in suggesting a suitable crop sequence for sustainable agricultural development.

1.1. Study area

Katihar is a district in Bihar, India covers an area of 3057 km^2 lies between 25°13' to 25°53' north latitudes and 87°12' to 87°04' east longitudes (Figure 1). The district comprises 16 blocks (administrative division of the district). It relishes a warm temperate climate with three distinct seasons winter, summer and rainy seasons. Average temperature and rainfall of the district is 24 °C and 1281 mm. Monsoon showers take place during June to September which leads to increase in water level up to 50 times higher causing devastating floods. Numerous tributaries of *Kosi* and *Mahananda* Rivers flow across the study area. Major soils in the district are Haplic Fluvisols, Stagnic Cambisols, Fluvic Cambisols, Haplic Cambisols, Endogleyic Cambisols and Haplic Arenosols (Reza *et al.*, 2017). Nearly 2.41 lakhs people reside in the district. Agricultural population comprises nearly 11279 and marginal workers around 13049 (Census, 2011). Agriculture is the major source of livelihood to the rural masses as this district lies in Mid Gangetic plane region of agro-climate zone. Of the total area of district (291 ha) nearly 146 ha are cultivable and 39 hac are non-agricultural lands while 10 ha came under miscellaneous tree crops and groves, 22 ha under barren and uncultivable and 1.7 ha area came under forest (Agriculture Contingency Plan for District, 2012). Katihar is one of the agriculturally advanced districts of Bihar in India. The farmers grow crop during all the three seasons (*Rabi*, *Kharif* and *Zaid*).

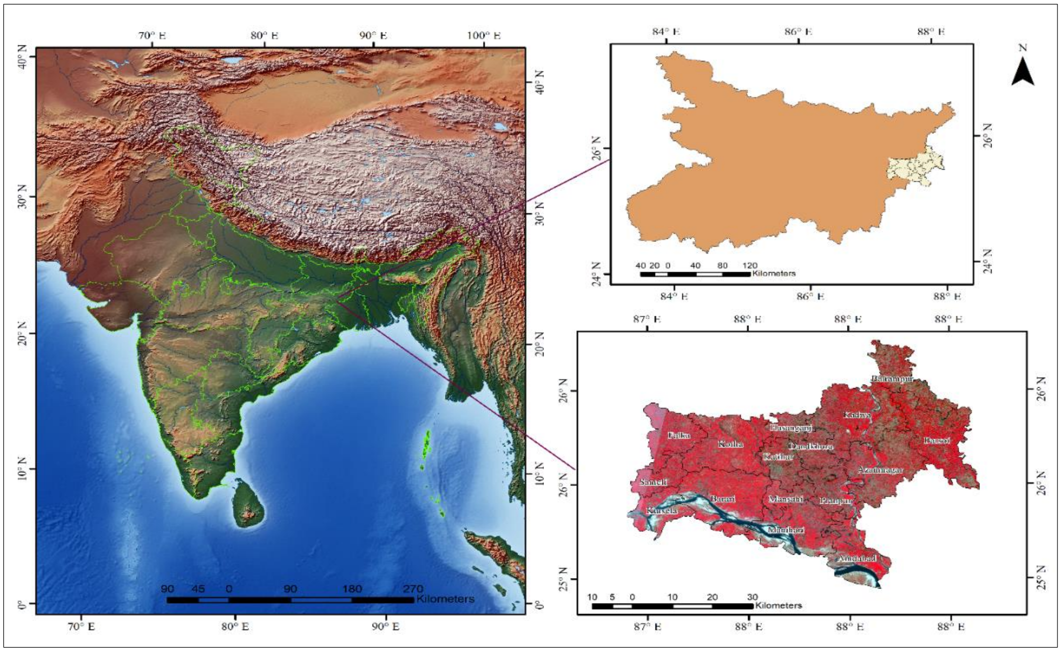

Figure 1: Location map of the study area

2. METHODOLOGY

For identifying the land use under agriculture, land use/land cover map was prepared from Sentinel 2A data through supervised classification. Cropping pattern was identified using Sentinel 2A data and verified with GPS locations. Maps of cropping pattern in *kharif* (rainy season crop), *rabi* (winter season crop) and *Zaid* (short season between *kharif* and *rabi* seasons) seasons were used to examine the crop sequence in the study area.

Cultivated land utilization index (CLUI) is essential for assessing the utilization of efficiency and designates where the land is being utilized. It is generally represented in percentage or fraction. If the value of CLUI is 1 it shows that the land is fallow if it is more than 1 then it represents the relay and intercropping (Rana and Rana, 2011). CLUI assists in identifying the cropping sequence and to increase the land productivity for agriculture (Panigrahy *et al.*, 2005). Block wise CLUI was calculated to identify the land utilization in *kharif*, *rabi* and *Zaid* seasons as:

$$CLUI = \frac{a_1 b_2}{A \times 365} \times 100$$

Where, $a1$ refers to area occupied by ith crop, 1,2 is the total number of crops, A is the total cultivated land area available for 365 days.

Relationship of yield with soil bulk density, nitrogen, phosphorus and potassium (NPK) and irrigation was determined to distinguish the suitable cropping sequence in the study area. The detailed methodology is presented in Figure 2.

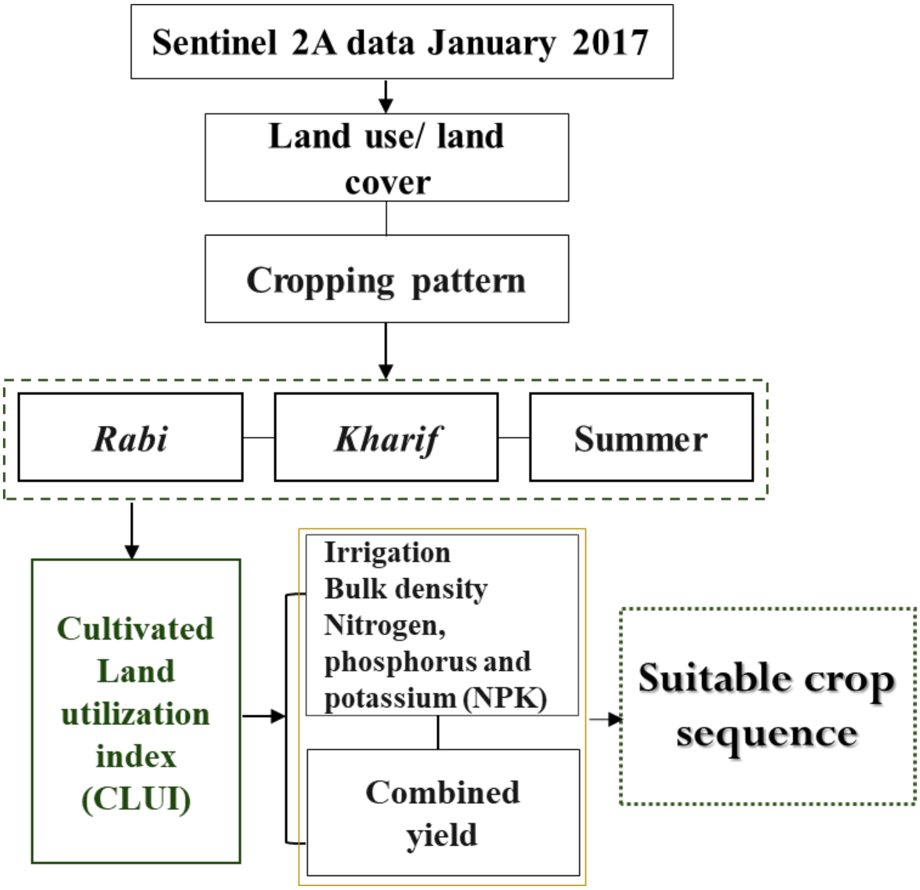

Figure 2: Methodological framework of the study

3. RESULTS AND DISCUSSION

Of the total geographical area (183160 hectares), nearly 60% is under agriculture including fallow land (Table 1 and Figure 3). Not all the area under agriculture is utilized in all the seasons because of low rainfall and non-availability of irrigation. Nearly 133939 ha is utilized for agriculture during *Kharif* season, 119910 ha during *Rabi* season and 128574 ha in *Zaid* season. Largest area under agriculture is utilized during *Kharif* season mainly due to monsoon rainfall.

Table 1: Block wise area under various classes of land use/land cover in Katihar district (2017)

Block	Area in Ha						
	Agricultural & fallow land	Built-up Land	Plant/Forest	Scrub and Grass	Wetlands	Rivers	Total
Azamnagar	16460	3170	3600	2630	1230	1420	28500
Amdabad	10420	3100	1440	1040	490	3700	20200
Barari	20940	3560	2280	1430	750	3890	32900
Balrampur	9500	2700	2090	1550	720	1120	17700
Barsoi	19200	2350	2860	1790	950	1000	28200
Dandkhora	4600	1210	1280	1000	450	520	9100
Falka	11440	580	2450	1490	810	150	16900
Hasangunj	3890	930	850	680	290	400	7100
Kadwa	20960	3350	3990	2560	1340	1650	33900
Katihar	5890	1710	1300	1080	460	610	11000
Korha	21980	1160	3210	1930	1060	580	29900
Kursela	6520	2360	800	530	260	2310	12800
Manihari	12020	4340	2050	1330	690	4310	24700
Mansahi	5040	640	900	620	300	420	7900
Pranpur	7690	1950	1930	1370	670	1740	15300
Sameli	6610	370	1280	810	430	150	9600
Total	183160	33480	32310	21840	10900	23970	305700

Source: Authors' own calculations based on Sentinel 2A data (January, 2017)

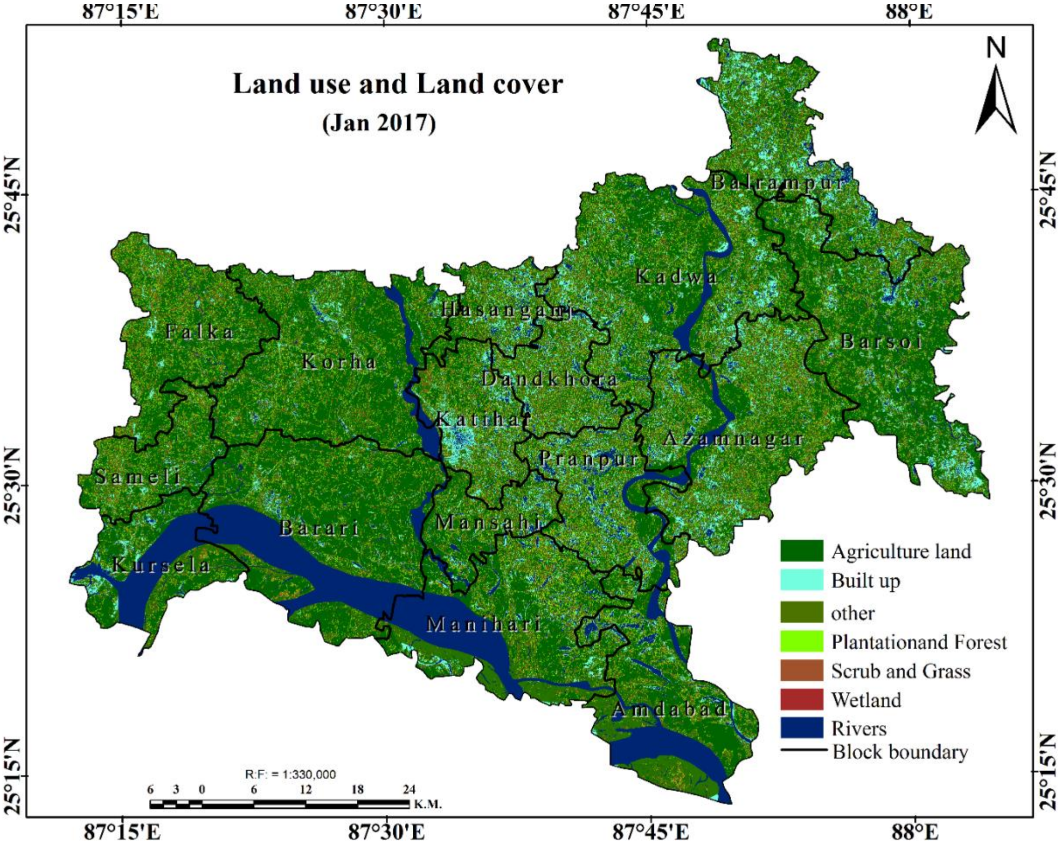

Figure 3: Land use/land cover of Katihar district (2017)

Major crops in the *kharif* season are rice, maize, pulses and vegetables (Figure 4A). Wheat, rice, maize, mustard, pulses, banana and vegetables are the dominant crops in *rabi* season in the study area while rice, maize, jute and pulses are important crops in the *Zaid* season (Figure 4B & C). Crop land utilization index (CLUI) is a measure to understand the availability of agricultural land for whole year. However, it also determines the land occupancy for crop during a particular season. Therefore, CLUI was calculated for both seasonal and annual cultivation practices (Table 2). For *Kharif* season high CLUI was found in Sameli, Pranpur, Mansahi, Korha, Katihar, Kadwa, Hasangunj, Dandkhora, Azamnagar and Balrampur blocks of the district. Falka, Amdabad, Manihari, Barari and Kursela blocks have recorded moderate CLUI while low CLUI was found in Barsoi. In *Rabi* season high CLUI was observed in Amdabad, Manihari and Pranpur blocks of Katihar district. Moderate CLUI was found in Barari, Kadwa, Mansahi, Kursela, Korha, Dandkhora and Hasangunj blocks while Falka, Sameli, Azamnagar, Balrampur, Katihar and Barsoi blocks have experienced low CLUI in Rabi season. High CLUI in *Zaid* season was found in Pranpur, Balrampur, Azamnagar, Dandkhora, Hasangunj, Kadwa, Amdabad, Katihar and Barsoi blocks of the districts. Moderate CLUI was observed in Mansahi, Manihari, Falka, Sameli and Korha blocks while low CLUI was found in Barari and Kursela blocks. High annual CLUI was found in Pranpur, Amdabad, Dandkhora, Kadwa.

Table 2: Block wise cultivated land utilization index during different seasons in Katihar district

Blocks	Kharif		Rabi		*Zaid*		Annual	
	Net shown	CLUI	Net shown	CLUI	Net shown	CLUI	CLUI	Crop Intensity
Azamnagar	14297.50	0.26	8448.00	0.14	15432.00	0.30	0.73	245.08
Amdabad	5873.00	0.17	8584.00	0.22	8506.00	0.26	0.78	264.01
Barari	15476.50	0.22	15958.00	0.20	7141.00	0.11	0.62	210.31
Balrampur	9474.90	0.30	4934.00	0.14	9302.00	0.31	0.74	249.85
Barsoi	2250.80	0.04	8977.00	0.13	14499.00	0.24	0.66	222.27
Dandkhora	4434.60	0.29	2887.00	0.17	4348.00	0.30	0.76	257.28
Falka	5181.60	0.14	6666.00	0.16	7226.00	0.20	0.66	221.43
Hasangunj	3863.50	0.30	2531.00	0.17	3244.00	0.27	0.74	248.46
Kadwa	17575.40	0.25	15235.00	0.20	17448.00	0.27	0.76	255.93
Katihar	5830.00	0.30	3052.00	0.14	4515.00	0.25	0.68	228.47
Korha	19707.50	0.27	15133.00	0.18	12039.00	0.18	0.66	223.62
Kursela	4448.20	0.21	4654.00	0.19	1736.00	0.09	0.59	198.01
Manihari	8656.40	0.22	9463.00	0.21	7851.00	0.21	0.72	244.04
Mansahi	4575.10	0.27	3719.00	0.20	3534.00	0.22	0.72	243.91
Pranpur	7112.40	0.28	6058.00	0.21	7666.00	0.32	0.82	278.47
Sameli	5181.60	0.24	3611.00	0.15	4087.00	0.20	0.64	216.46
Total	133939.00	0.22	119910.00	0.18	128574.00	0.23	0.70	235.66

Source: Authors' own calculations based on Sentinel 2A data (January, 2017)

Balrampur and Hasangunj blocks. Moderate annual CLUI was found in Azamnagar, Manihari, Mansahi and Katihar blocks whereas Barsoi, Falka, Korha, Sameli, Barari and Kursela blocks have experienced low annual CLUI. From the above results it is very clear that CLUI in Katihar district is not homogeneous due to rainfall availability and irrigation potential. The farmers are bound to carry out their agricultural practices influenced by rainfall, flood, irrigation potential and land quality. Various crops are grown during *kharif* season in the district specially rice, maize, pulses and vegetables. Number of crops grown are more during *rabi* season than *kharif* due to variation in topography and flood which includes wheat, rice, maize, mustard, pulses and vegetables. Rice, maize, Jute, pulses and vegetables are dominant crops during *Zaid* season.

Crop sequence in a year was identified to suggest a suitable crop farming system in Katihar district. Maps of cropping pattern during different seasons were prepared using remote sensing data. Based on those thematic maps, crop sequence was identified and area occupied by those crop sequences was determined. Crop yield data of all blocks were used to identify the suitable crop sequences (Table 3). The combined average yield for three seasons of 150 q/ha was used as a lower margin for selection of crop sequences. In this way eight sequences were suggested for sustainable farming system. These sequences are rice-rice-vegetables, rice-maize-rice, rice-maize-maize, rice-maize-jute, rice-pulse-rice, rice-pulse-jute, rice-pulse-potato and maize-maize-rice. Yield and CLUI for these sequences were also calculated for every block in the district (Table 4 and Table 5).

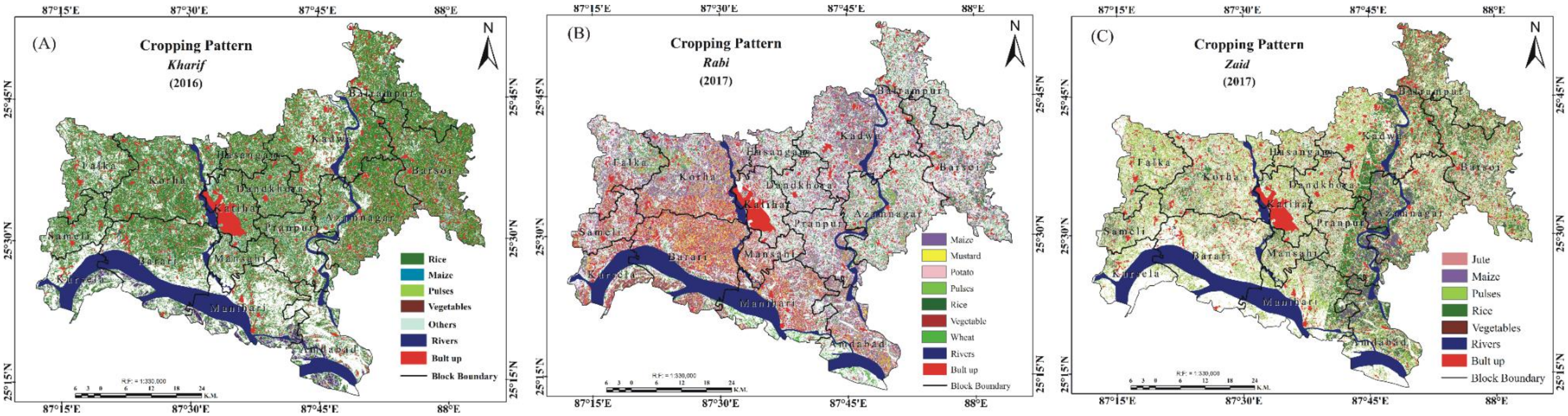

Figure 4: Cropping pattern in Katihar district: A) *Kharif* (during 2016), B) *Rabi* (during 2017) and C) *Zaid* (during 2017)

Table 3: Yield of crops during *Rabi, Kharif* and *Zaid* seasons in the study area

Blocks	Kharif Yields (Q/ha)				Rabi crop Yields (Q/ha)							Zaid Crop Yields (Q/ha)				
	Rice	Maize	Pulses	Vegetables	Wheat	Rice	Maize	Mustard	Pulses	Vegetable	Potato	Rice	Maize	Jute	Pulses	Vegetables
Azamnagar	32.67	92.86	7.72	150.52	28.89	47.65	133.45	12.35	8.47	188.1543	262.1055	24.7128	62.860	30.99286	8.09381	123.5235
Amdabad	25.57	0.00	8.92	144.68	25.32	40.54	137.57	14.27	9.67	180.8528	284.5717	26.2106	0.000	36.40361	9.29620	117.6823
Barari	22.64	84.73	6.05	135.33	21.33	34.41	0.00	9.68	6.64	169.1651	217.7081	23.5360	74.730	24.28692	6.34507	108.332
Balrampur	32.85	0.00	7.44	137.79	26.34	47.83	140.81	11.91	8.19	172.2408	247.1281	22.4662	0.000	29.74976	7.81757	110.7926
Barsoi	29.10	0.00	8.12	149.03	25.58	44.07	0.00	12.98	8.86	186.2821	256.8634	23.2151	0.000	32.77487	8.48982	122.0257
Dandkhora	23.20	92.97	4.90	108.27	19.68	34.97	106.78	7.84	5.49	135.332	209.4705	19.4172	72.967	19.11196	5.19507	81.26563
Falka	24.20	92.97	5.78	147.10	19.25	35.97	108.27	9.25	6.37	183.8751	250.0701	24.1244	62.967	23.07079	6.07482	120.1
Hasangunj	22.13	87.67	5.64	110.62	18.83	33.90	109.01	9.02	6.22	138.274	234.7717	19.1230	77.672	22.41599	5.92930	83.61923
Kadwa	21.21	84.73	6.15	112.97	18.41	32.98	107.97	9.83	6.73	141.216	247.1281	22.3592	74.730	24.71625	6.44047	85.97283
Katihar	20.30	82.20	6.95	135.33	17.99	32.07	106.78	11.12	7.54	169.1651	234.1833	17.6520	72.200	28.33721	7.24513	108.332

Korha	19.38	79.43	5.95	150.04	17.57	31.15	106.42	9.52	6.54	187.5526	323.6201	24.1244	73.434	23.82829	6.24315	123.042
Kursela	21.65	76.67	6.03	132.39	17.14	33.41	106.36	9.65	6.62	165.4875	264.7801	23.8302	66.669	24.1963	6.32493	105.39
Manihari	21.68	73.90	6.51	138.27	19.60	33.44	106.30	10.41	7.10	172.8426	294.2001	22.0650	63.903	26.34592	6.80262	111.274
Mansahi	20.93	71.14	6.35	140.04	20.44	32.70	106.24	10.16	6.94	175.0491	235.9485	21.1824	61.138	25.64016	6.64579	113.0392
Pranpur	22.03	68.37	5.90	112.38	20.90	33.80	106.18	9.44	6.49	140.4805	235.2424	20.5940	58.372	23.62025	6.76660	85.38443
Sameli	24.05	68.73	6.04	140.04	21.48	35.82	114.08	9.66	6.63	175.0491	289.4929	23.6537	58.725	24.22444	6.33118	113.0392
Total	383.59	1056.37	104.44	2144.81	338.75	584.71	1596.22	167.11	114.50	2681.02	4087.28	358.2662	880.3655	419.7156	110.0416	1712.815

Source: Authors' own calculations based on field survey (2016-2017)

Table 4: Block-wise yield of sequential crops in Katihar district

Blocks	Rice-rice-vegetable	Rice-maize-rice	Rice-maize-maize	Rice-maize-jute	Rice-pulse-rice	Rice-pulse-jute	Rice-pulse-potato	Maize-maize-rice
Azamnagar	176.91	173.83	211.98	180.11	315.49	321.77	298.87	238.02
Amdabad	169.46	179.34	153.13	189.54	336.35	346.54	319.43	153.78
Barari	156.51	178.99	230.19	179.74	265.89	266.64	248.70	239.08
Balrampur	164.11	53.32	30.85	60.60	300.45	307.73	285.80	22.47
Barsoi	174.34	52.31	29.10	61.87	309.18	318.74	294.45	23.22
Dandkhora	126.88	162.39	215.94	162.09	255.09	254.78	240.86	221.16
Falka	168.43	156.60	195.44	155.54	298.40	297.34	280.35	215.36
Hasangunj	127.87	153.26	211.81	156.55	279.03	282.32	265.83	215.80
Kadwa	137.35	187.34	239.71	189.70	298.50	300.86	282.58	243.05
Katihar	151.28	160.73	215.28	171.42	277.13	287.82	266.73	217.63
Korha	174.55	187.92	237.23	187.63	375.12	374.83	357.24	243.98
Kursela	155.57	166.54	209.38	166.90	314.96	315.32	297.45	216.86
Manihari	159.02	174.04	215.88	178.32	341.94	346.22	326.68	222.27
Mansahi	159.15	162.35	202.31	166.81	282.06	286.52	267.52	208.56
Pranpur	128.01	168.81	206.59	171.84	277.87	280.89	264.04	215.15
Sameli	160.74	175.79	210.86	176.36	337.20	337.77	319.87	220.46

Source: Authors' own calculations based on Sentinel 2A data (2016-2017)

Table 5: Block-wise cultivated land utilization index of identified crop sequence in Katihar district

Crop Sequence	Rice-rice-vegetable	Rice-maize-rice	Rice-maize-maize	Rice-maize-jute	Rice-pulse-rice	Rice-pulse-jute	Rice-pulse-potato	Maize-maize-rice
Azamnagar	0.90	0.90	0.90	0.90	0.82	0.89	0.92	0.74
Amdabad	0.90	0.90	0.90	0.90	0.82	0.89	0.92	0.74
Barari	0.89	0.89	0.81	0.81	0.82	0.89	0.92	0.74
Balrampur	0.92	0.92	0.82	0.82	0.92	0.92	0.82	0.82
Barsoi	0.88	0.88	0.74	0.74	0.88	0.88	0.74	0.82
Dandkhora	0.74	0.74	0.82	0.82	0.74	0.74	0.82	0.81
Falka	0.74	0.74	0.81	0.81	0.74	0.74	0.81	0.81
Hasangunj	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.82
Kadwa	0.74	0.74	0.82	0.82	0.74	0.74	0.82	0.74
Katihar	0.81	0.81	0.82	0.82	0.81	0.81	0.82	0.82
Korha	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.81
Kursela	0.74	0.74	0.89	0.89	0.74	0.74	0.89	0.74
Manihari	0.90	0.90	0.92	0.92	0.90	0.90	0.92	0.82
Mansahi	0.82	0.82	0.89	0.89	0.82	0.82	0.89	0.82
Pranpur	0.82	0.82	0.63	0.63	0.82	0.82	0.63	0.74
Sameli	0.82	0.82	0.67	0.67	0.82	0.82	0.89	0.74
Average	0.82	0.82	0.81	0.81	0.80	0.82	0.83	0.78

Source: Authors' own calculations based on Sentinel 2A data (2016-2017)

Relationship of yield and CLUI were analyzed through the graphical representation. The analysis helped to understand the production and land utilization (Table 6). Relationship of crop sequence yield with NPK, bulk density and irrigation was also analyzed to suggest suitable crop sequence.

Table 6: Correlation between crop sequence yield and supporting land resources

Crop Sequence	Coefficient of correlation (R^2)			Average Production (Q/ha)
	NPK	Bulk Density	Irrigation	
Rice-rice-vegetable	0.167	0.0159	0.0692	155.64
Rice-maize-rice	0.238	0.00003	0.0734	155.85
Rice-maize-maize	0.297	0.00007	0.092	188.48
Rice-maize-jute	0.0199	0.0003	0.0535	259.69
Rice-pulse-rice	0.2311	0.0469	0.2716	304.04
Rice-pulse-jute	0.0113	0.0431	0.2062	307.88
Rice-pulse-potato	0.0231	0.0521	0.2624	288.53
Maize-maize-rice	0.255	0.00002	0.0943	194.80

Source: Authors' own calculations based on field survey (2016-2017)

Rice- rice-vegetable sequence will be suitable in Korha and Falka blocks due to low CLUI and high yield (Figure 5). Rice-maize-rice was found suitable in Kadwa and Korha blocks (Figure 6). However, Balrampur and Barsoi have very low potential for this crop sequence. Rice-maize-maize, rice-maize-jute and maize-maize-rice were not suitable crop sequences except Korha block which has some potential in these sequences (Figure 7, 8 & 9). Rice-maize-jute will be more beneficial in Pranpur and Sameli blocks (Figure 8). Korha block has more advantage for rice-pulses-rice, rice-pulses-jute and rice-pulses-potato sequences (Figure 10, 11 & 12). In terms of productivity and CLUI maize-maize-rice sequence will be beneficial for Azamnagar, Barari, Kadwa, Kursela, Pranpur and Sameli blocks (Figure 9).

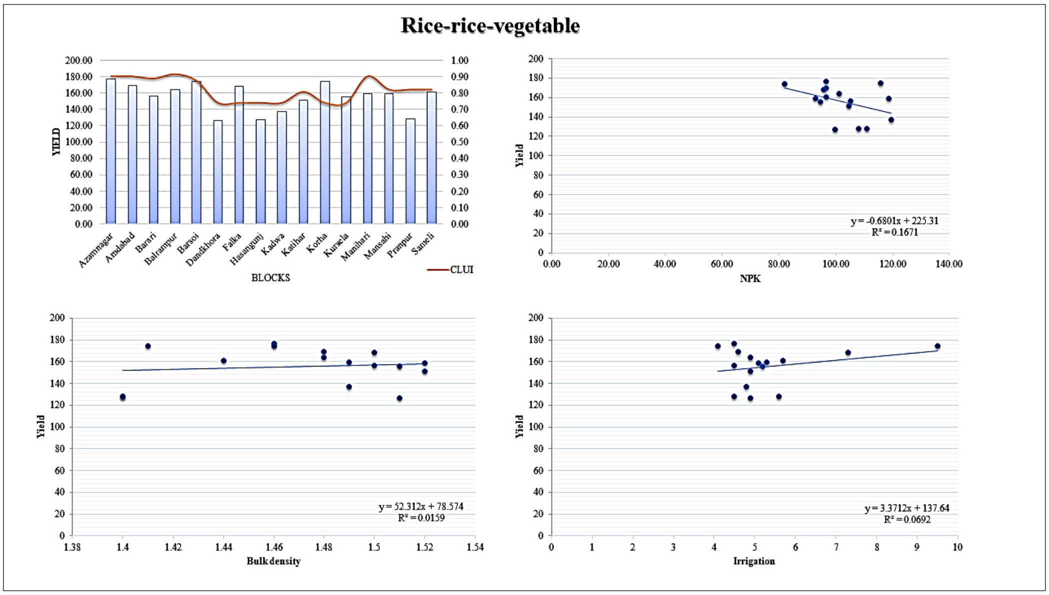

Figure 5: Relationship of yield with CLUI, NPK, bulk density and irrigation for rice-rice-vegetable crop sequence

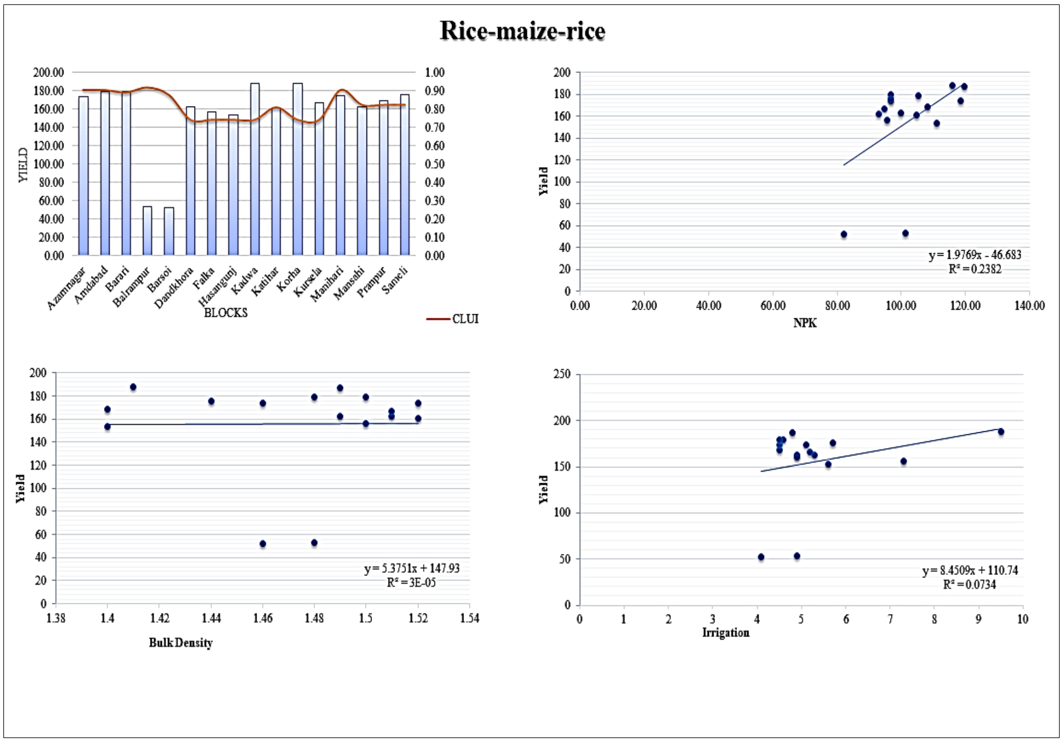

Figure 6: Relationship of yield with CLUI, NPK, bulk density and irrigation for rice-maize-rice crop sequence

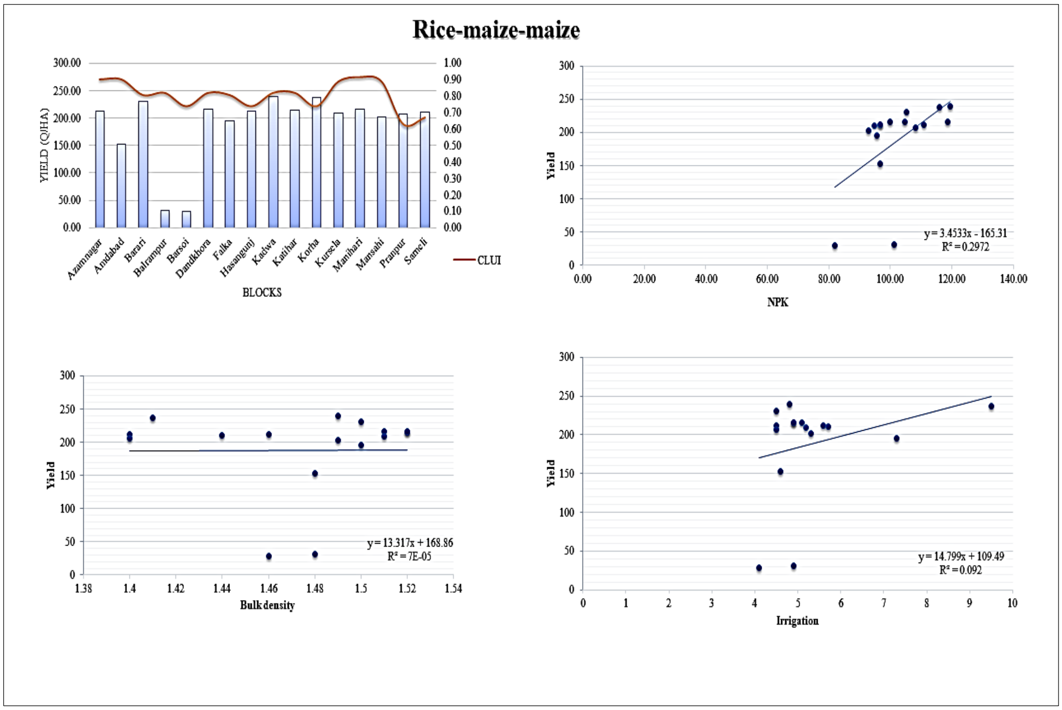

Figure 7: Relationship of yield with CLUI, NPK, bulk density and irrigation for rice-maize-maize crop sequence

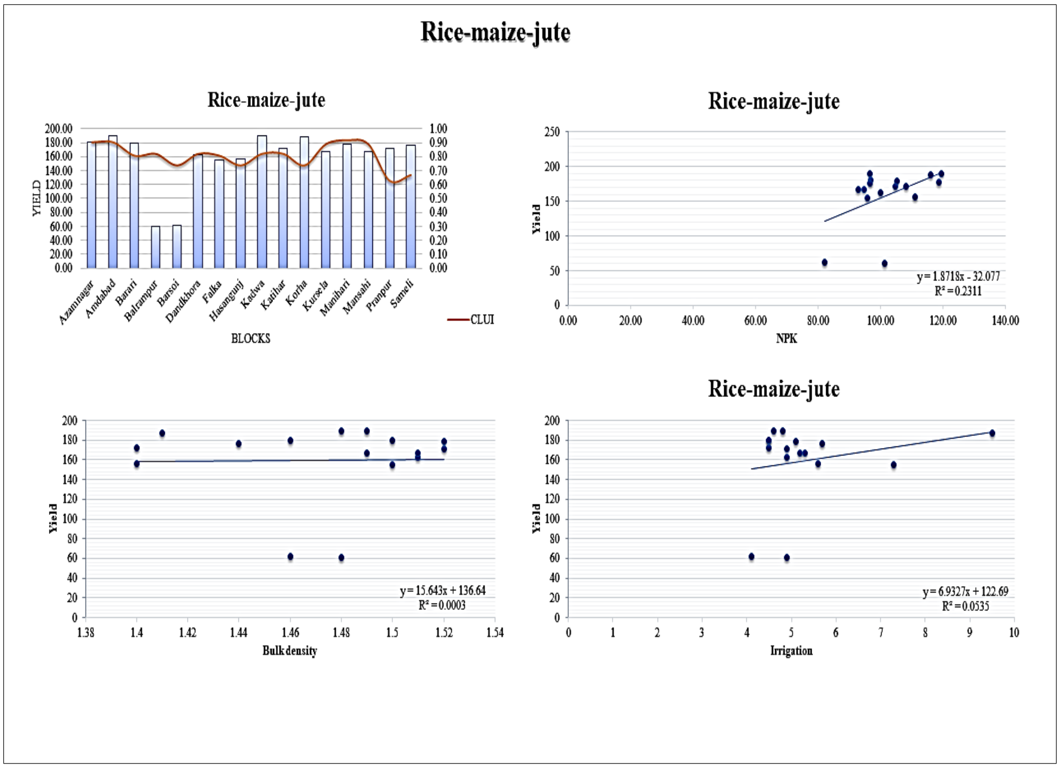

Figure 8: Relationship of yield with CLUI, NPK, bulk density and irrigation for rice-maize-jute crop sequence

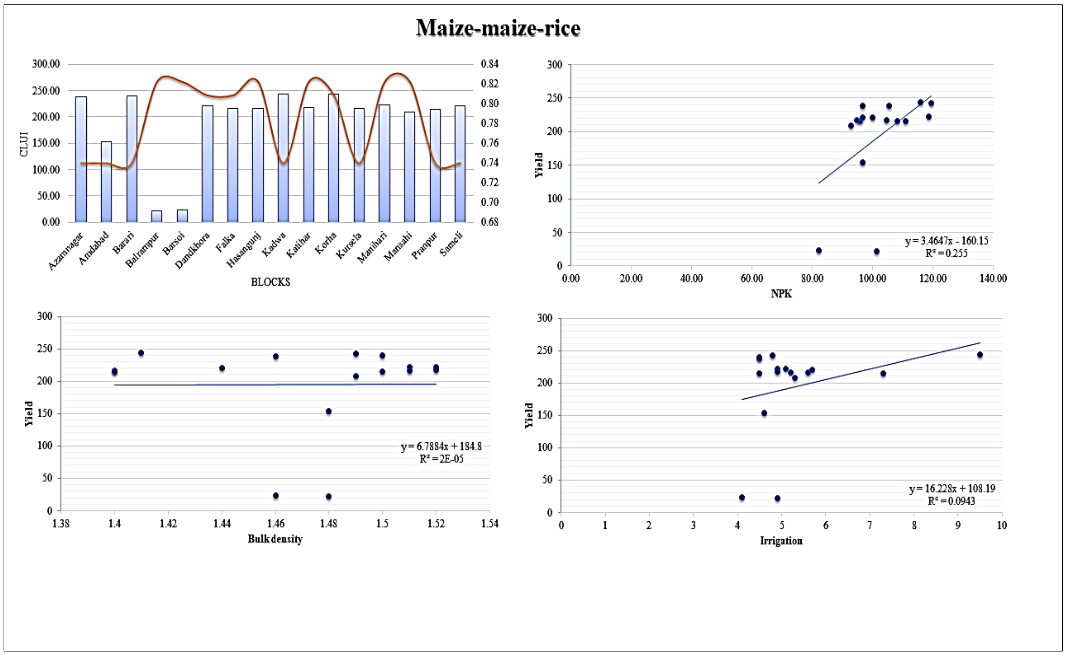

Figure 9: Relationship of yield with CLUI, NPK, bulk density and irrigation for maize-maize-rice crop sequence

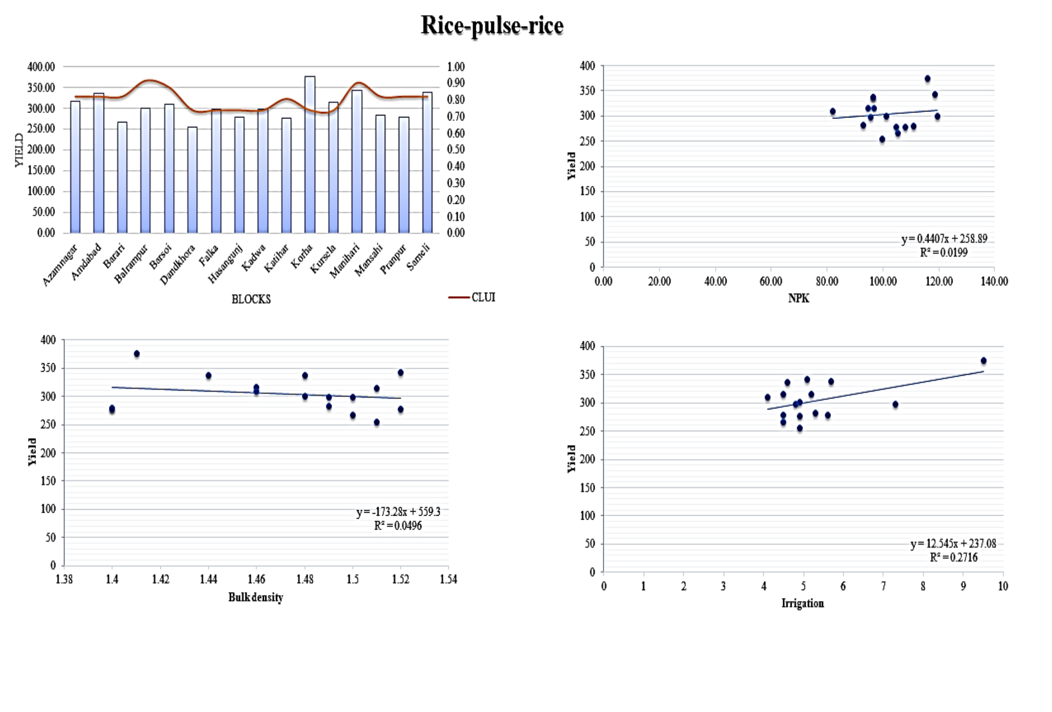

Figure 10: Relationship of yield with CLUI, NPK, bulk density and irrigation for maize-pulse-rice crop sequence

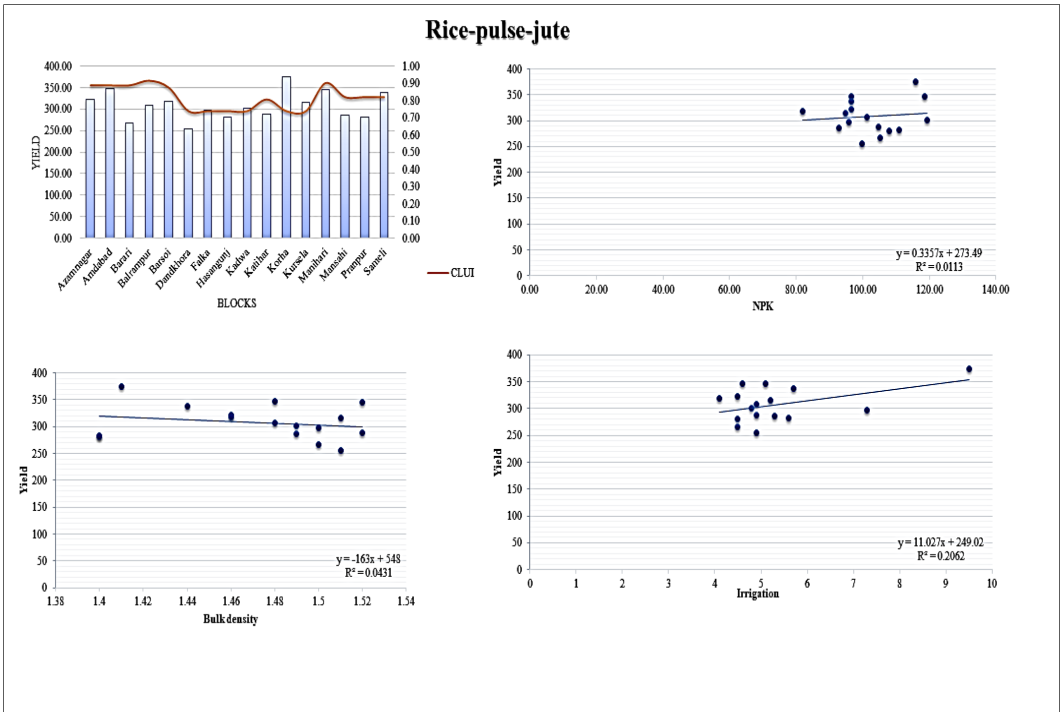

Figure 11: Relationship of yield with CLUI, NPK, bulk density and irrigation for rice-pulse-jute crop sequence

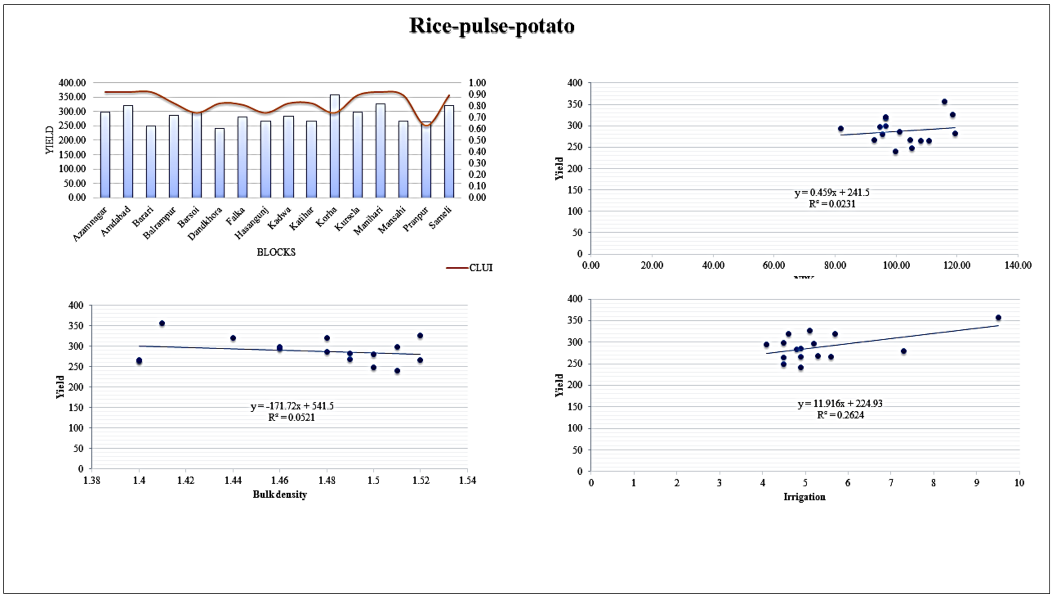

Figure 12: Relationship of yield with CLUI, NPK, bulk density and irrigation for rice-pulse-potato crop sequence

Korha has high potential for rice-rice-vegetable and rice-maize-rice. Rice-rice-vegetable is highly potential in Falka block. Kadwa block has high potential in rice-maize-rice sequence while Balrampur and Barsoi blocks have low potential in rice-maize-rice sequence. In rice-maize-maize crop sequence. Korha block has registered moderate potential in rice-maize-maize, rice-maize-jute, rice-pulse-rice, rice-pulse-rice, rice-pulse-jute and rice-pulse-potato sequences. Pranpur and Sameli blocks have high potential in rice-maize-maize. Azamnagar, Amdabad, Barari, Balrampur, Barsoi, Dandkhora, Falka, Hasangunj, Kadwa, Katihar, Kursela, Manihari, Mansahi and Pranpur blocks have registered potential in all sequence (Table 7). The scatter plots of NPK, bulk density and irrigation shows the relationship between yield and land resource potential.

The higher R^2 value shows the increasing yield with increase in land resource potential. However, lower R^2 value represents increasing yield with decreasing land resource potential. Therefore, in this study, the lower R^2 value is most desirable as it represents the high yield production in marginally available land resources like NPK, bulk density and irrigation. Crop sequence with maximum average yield found in the rice - pulses - jute followed by rice - pulses - rice, rice - pulse - potato and rice- maize - jute. However, rice -maize- jute (R^2 =0.02) is the most suitable sequence with low land resource potential followed by rice-pulse-jute (R^2 =0.09), rice-pulse-potato (R^2 =0.11) and rice-pulse-rice (R^2 =0.18). Based on the analysis of the study, the ranking of crop sequences for maximum production in Katihar district are rice-pulse- jute followed by rice -maize-jute, rice-pulse-rice and rice- pulse-potato. Jute is most suitable crop in flood inundated areas due to its resistance in flood. Rice is the prime food crop of the region and suitable for low laying areas. These crop sequence-based farming system will be more effective in the district due to their potential of maximum return with limited land resources. The production through these crop sequence may be increased from present condition with the use of farm machinery and fertilizers.

4. CONCLUSION

The study sought to determine a suitable crop sequence for sustainable agricultural development in flood-prone districts of Bihar in India. Sentinel 2A satellite data (2016-2017) was used to identify major land uses and cropping patterns for different agricultural seasons. A cultivated land utilization index was calculated to identify the period that land was under various crop sequences. A relationship was established between yield of crop sequences, NPK, bulk density, and irrigation. Rice-rice-vegetables, rice-maize-rice, rice-maize-maize, rice-maize-jute, rice-pulse-rice, rice-pulse-jute, rice-pulse-potato, and maize-maize-rice were found to be the suitable crop sequences for this area under study. This study revealed rice-pulse-rice as the most suitable crop sequence, followed by rice-pulse-potato, and rice-maize-jute in terms of average maximum yield. With low resource potential, rice-maize-jute was found to be the most suitable sequence, followed by rice-pulse-jute, rice-pulse-potato, and rice-pulse-rice. Balrampur and Barsoi blocks registered low potential in the rice-maize-rice sequence. In these blocks, effective farming techniques will play in important role in increasing the agricultural yield. In rice-maize-maize, rice-maize-jute, rice-pulse-rice, rice-pulse-rice, rice-pulse-jute, and rice-pulse-potato sequences, the Korha block registered moderate potential. However, the Azamnagar, Amdabad, Barari, Balrampur, Barsoi, Dandkhora, Falka, Hasangunj, Kadwa, Katihar, Kursela, Manihari, Mansahi and Pranpur blocks registered potential in all sequence. In these blocks, farm machinery is required to maximize the yield and achieve sustainability in agricultural productivity of the area under study. Efficiency in farm inputs, fertilizers, scrupulous irrigation, and maintenance of fallow cycles will help increase the overall productivity of the suitable crop sequences in the area under study.

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