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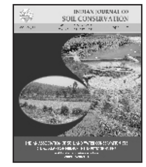

Impact assessment of land resource inventory towards optimizing land use plan in Brahmaputra valley ecosystem, Assam, India

Siladitya Bandyopadhyay[1,4], B.N. Ghosh[1], P. Ray[2], S. Ramachandran[2], R.K. Jena[2], P. Deb Roy[2], S.K. Singh[3], S. Mukhopadhyay[1], D.C. Nayak[1] and S.K. Ray[2]

[1]*ICAR-National Bureau of Soil Survey and Land Use Planning (NBSS&LUP), Kolkata – 700091, West Bengal;* [2]*ICAR-NBSS&LUP, Jorhat – 785004, Assam;* [3]*ICAR-NBSS&LUP, Nagpur – 440033, Maharashtra.*

[4]*E-mail: siladitya_555@yahoo.co.in*

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ABSTRACT

In the present investigation, it has been attempted to ascertain the impact of Land Resource Inventory (LRI) for evaluating bio-physically viable and economically acceptable alternate agricultural Land Use Plan (LUP) in Upper Brahmaputra Valley eco-system of Assam, India. The study area is situated in North West Jorhat Development Block, Jorhat district, Assam. Based on soil survey and satellite image database, 4 landforms, 10 land use/land covers, 18 Landscape Ecological Units (LEUs), 12 soil series and 8 Land Management Units (LMUs) were identified for management intervention in the study area. Soil-site suitability for crops was ascertained in each land management unit for specific crops grown in the region based on site and soil characteristics. The studies revealed significant impact of LRI on LUP in terms of crop productivity and net return. The average yield of crops, along with annual net returns and benefit to cost ratios increased by 108, 85.9 and 33% when LRI based LUP was employed with respect to traditional system of cultivation. The same were increased by 304, 249 and 87.9% when LRI based LUP was adopted with crop specific Customized Recommended Management Practices (CRMPs) based on the need of the local conditions. The present investigation unfolds a novel approach of LUP using LRI base LMU as a base and can be exercised in other parts of North Eastern states of India under similar agro-ecological environment.

1. INTRODUCTION

Soil is a natural resource (Baveye *et al.,* 2016) and hence it's detailed and real time information is very much required for developing to eco-system specific LUP (Robinson and Leborn, 2010). Henceforth, the importance of LRI can no longer be undermined since, it has become a prime need for optimizing agricultural LUP at site specific levels (Bocco *et al.,* 2001). The information derived from such large-scale LRI are highly useful for developing watershed and village-level sustainable agricultural LUP in India (Saxena and Prasad, 2008 and Walia *et al.,* 2010). Moreover, the novel LRI approach avoids the mapping risks as it deals with large scale mapping using latest and fine resolution imageries and thereby generate unique and detailed land mapping units (Srivastava and Saxena, 2004) without compromising any geomorphic information (Velmurugan and Carlos, 2009).

The concept of land management unit is a recent endeavour of its own kind describing the unique characteristics of a land parcel under similar bio-physical (climate, physiography, soil, land use and eco-system) and socio-economic environments (Bandyopadhyay *et al.,* 2017 and Ramamurthy *et al.,* 2015). The concept may be used for optimizing LUP at block level in a site specific mode. Successful agricultural technology implementation depends upon crop planning based on need based soil resource inventory which can respond similar soil and input management practices. Such models are highly accepted by the state agricultural and allied line departments for implementation of LUP at regional and local levels. It is felt from recent LRI based studies (Ramamurthy *et al.*, 2015 and Singh *et al.*, 2016) that LMU based LUP will be more rational and viable management options. Land management unit based suitability assessment of crops may lead to efficient and alternate crop planning in site specific mode. A fewer research attempts were made on land management unit based LUP in North East India (Bandyopadhyay *et al.*, 2015 and Baruah *et al.*, 2014).

The Upper Brahmaputra Valley Region is known as one of the most important rainfed eco-system in North East India (Bhowmick *et al.*, 1999). In spite of richness in bio-diversity, the agricultural productivity of the region is needed to be enhanced many-folds to meet the demand of the population (NRAA, 2012). The idea is made to evaluate the productivity in terms of increase in yield, net returns and benefit to cost ratios of the farmers thriving in the region for their better livelihood. It is important to ascertain the economic evaluation of LRI towards efficient crop planning for a given area and has not been worked out so far. However, impact assessment of the same has not either been studied elsewhere or sporadically exercised. The innovative idea of the present investigation is to evaluate the profitability in terms of net returns and benefit to cost ratios for the farmers thriving in the Upper Brahmaputra Valley Regions towards developing improved and farmers' need based crop planning.

Impact assessment of LRI based LUP is conceivably one of the novel attempts. The main intention of such study is to work-out the efficacy of LRI in terms of agricultural productivity and farmers' profitability. Besides, GIS based LRI with fine resolution imagery is considered as most authentic tool for soil resource mapping. Soil resource mapping using the concept of soil series in a smaller scale limits its wide application and also its impact assessment for crop suitability is controversial. Because, soil mapping at smaller scales (1:250,000) limits the scope of delineation of mapping units on a single soil series, rather, the association of two or more soils makes the map generalized and lacks site specific soil informations as well as the crop suitability options. Hence, the need of the hour is to generate soil resource information at mono-series level with phases of series as mapping units so that each mapping unit may be characterized for unique soil and site characteristics for better management interventions. Very fewer attempts have been made to assess the impact of large scale LRI (1:10,000 scale) for LUP (Ghosh *et al.,* 2018). Such impact studies are quite helpful in understanding the viability of LUP using various physical, soil and economic indicators. In this endeavour, land management unit approach appeared to be most scientific and accurate. The innovative idea using LMU which responded to similar management practices as a basis for LUP and its impact assessment. The impact of LRI towards LUP can be ascertained by evaluation of bio-physical and as well as socio-economic indicators in region specific mode. Crop performances under traditional system of a given area may be improved to a great extent by adopting the LRI based management strategies.

Considering the immense scope for agricultural diversification in Upper Brahmaputra Valley Regions of India, North West Jorhat development block of Jorhat district (Assam) was selected to represent the zone for conducting LRI programme. The present investigation has been formulated with the objectives to assess the impact of LRI towards optimizing agricultural LUP by taking a case study in Upper Brahmaputra Valley Region of Assam under rainfed eco-system.

2. MATERIALS AND METHODS

Study Area

The study area is situated as in North West Jorhat Development Block of Jorhat District of Assam, situated in the geographic extent from 26°35'N to 26°55'N Latitudes and 93°55'E to 94°15'E Longitudes and covering an area of 30, 700 ha (Fig. 1.). The general topography is flat with slope varying from 0-1% to 1-3%. Humid sub tropical climate prevails in the study area with mean annual rainfall of 1977 mm. The calculated mean annual soil temperature is 24.5^{0}C with mean summer soil temperature of 26.3^{0}C and mean winter soil temperature of 19.1^{0}C, respectively. The soil temperature regime is *Hyperthermic* and soil moisture regimes are *Udic* and *Aquic*. (Vadivelu *et al.*,

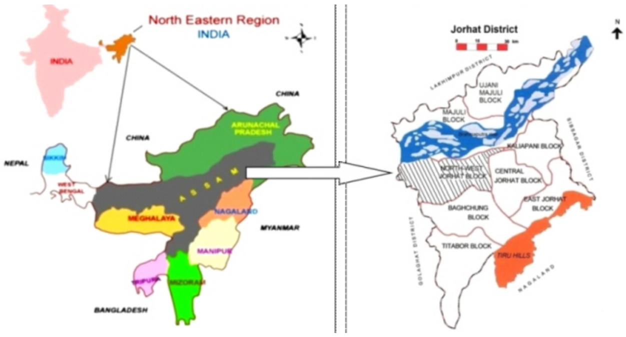

Fig. 1. Location map of the study area

2004[a]). The agro-ecological sub region is 15.4 (Upper Brahmaputra Valley Zone, hot, moist per-humid climate with length of growing period of more than 300 days) (Velayutham *et al.*, 1999 and 2000). The study area is under rain-fed system with rice-fallow and rice-rice cultivation under open sourced irrigation *viz.*, open well, scattered water bodies, structural ponds, drainage streams and rivulets of Brahmaputra (Statistical Handbook, 2015). The farmers often cultivate mustsard, *rabi*-pulses and *rabi*-vegetables in their homestead gardens. According to the legacy data, the study area comprises soils in Inceptisols and Entisols orders and soils are classified in the sub groups of *Typic Dystrudepts, Typic Eutrudepts, Typic Endoaquepts, Typic Endoaquents* and *Typic Udorthents* (Vadivelu *et al.*, 2004[b]).

Methodology of LRI

LRI based LUP pursues three basic steps. At the outset, detailed LRI on 1:10,000 scale (*i.e.* at block level) was conducted using Survey of India (SoI) toposheets (83 F/13, 14, J/1, 2) in conjunction with Resourcesat-2 Indian Remote Sensing Satellite (IRS) Linear Imaging Self Scanning Sensor (LISS-IV) cloud free full multispectral scenes with swath of 70 (2 scenes) (row-53; path-118; data captured dated November, 2014-January, 2015) and Resouecesat-1 Cartosat-1 stereo-pairs (Panchromatic image; data captured dated November, 2014) (6 scenes) as base maps (Fig. 2) (Srivastava and Saxena, 2004). Land use/land covers were identified and delineated through visual interpretation technique followed by ground truth verification in the field by intensive traversing (Gautama, 2006). The fine spatial resolution (5.8 m at nadir) of multi-spectral images of LISS-IV with wide swath coverage (70 km) helped in identifying the land use/land covers at length (1:10,000 scale). The spectral signatures were sharply

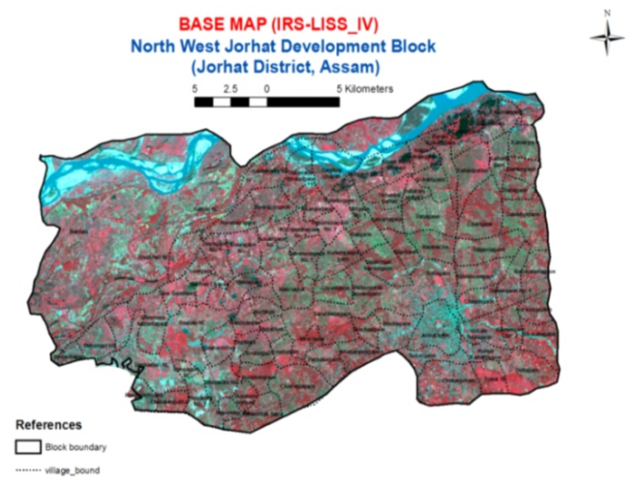

Fig. 2. Base map of the study area (IRS LISS-IV)

identified in 4-3-2 (RGB) band combinations using the variability in tone, texture, pattern, shape, size and association of land features. The SoI topographical sheets (1:50,000 scale) are used to demarcate permanent land features like roads, railway tracks, important locations, etc. in the base map, which helped in navigation during the progress of field level survey. Digital Elevation Model (DEM) was generated using Cartosat-1 stereo pair. Landform analysis was made using terrain analysis (slope, elevation, etc.) by spatial analyst tool using Cartosat-DEM as base, which helps in precise judgment of local topographic variability and hence, accurate delineation of landforms of the study area. LRI is dependent on soil-landform relationship. LRI is basically meant for developing sustainable agricultural LUP, which is dynamic and dependent on present climatic conditions and the prevailing soil forming process. Therefore, LEU, which represents agro-ecosystem as a whole, is preferred over landform as the basis of mapping. LEU is the assemblage of landform, slope and land use. Landform is the testimony of climatic events, whereas slope and land use represent the influence of present climatic conditions on the soil formation. It has been regarded as the base for conducting LRI (Singh *et al.*, 2016). GIS-overlay of landforms, slope and land use/ land covers was made using union-overlay operation by data management tool to obtain LEU. All the GIS operations were conducted using ARC-GIS software ver. 10.0. Both the transect and free surveys were conducted across the LEUs for delineating soil boundaries. Transects were selected in such a way so that each transect strip should cover maximum number of LEUs. The soil map of the block was finalized by examination of soil profiles in selected sites followed by field level soil correlation (Soil Survey Staff, 2003). The micro-level variability in slope and changes in surface texture and erosion status of soils were identified by intensive traversing of the LEUs for delineation of phases of soil series as ultimate soil mapping units.

Methodology of LRI based LUP

The concept of LMU has been introduced to bring out the mapping units to a meaning and manageable quantities so as to undertake management interventions (Annual Report, 2012-13 and 2013-14 and Ramamurthy *et al.*, 2015). The narrow ranges in soil characteristics are generalized by merging similar soils under broad ranges in characteristic under similar production/cropping system affecting the land use types for long term to develop unique LMU (Baruah *et al.*, 2014). The LMUs were obtained after rigorous exercise made by mapping unit generalization technique. Salient soil properties *viz.*, internal soil drainage (based on formation of mottles and redox depletions at variable soil depths), soil reaction, organic carbon, texture of soil control section (0-100 cm), flooding hazards, etc. were found as the major limiting characteristics of soils that affect greatly the changes in land use systems of the region. As a consequence, these characteristics were regarded as the critical indicators for obtaining LMUs. The soil series comprising broad similar properties of those indicators were grouped into one land management unit. Henceforth, from 23 soil mapping units (phases of soil series) effectively, 8 LMUs have derived through map generalization technique under GIS environment. These LMUs were considered for land suitability assessment for crop planning in the step way forward. Soil site suitability of the crops was evaluated for each LMU following the procedures of Sys *et al.* (1991 and 1993). Bio-physically suitable alternate crop combinations were identified for each LMU.

Economic analysis of LRI was carried out separately for all established LMU following Benefit: Cost (B:C) ratio and net return of the cropping system as indicator following the procedure evolved for assessing the bio-physical as well as socio-economic impacts of watershed by Sharda *et al.* (2005 and 2012). In the third step, basic crop performance parameters *viz.*, crop yield, B:C ratio and net return components were chosen as impact indicator. The crop performance data were collected primarily from farm level house-holds (average of five farmers) through Participatory Rural Appraisal (PRA). An exercise was carried out to evaluate economic performances of crops before and after soil survey (LRI) in all the eight LMU in three distinct systems *viz.*, (i) traditional or existing cropping systems, (ii) LRI based improved cropping system; and (iii) LRI based improved cropping system with customized management practices considering bio-physical suitability of land and as well as the socio-economic viability of the region. In order to avoid the large error of estimation in PRA procedure, these dataset were also crossed verified through District Contingency Plan (2012) and available secondary data sources from Agronomic Data Centre and Regional Agricultural Research Station (RARS) of Assam Agricultural University and local Krishi Vigyan Kendras (KVKs). To work out the crop performance each component parameters *viz.*, net return and B:C ratio of crops and cropping system (annual), were assessed for each land management categories based on dataset finalized through PRA and District Contingency Plan (Joshi *et al.*, 2005). The minimum support prices of GoI in respective years were considered as sale price of the produce for estimation of gross benefit. The net return was evaluated as benefit minus cost of cultivation and B:C ratio by division of benefit with cost of cultivation for each crop and as well as for the cropping system (Joshi *et al.*, 2008). The methodology of impact assessment of LRI based LUP is shown in schematic diagram (Fig. 3). Based on district contingency plan of Jorhat and also the experimental management practices conducted in

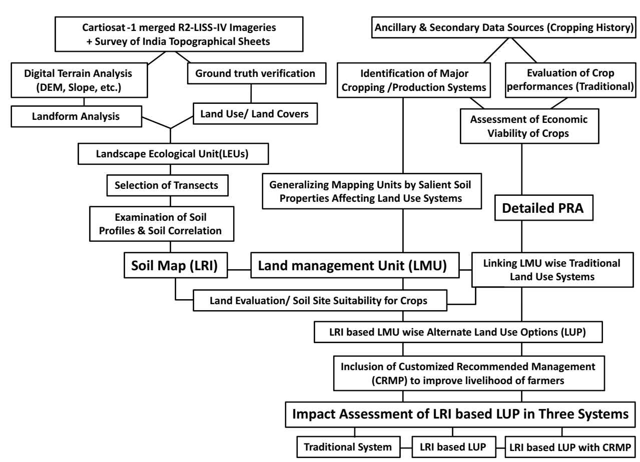

Fig. 3. Methodology of impact assessment of LRI based LUP

KVKs and RARSs of State Agricultural University, the packages of practices were demonstrated in farmers' field of the block area. The recommendations were customized for different LMU based on land suitability for crops as follows:

1. Use of improved and high yielding varieties of crops (Ahu rice - *Luit*, Sali rice - *Ranjit*, Mustard - *TS - 38*, Potato - *Kufri Jyoti*, Cabbage and Pea - *F1 hybrid*) for LMU-1, 2, 4, 5, 6 and 7.
2. Raise-bedded and furrow preparation using one rotarvator and one cultivator ploughing for LMU - 4, 5, 6 and 7 and broad bedded furrows with one rotarvator for LMU-1 and 2.
3. Integrated Rice-cum-Fishery (bunded) for LMU - 3.
4. Integrated nutrient management approach with 50% of the recommended dosages of fertilizers in case of moderate suitability of land and 75% of the same for marginal suitability of land for specific crops for LMU-1, 2 and 3.
5. 75% of the recommended dosages of fertilizers in case of moderate suitability of land and 100% of the same for marginal suitability of land for specific crops for LMU - 4, 5, 6 and 7.

Use of low lifting pump set with shallow tubewell as micro-irrigation for *rabi* crops for LMU-4, 5, 6 and 7.

3. RESULTS AND DISCUSSION

Land Resource Inventory (LRI)

Landform analysis of the study area resulted four geomorphic features *viz.*, (i) active flood plains (9.4% of TGA), younger flood plains (31.1% of TGA), (iii) older flood plains (31.4%), and (iv) marshes and swamps (6.1% of TGA) (Fig. 4). The active flood plains occurred on very gently sloping lands (1-3% slope gradient), whereas, older flood plains and marshes and swamps were developed on both nearly level (0-1%) and very gentle (1-3%) slope. The younger flood plains were formed on nearly level (0-1%) slope only. Ten distinct land use land cover units were identified (Fig. 5) including (a) cultivated lands-single cropped (5.7% of TGA), (b) cultivated land-multi-cropped (48.7% of TGA), (c) tea plantation (1.2% of TGA), (d) homestead orchard plantation (3.9% of TGA), (e) barren/scrub/waste lands (4.4% of TGA), (f) currently fallow marshy lands (6.1% of TGA), (g) channel fills/sand bars (5.0% of TGA), (h) water bodies/wet lands/*beels* (2.6% of TGA), (i) rivers (2.8% of TGA) and (j) built-up (19.7% of TGA). The GIS- overlay of landforms and land use/land covers was made to obtain 18 LEU (Table 1 and Fig. 6), which was used as a base for soil boundary delineation.

Soil Resources

12 soil series were identified in the study area with 23 phases as mapping units based on variability in surface texture, slope and erosion (Table 3 and Fig. 5). The depth wise morphological and physico-chemical characteristics of soils under different landform situations were comprehended by studying the soil-landform relationship (Table 3 and Fig. 6).

Soils on Active Flood Plains

Soils were very deep (>150 cm), somewhat poorly (imperfectly) to poorly drained with strong redoximorphic features (*i.e.* mottles) at a depth below 50 cm, loamy sand to silt loam in surface and loamy sand to sandy loam in sub surface with abrupt textural change with stratified sand and silt layers in sub

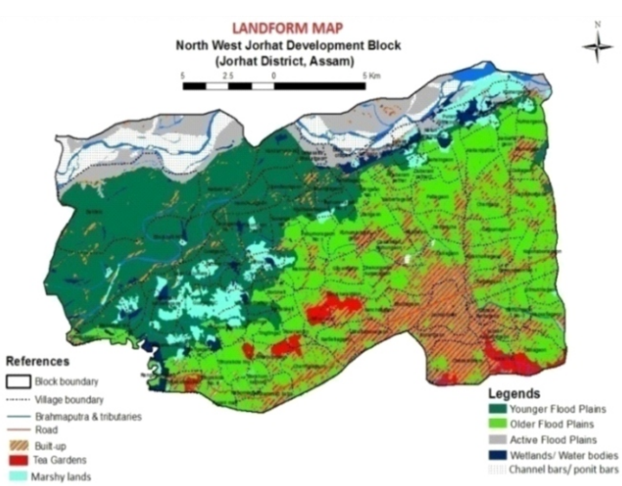

Fig. 4. Landform map of the study area

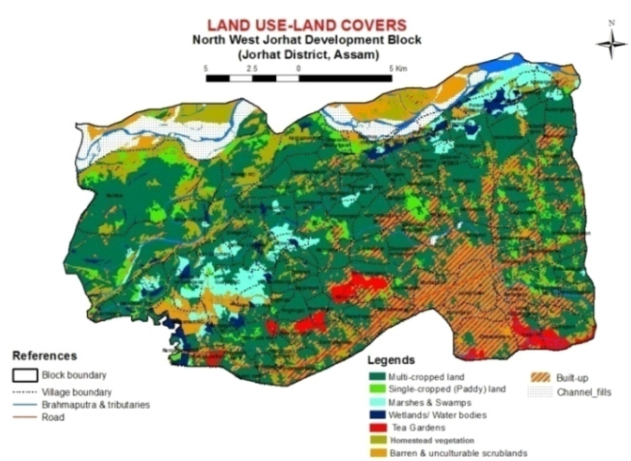

Fig. 5. Land use/land cover map of the study area

Table: 1
Landscape Ecological Units (LEUs) of the study area

LEUs	Descriptions	Area (ha)	% of TGA
NaBrFP$_a$2d	Very gently sloping active flood plains (Double-crop)	1071	3.5
NaBrFP$_a$2f6	Very gently sloping active flood plains (Homestead vegetation)	98	0.3
NaBrF$_a$P2s	Very gently sloping active flood plains (Single-crop)	220	0.7
NaBrFP$_a$2w1	Very gently sloping active flood plains (Barren/ scrub-lands)	807	2.6
NaBrFP$_a$2w5	Very gently sloping active flood plains (Marshes & swamps)	480	1.6
NaBrFP$_a$2wb	Very gently sloping active flood plains (Wet-lands/ water-bodies)	200	0.7
NaBrFP$_o$1d	Nearly level older flood plains (Double-crop)	7511	24.5
NaBrFP$_o$1f6	Nearly level older flood plains (Homestead vegetation)	457	1.5
NaBrFP$_o$1s	Nearly level older flood plains (Single-crop)	748	2.4
NaBrFP$_o$1w1	Nearly level older flood plains (Barren/ scrub-lands)	118	0.4
NaBrFP$_o$1w5	Nearly level older flood plains (Marshes & swamps)	206	0.7
NaBrFP$_o$2p	Very gently sloping older flood plains (Plantation-tea)	610	2.0
NaBrFP$_y$1d	Nearly level younger flood plains (Double-crop)	6356	20.7
NaBrFP$_y$1f6	Nearly level younger flood plains (Homestead vegetation)	630	2.1
NaBrFP$_y$1s	Nearly level younger flood plains (Single-crop)	782	2.5
NaBrFP$_y$1w1	Nearly level younger flood plains (Barren/ scrub-lands)	441	1.4
NaBrFP$_y$1w5	Nearly level younger flood plains (Marshes & swamps)	1170	3.8
NaBrFP$_y$1wb	Nearly level younger flood plains (Wet-lands/ water-bodies)	168	0.5
Miscellaneous area		8627	28.1
Total		30700	100.0

Na: North East Zone-Assam Plains; Br-Brahmaputra Valley (Broad Physiography); FP-Flood Plains; a-Active Flood Plains; o-Older Flood Plains; y-Younger Flood Plains; 1-Nearly level slope (0-1%); 2-Very gentle slope (1-3%); d-Double crop; s-Single crop; f6-Homestead vegetation; w1-Barren/ scrub lands; w5-Marshes & swamps; wb-Wetlands/ water bodies; p- under Tea plantation

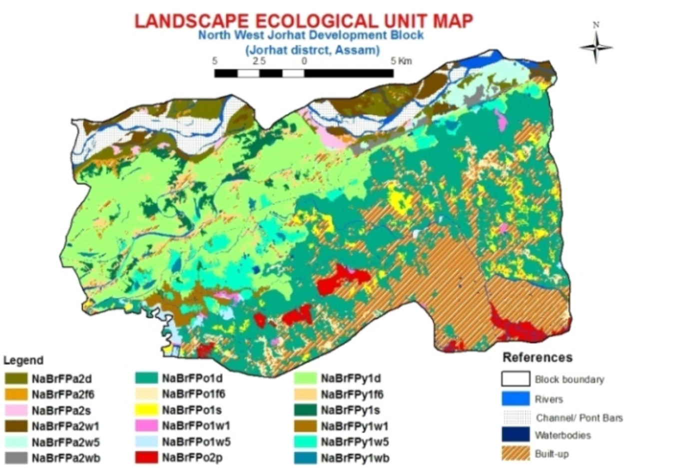

Fig. 6. LEU map of the study area

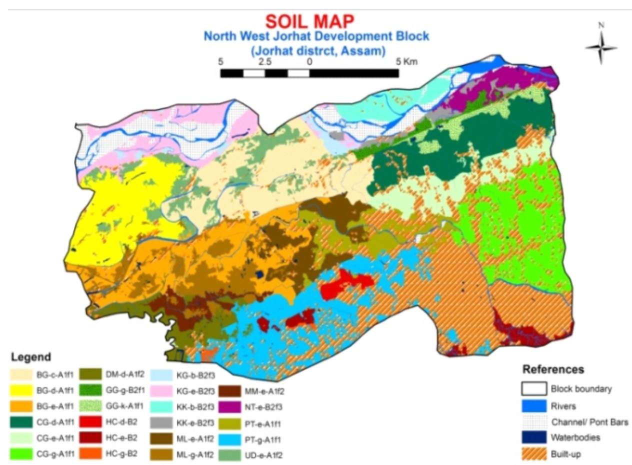

Fig. 7. Soil map of the study area

surface horizons due to cycles of fluvial activities of mighty river Brahmaputra. The matrix colour of these soils comprise yellowish grey to grey hue (10 YR to 2.5 Y) with chroma less than or equals to 2 indicating predominance of aquic moisture regime with endo-saturation. These soils are gleyed below 50 cm with formation of strong Fe-Mn nodules. The profile development is either in significant (Ap-2ACg-3Cg type) or to a very little extent (Ap-Bwg-2ACg type). The soils were neutral to slightly alkaline in reaction (pH 7.3-7.5), medium in organic carbon (0.43-0.48%) (Bandyopadhyay *et al.*, 2014 and Takkar, 2009) with irregular distribution with depth and high in base saturation (51-88%). The CEC/Clay ratio (0.37 to 0.85) indicates mixed mineralogy (Smith, 1986). Three soil series were identified *viz.*, Neemati, Kareng and

Table: 2
Soil resources of the study area

Landforms	Soil Series	Soil Taxonomy (USDA, 2010)	Mapping Units	Area (ha)	% of TGA
Active flood plains	Neemati (NT)	*Fine-loamy, mixed, hyperthermic Fluventic Endoaquepts*	NT-e-B2f3	481	1.6
	Kareng (KG)	*Coarse-loamy, mixed, hyperthermic Typic Endoaquents*	KG-e-B2f3	1058	3.5
			KG-b-B2f3	221	0.7
	Kokila (KK)	*Coarse-loamy, mixed, hyperthermic Typic Fluvaquents*	KK-e-B2f3	255	0.8
			KK-b-B2f3	600	1.9
Younger flood plains	Upar Deuri (UD)	*Fine-loamy, mixed, hyperthermic Fluventic Dystrudepts*	UD-e-A1f2	1025	3.3
	Mahumari (MM)	*Coarse-loamy, hyperthermic Fluventic Eutrudepts*	MM-e-A1f2	394	1.3
	Dorikamari (DM)	*Fine-loamy, mixed, hyperthermic Typic Endoaquepts*	DM-d-A1f2	712	2.3
	Malow (ML)	*Coarse-loamy, mixed, hyperthermic Typic Udifluvents*	ML-g-A1f2	1199	3.9
			ML-e-A1f2	952	3.1
Older flood plains	Charigaon (CG)	*Fine-loamy, mixed, hyperthermic Dystric Eutrudepts*	CG-d-A1f1	1676	5.5
			CG-e-A1f1	998	3.3
			CG-g-A1f1	2005	6.5
	Parbatia (PT)	*Coarse-loamy, mixed, hyperthermic Typic Endoaquepts*	PT-e-A1f1	779	2.5
			PT-g-A1f1	2388	7.8
	Balijangaon (BG)	*Fine-loamy, mixed, hyperthermic Fluvaquentic Eutrudepts*	BG-d-A1f1	1768	5.8
			BG-e-A1f1	1917	6.2
			BG-c-A1f1	2399	7.8
	Harucharai (HC)	*Fine-loamy, mixed, hyperthermic Typic Hapludalfs*	HC-d-B2	177	0.6
			HC-e-B2	374	1.2
			HC-g-B2	59	0.2
Marshes and swamps	Gohaingaon (GG)	*Fine, mixed, hyperthermic Typic Endoaqualfs*	GG-g-B2f1	262	0.9
			GG-k-A1f1	374	1.2
Miscellaneous area				8627	28.1
Total				30700	100.0

loamy sand; c - sandy loam; d - loam; e - silt loam; g - silty clay loam; k - silty clay; A - 0-1% slope; B-1 - 3% slope; 1 - slight erosion; 2 - moderate erosion; f1 - slight flooding; f2 - occasional flooding; f3 - frequent flooding

Kokila and were classified as *Fluventic Endoaquepts, Typic Endoaquents* and *Typic Fluvaquents*, respectively.

Soils on Younger Flood Plains

Soils were very deep, imperfectly drained with formation of prominent mottles at a depth below 50 cm, loamy to silty clay loam in surface and silt loam to silty clay loam in sub surface with sign of little profile development (Ap-Bw type). The soils were yellowish grey to yellowish brown in matrix colour with hue of 10 YR to 2.5 Y and Chroma of 2 to 3. The soils were strongly to weakly acidic in reaction (pH 6.6-7.1), medium to high in organic carbon (0.79-1.01%) and medium to high in base saturation (56-63%). Low CEC/Clay ratio (0.24 to 0.53) indicates mixed mineralogy influenced by kaolin inter stratification (Bhattacharyya *et al.*, 2010). Stratification of sand and silt fractions with irregular distribution of organic carbon is common in Malow, Upar Deuri and Mahumari series indicating their fluventic behaviour as influenced by tributaries of Brahmaputra. The soils were classified as *Typic Udifluvents, Fluventic Dystrudepts* and *Fluventic Eutrudepts*. Dorikamari series showed endo-saturation (2.5 Y with chroma ≤ 2) and classified as *Typic Endoaquepts*.

Soils on Older Flood Plains

Soils on nearly level old flood plains were very deep, moderately well drained with redoximorphic features prominently formed below 75 cm from soil depth, loamy to silty clay loam in surface and sandy loam to silty clay loam in sub surface, profile development with prominent cambic horizon (Ap-Bw1-Bw2 type) down the depth. The soils were strongly to moderately acidic in reaction (5.5-5.6), medium in organic carbon (0.41-0.71%) and base saturation (39-71%). The low CEC/Clay ratio (0.23-0.59) indicates enhancement of kaolin inter-stratification in the mineral assemblage of soils (Bhattacharyya *et al.*, 2010). The soils were under

Table: 3

Depth wise morphological and physico-chemical characteristics of some soils in different landform situations

Pedons	Depth (cm)	Morphological Characteristics				Physico-chemical Characteristics					
		Horizon	Colour	Texture	Diagnostic features	pH (1: 2.5 H_2O)	OC (%)	CEC	CEC/ Clay	Sum of bases	Base saturation (%)
								cmol (p+) kg^{-1}			
Very Gently Sloping Active flood plains (*Coarse-loamy, mixed, hyperthermic Typic Endoaquents*)											
P1	Ap	0-21	2.5Y5/3	Silt loam	--	7.5	0.48	6.77	0.50	3.42	51
	AB	21-49	2.5Y5/2	Silt loam	Strong mottles	7.4	0.43	7.47	0.37	3.16	42
	2ACg1	49-79	2.5Y5/3	Sandy loam	Strong mottles	7.3	0.16	4.95	0.54	3.1	63
	2ACg2	79-118	2.5Y6/2	Loamy sand	--	7.5	0.14	3.13	0.51	2.76	88
	3Cg1	118-152	25.Y6/2	Sand	--	7.5	0.11	3.23	0.85	1.75	54
Nearly Level Younger flood plains (*Fine-loamy, mixed, hyperthermic Fluventic Dystrudepts*)											
P2	Ap	0-25	10YR5/3	Silt loam	--	7.1	0.79	5.83	0.30	3.68	63
	Bw1	25-55	10YR5/3	Sandy loam	Strong mottles	6.9	0.11	5.23	0.53	3.02	58
	Bw2	55-85	10YR5/3	Silt loam	Strong mottles	7.0	0.32	5.77	0.25	3.26	56
	Bw3	85-120	10YR5/3	Silt loam	Strong mottles	6.6	0.17	4.97	0.49	2.84	57
	Bw4	120-160	2.5Y4/1	Silty clay loam	Strong mottles	6.6	0.32	9.29	0.24	5.41	58
Nearly Level Marshes and swamps (*Fine, mixed, hyperthermic Typic Endoaqualfs*)											
P3	Ap	0-11	2.5Y4/1	Silty clay loam	--	6.3	1.14	10.56	0.42	4.64	44
	Btg1	11_35	2.5Y5/1	Silty clay	--	7.1	0.72	9.79	0.20	3.72	38
	Btg2	35-68	2.5Y6/1	Silty clay	Redox depletions	7.0	0.29	7.87	0.15	3.22	41
	Btg3	68-105	2.5Y6/1	Silty clay	Redox depletions	7.1	0.18	5.47	0.13	2.25	41
	Btg4	105-125	2.5Y7/1	Silty clay	Redox depletions	7.0	0.42	11.9	0.27	6.47	54
Nearly Level Older flood plains (*Fine-loamy, mixed, hyperthermic Dystric Eutrudepts*)											
P4	Ap	0-18	10YR5/2	Loam	--	5.5	0.71	6.57	0.32	2.88	44
	Bwg1	18-37	10YR6/2	Loam	Strong mottles	5.5	0.41	6.72	0.31	2.64	39
	Bwg2	37-66	10YR6/3	Loam	Strong mottles	5.4	0.32	5.15	0.23	3.65	71
	Bwg3	66-91	10YR6/3	Loam	Strong mottles	5.5	0.23	11.4	0.59	7.25	64
	2ACg1	91-136	10YR6/1	Loamy sand	--	5.6	0.07	4.34	0.42	3.04	70
Very Gently Sloping Older flood plains (*Fine-loamy, mixed, hyperthermic Typic Hapludalfs*)											
P5	Ap	0-23	10YR6/4	Loam	--	4.5	0.47	5.05	0.31	1.86	37
	Bt1	23-58	10YR6/2	Silty clay loam	--	4.5	0.23	5.45	0.19	1.44	26
	Bt2	58-95	10YR5/3	Silty clay loam	--	4.6	0.14	5.96	0.19	1.66	28
	Bt3	95-120	10YR5/3	Silty clay loam	Patchy Argillans	4.7	0.09	6.67	0.22	2.65	40
	Bt4	120-151	10YR5/3	Silty clay	Patchy Argillans	4.5	0.04	5.76	0.13	2.05	36

Charigaon, Parbatia and Balijangaon series and classified as *Dystric Eutrudepts*, *Typic Endoaquepts* and *Fluvaquentic Eutrudepts*. The soils on very gently sloping lands were very deep, well drained with occurrence of faint patchy argillans below 75 cm. Prolonged tea based land use system resulted very strong soil acidity (pH 4.46-4.54) and low base saturation (36-40%). The CEC/Clay ratio is low (0.13-0.31) indicating occurrence of kaolonitic minerals in clay fraction of soils (Smith, 1986). The soils were under Harucharai series and classified as *Typic Hapludalfs.*

Soils on Marshes and Swamps

The marshes and swamps comprise two micro-relief features *viz.*, nearly level land (0-1% slope gradient) and very gently sloping land (1-3% slope gradient). On nearly level land, the soils were very deep, poorly drained with occurrence of Fe-Mn depletions below 25 cm from surface and reduced soil matrix with hue of 2.5Y - 5Y and chroma of 2 or less, indicating the endo-saturation and formation of gleyed cambic horizon (Bwg). The water table fluctuates at a depth between 1.0 to 1.5 m from the surface layer. Formation of stress features (below 50 cm) were noted due to clay illuviation processes. These soils were silty clay loam to silty clay in texture with gradual increase of clay with depth indicating the formation of gleyed argillic horizon (Btg). The horizon sequence is Ap-Bwg-Btg-2Cg type with abrupt textural change below 100 cm. Soils on very gently sloping land were similar in characteristics except the horizon sequence (Ap-Bwg-Btg type). The soils were slightly acidic to neutral in reaction (6.3-7.1) with high organic carbon (0.72-1.14%) and medium base saturation (38-54%). The CEC/Clay ratio was low (0.13-0.42) indicating influence of kaolin interstratifications in clay fractions of soils. The soils were under Gohaingaon Series and classified as *Typic Endoaqualfs.*

Land management units (LMUs)

Important landscape (site) characteristics namely, landforms, slope and drainage; morphological properties of soils namely, texture of soil control section (0-100 cm), nature and formation of redoximorphic features and formation of diagnostic horizons and physico-chemical properties like soil pH, organic carbon, CEC and base saturation were addressed to play the key roles in affecting the land use systems of the region. In the study area, 8 LMU were established (Fig. 9) after merging 12 soil series based on similarity on broad range in the aforesaid characteristics. Soil site suitability was assessed for important crops on LMU basis (Table 4).

Land Suitability Assessment for Crops

The soil site suitability for crops was evaluated for each land management unit. It was noted that LMU-1 and 2 were moderately suitable for mustard, potato and pea with moderate soil physical and fertility limitations and marginally suitable for rice with severe limitations of soil physical properties. Coarse loamy texture (loamy sand and sandy loam soils) with occurrence of lithologically discontinued sand layers in upper sub surface (25-50 cm soil depth) horizons were found to be the major limitations for rice. LMU-3 was moderately suitable for rice but marginally for mustard, cabbage, pea and potato due

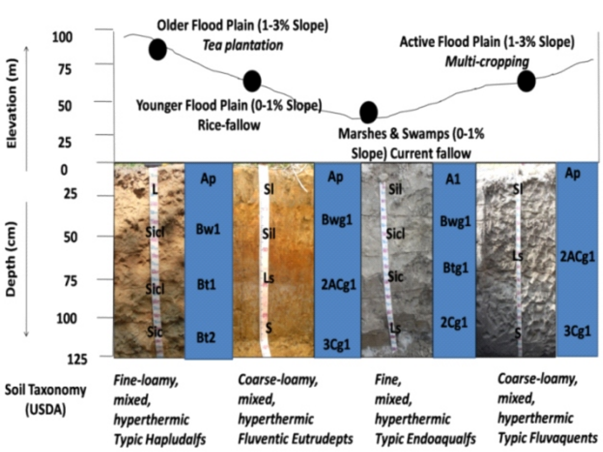

Fig. 8. Soil-landform relationship of the study area

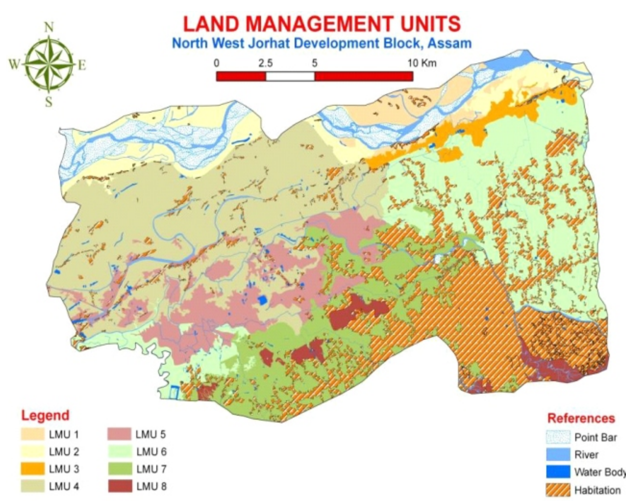

Fig. 9. LMU map of the study area

Table: 4
LMU based land suitability evaluation of crops of North West Jorhat development block

LMU	Descriptions	Soil Series	Present Land Use	Soil Site Suitability
1	Well drained, coarse-loamy, soils on active flood plains under multi-cropping	Kokila (*Typic Fluvaquents*)	Ahu Rice (pre-*kharif*)-Mustard/*rabi*-veg	Rice-S3s3f2; Mustard-S2s2f2; Cabbage-S2s2f2; Potato-S2s2f2; Pea-S2s2f2
2	Imperfectly drained, fine-loamy, soils on active flood plains under mono-cropping	Kareng (*Typic Endoaquents*) Neemati (*Fluventic Endoaquepts*)	Ahu Rice (pre-*kharif*)-Fallow	Rice-S3s3f2; Mustard-S2s2f2; Cabbage-S2s2f2; Potato-S2s2f2; Pea-S2s2f2
3	Very poorly drained, fine, gleyed soils on marshes & swamps under currently fallow	Gohaingaon (*Typic Endoaqualfs*)	Current Fallow	Rice-S2f2; Mustard-S3w3; Cabbage-S3w3; Potato-S3w3; Pea-S3w3
4	Imperfectly drained, fine-loamy soils on younger flood plains under multi-cropping	Balijangaon (*Fluvaquentic Eutrudepts*) Upar Deuri (*Fluventic Dystrudepts*)	Ahu Rice (pre-*kharif*)- Sali Rice (*kharif*)-Mustard (*rabi*)	Rice-S2s3f2; Mustard-S2s2f2; Cabbage-S2s2f2; Potato-S2s2f2; Pea-S2s2f2
5	Imperfectly drained, coarse-loamy, soils on younger flood plains under currently fallow	Malow (*Typic Udifluvents*) Mahumari (*Fluventic Eutrudepts*)	Current Fallow	Rice-S2s3f2; Mustard-S2s2f2; Cabbage-S2s2f2; Potato-S2s2f2; Pea-S2s2f2
6	Imperfectly drained, fine-loamy soils on older flood plains under double cropping	Charigaon (*Dystric Eutrudepts*) Dorikamari (*Typic Endoaquepts*)	Ahu Rice (pre-*kharif*)-Sali Rice (*kharif*)	Rice-S2f2; Mustard-S2f2w2; Cabbage-S2f2w2; Potato-S2f2w2; Pea-S2f2w2
7	Imperfectly drained, coarse-loamy Soils on older flood plains under mono- cropping	Parbatia (*Typic Endoaquepts*)	Sali Rice (*kharif*)-Fallow	Rice-S2f2; Mustard-S2f2w2; Cabbage-S2f2w2; Potato-S2f2w2; Pea-S2f2w2
8	Moderately well drained, fine-loamy soils on older flood plains under tea plantation	Harucharai (*Typic Hapludalfs*)	Tea Plantation (Permanent)	Tea-S2f2; Rice-N1f3s3; Mustard-N1f32s3; Cabbage-N1f3s3; Potato-N1f3s3; Pea-N1f3s3

S2 - moderately suitable; S3 - marginally suitable; s - soil physical factor; f - soil fertility factor; w - wetness / drainage factor; 2 - moderate limitation; 3 - Severe limitation

to wetness limitations. Poor internal drainage evident from endo-saturation and reduced soil matrix are found to be the major constraints for these crops. LMU-4, 5, 6 and 7 were moderately suitable with moderate limitations of soil physical and soil fertility parameters for rice and moderate limitations of soil fertility and wetness for mustard, cabbage, potato and pea. LMU-8 is moderately suitable for tea only owing to its strong soil acidity and moderately well drained nature and fine-loamy texture and temporarily not suitable for other crops due to severe soil fertility limitations (extremely acidic soils with pH<4.5).

Impact Assessment

The land use system under traditional/ conventional system of farming has been identified and was characterized for each LMU (Table 5). It was noted that the major cropping system of LMU-1 was Ahu Rice (pre-*kharif*) followed Mustard/ *rabi*-vegetables (*rabi*), whereas, the same for LMU-2 was Ahu Rice (pre-*kharif*)-Fallow. LMU-3 and 5 were found currently fallow, whereas, in LMU-4 was Ahu Rice (pre-*kharif*) followed by Sali Rice (*kharif*) andMustard (*rabi*) are grown. In LMU-6, major cropping sequence was was Ahu Rice (pre-*kharif*) followed by Sali Rice (*kharif*). LMU-8 was occupied by tea plantation as a permanent land use feature (tea gardens) for long duration in the region and hence it was not included for impact assessment.

It was noted that the average annual yield of under traditional system was only 1.99 t ha^{-1}. The average annual B:C ratio was only 0.93 and annual net returns for the farmers has been estimated as ₹ 34852/- ha^{-1}. If LRI is employed, the choices of crops are enhanced. Thus, LRI based LUP resulted better and appropriate crop combinations with 108% increase in average annual yield (4.27 t ha^{-1}), 85.9% increase in annual net returns (₹ 64781 ha^{-1}) and 33.3% increase in average B:C ratio (1.24). It shows that LRI based crop planning is highly superior over the traditional system of cropping practices. If the management practices are customized as per the need of the local conditions the profitability is enhanced many-folds.

By implementing the e customized recommendations drastic enhancement in productivity was observed in the farmers' field. LRI with CRMP

Table: 5
Impact Assessment of LRI based Land Use Plan of North West Jorhat Development Block

LMU	Traditional Land Use System								Conventional Management Practice
	Land Use			Av. Yield (t ha^{-1})			Net Return from Cropping System (₹ ha^{-1}yr^{-1})	B:C Ratio	
	Pre-*kharif*	*kharif*	*rabi*	Pre-*kharif*	*kharif*	*rabi*			
1	Ahu Rice	No Crop	Mustard	2.0	0.0	1.2	64322	1.65	• Conventional and low input management with no tillage operation and minimal use of fertilizers (less than 25% of the recommended dosages of N only) using open source irrigation
	No Crop	No Crop	Cabbage	0.0	0.0	26	98729	1.66	
	No Crop	No Crop	Potato	0.0	0.0	9	48215	0.85	
2	Ahu Rice	No Crop	No Crop	2.6	0.0	0.0	5961	0.82	
3	No Crop	No Crop	No Crop	0.0	0.0	0.0	0	0.0	
4	Ahu Rice	Sali Rice	Mustard	1.8	2.5	0.9	61758	1.26	
5	No Crop	No Crop	No Crop	0.0	0.0	0.0	0.0	0.0	
6	Ahu Rice	Sali Rice	No Crop	1.7	3.6	0.0	22369	1.03	
7	No Crop	Sali Rice	No Crop	0.0	2.4	0.0	12315	1.07	
	Average			0.90	0.94	4.12	34852	0.93	
	LRI based Alternate Land Use Options								
1	Ahu Rice	No Crop	Mustard	2.0	0.0	1.2	64322	1.65	• Conventional and low input management with no tillage operation and minimal use of fertilizers (less than 25% of the recommended dosages of N only) using open source irrigation
	Ahu Rice	No Crop	Cabbage	2.0	0.0	26	98729	1.66	
	Ahu Rice	No Crop	Potato	2.0	0.0	9	48215	0.85	
	Ahu Rice	No Crop	Pea	2.0	0.0	1.2	32039	1.35	
2	Ahu Rice	Sali Rice	Mustard	2.6	2.4	1.2	78013	1.52	
	Ahu Rice	Sali Rice	Cabbage	2.6	2.4	26	112420	1.52	
	Ahu Rice	Sali Rice	Potato	2.6	2.4	9	61906	0.98	
	Ahu Rice	Sali Rice	Pea	2.6	2.4	1.2	45730	1.32	
3	Ahu Rice	Sali Rice	No Crop	2.8	3.6	0.0	24892	1.19	
4	Ahu Rice	Sali Rice	No Crop	1.8	2.8	0.9	63297	1.28	
	Ahu Rice	Sali Rice	No Crop	1.8	2.8	25	109017	1.44	
	Ahu Rice	Sali Rice	Potato	1.8	2.8	8	54852	0.88	
	Ahu Rice	Sali Rice	Pea	1.8	2.8	1.0	41372	1.16	
5	Ahu Rice	Sali Rice	Mustard	1.7	2.5	0.9	61528	1.25	
	Ahu Rice	Sali Rice	Cabbage	1.7	2.5	25	107248	1.42	
	Ahu Rice	Sali Rice	Potato	1.7	2.5	8	53083	0.85	
	Ahu Rice	Sali Rice	Pea	1.7	2.5	1.0	39603	1.13	
6	Ahu Rice	Sali Rice	Mustard	1.8	3.6	0.8	63309	1.33	
	Ahu Rice	Sali Rice	Cabbage	1.8	3.6	24	108912	1.52	
	Ahu Rice	Sali Rice	Potato	1.8	3.6	7.5	48628	0.91	
	Ahu Rice	Sali Rice	Pea	1.8	3.6	0.8	40955	1.16	
7	Ahu Rice	Sali Rice	Mustard	1.7	2.5	0.9	61528	1.25	
	Ahu Rice	Sali Rice	Cabbage	1.7	2.5	25	107248	1.42	
	Ahu Rice	Sali Rice	Potato	1.7	2.5	8	53083	0.85	
	Ahu Rice	Sali Rice	Pea	1.7	2.5	1.0	39603	1.13	
	Average			1.97	2.35	8.50	64781	1.24	

Increase in Av. Yield = 108%; Increase in B:C ratio = 33.3%; Increase in NR = 85.9%

Table: 5
Continued...

LMU	LRI based Land Use Plan with Customized Recommended Management Practices								Customized Recommended Management Practices
	Land Use			Av. Yield (t ha^{-1})			Net Return from Cropping System (₹ $ha^{-1}yr^{-1}$)	B:C Ratio	
	Pre-*kharif*	*kharif*	*rabi*	Pre-*kharif*	*kharif*	*rabi*			
1	Ahu Rice	No Crop	Mustard	3.5	0.0	1.6	85604	2.89	• Use of improved and high yielding varieties of crops (Ahu rice - Luit, Sali rice - Ranjit, Mustard - TS-38, Potato - Kufri Jyoti, Cabbage and Pea - F1 hybrid) for LMU - 1, 2, 4, 5, 6 and 7. • Raise-bedded and furrow preparation using one rotarvator and one cultivator ploughing for LMU - 4, 5, 6 and 7 and broad bedded furrows with one rotarvator for LMU - 1 and 2. • Integrated Rice-cum-Fishery (bunded) for LMU - 3. • Integrated nutrient management approach with 50% of the recommended dosages of fertilizers in case of moderate suitability of land and 75% of the same for marginal suitability of land for specific crops for LMU-1, 2 and 3. • 75% of the recommended dosages of fertilizers in case of moderate suitability of land and 100% of the same for marginal suitability of land for specific crops for LMU-4, 5, 6 and 7. • Use of low lifting pump set with shallow tube well as micro-irrigation for *rabi* crops for LMU - 4, 5, 6 and 7.
	Ahu Rice	No Crop	Cabbage	3.5	0.0	60	226964	3.67	
	Ahu Rice	No Crop	Potato	3.5	0.0	20	132680	1.68	
	Ahu Rice	No Crop	Pea	3.5	0.0	2.8	65219	2.79	
2	Ahu Rice	Sali Rice	Mustard	3.8	3.8	1.6	105790	2.52	
	Ahu Rice	Sali Rice	Cabbage	3.8	3.8	60	247150	3.04	
	Ahu Rice	Sali Rice	Potato	3.8	3.8	20	152866	1.71	
	Ahu Rice	Sali Rice	Pea	3.8	3.8	2.8	85405	2.46	
3	Ahu Rice	Sali Rice	No Crop	4.0	5.5	0.0	37391	1.95	
4	Ahu Rice	Sali Rice	No Crop	4.0	5.5	1.3	100425	2.46	
	Ahu Rice	Sali Rice	No Crop	4.0	5.5	45	201596	2.76	
	Ahu Rice	Sali Rice	Potato	4.0	5.5	17	143349	1.82	
	Ahu Rice	Sali Rice	Pea	4.0	5.5	1.4	65989	2.29	
5	Ahu Rice	Sali Rice	Mustard	3.5	3.8	1.3	89017	2.21	
	Ahu Rice	Sali Rice	Cabbage	3.5	3.8	45	190188	2.51	
	Ahu Rice	Sali Rice	Potato	3.5	3.8	17	131941	1.57	
	Ahu Rice	Sali Rice	Pea	3.5	3.8	1.4	54581	2.04	
6	Ahu Rice	Sali Rice	Mustard	4.0	5.5	1.0	85879	2.35	
	Ahu Rice	Sali Rice	Cabbage	4.0	5.5	34	161457	2.45	
	Ahu Rice	Sali Rice	Potato	4.0	5.5	14	124650	1.64	
	Ahu Rice	Sali Rice	Pea	4.0	5.5	1.0	57859	2.29	
7	Ahu Rice	Sali Rice	Mustard	3.5	5.0	1.3	96705	2.37	
	Ahu Rice	Sali Rice	Cabbage	3.5	5.0	45	197876	2.67	
	Ahu Rice	Sali Rice	Potato	3.5	5.0	17	139629	1.73	
	Ahu Rice	Sali Rice	Pea	3.5	5.0	1.4	62269	2.20	
	Average			3.73	3.99	16.52	121699	2.32	

Increase in Av. Yield = 304% (over traditional); Increase in B:C ratio = 150% (over traditional); Increase in NR = 249% (over traditional); Increase in Av. Yield = 89.2% (over LRI); Increase in B:C ratio = 87.1% (over LRI); Increase in NR = 87.9% (over LRI) resulted an increase in average annual yield of 304% over traditional and 89.2% over LRI based LUP. The annual profitability was enhanced by 249% over traditional and by 87.9% over LRI based LUP, whereas, the increase in average B:C ratio was 150% over traditional and 87.1% over LRI based LUP. The overall study reveals that LRI based LUP with CRMP is much superior in up-scaling the agricultural productivity and profitability of the farmers of the block compared to traditional based land use system.

4. CONCLUSIONS

Results of the investigation revealed that application of latest fine resolution imageries was good enough to delineate soil map at a high accuracy level so that each mapping unit are comprehensibly representative. The concept of land management unit further accelerates the investigation towards management interventions. Land management unit wise land suitability evaluation of crops provided best possible crop combinations for the farmers. Methodologies developed to assess the impact of LRI based LUP for productivity enhancement and economic benefit were first in kind and have ample scope to utilize scientifically soil survey database and soil map. In brief, a novel and optimal LUP approach has been developed for Upper Brahmaputra Valley Region. This investigation puts an ample scope to conduct the exercise for spreading over the LRI based LUP technology in similar agro-climatic and physiographic regions in other parts of the country.

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