Journal of the Indian Society of Soil Science, Vol. 65, No. 2, pp 161-170 (2017)
DOI: 10.5958/0974-0228.2017.00019.6

A Scenario-Based Land and Irrigation Capability Assessment for Crop Intensification- A Case Study of Jharkhand, Eastern India

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Land suitability evaluation is an important tool to detect extended use of land and water for crop intensification at farm scales. In the present study, a land suitability evaluation in Balpahari area of Jharkhand (India) was carried out in 39,854 ha area through close examination of the indicators of land suitability. Three scenarios were constructed such as, soil scenario to support variety of crop cultivation; crop scenario in which multiple cropping system lead to further increase in the cultivation area; and an irrigation scenario in which crops of dry season can be irrigated. The parameters taken into consideration were soil texture, depth, slope, surface flooding, drainage, pH, soil nitrogen (N), phosphorus (P), potassium (K) and crop-water requirement. Based on landform analysis, field surveys, laboratory analysis and field reviews, various thematic maps were prepared on 1:250,000 scale for scenario analysis of the study area. The effective rainfall and evapotranspiration of various crops were computed using the CROPWAT8.0 model. The study revealed the potential of soil and irrigation for increasing the crop area to enhance the livelihood support of small farmers. About 14,467 ha area were categorized as LCC-II where wide range of crops like vegetables, oilseeds and some pulse crops can be grown during winter and summer season with supply of life saving irrigation besides rice during rainy season. About 21,011 ha area were grouped under LCC-III and found suitable for short duration variety of mustard and potato with proper management of land, fertilizer and water. Crop rotation like rice-potato-green gram and rice-mustard-vegetables in low land, and maize-mustard-green manuring and black gram-lentil-green manuring in upland were suggested as most feasible cropping systems. This information is important for both, at farm level for farmers' decision making on agricultural management, and at regional level for policy decision making on sustainability governance.

Key words: Land capability, crop intensification, soil suitability, irrigation, soil indicators

Globally, agriculture is facing an increasing demand for food, fibre and bio-based energy. Numerous studies suggest that integration of technological, environmental and socio-cultural services can only meet the increasing demand of agricultural production (Swaminathan 1996; Tillman *et al.* 2002; Rao *et al.* 2016). Farmers' adaptation to meet the increasing demand of agriculture production may include changes in the choice of crops, crop rotations, and finally crop intensification. Crop intensification is possible through systematic survey of the soils, evaluating their potentials for a wide range of crops cultivation and judicious use of irrigation water which should be economically viable, socially acceptable and environmentally sound (Sathish and Niranjana 2010). The potential of the quantitative land evaluation has been demonstrated by several researchers (Merolla *et al.* 1994; Beek *et al.* 1997). Moreover, such a kind of analysis help in identification of the main limiting factors for the agricultural production and enable decision makers to develop a suitable crop and water management system to overcome such constraints for increasing the agricultural land productivity.

The present study was undertaken in Jharkhand state of India to demonstrate the usefulness of soil data to assess crop suitability and irrigation potential

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in order to implement sustainability for crops in the study area. Several characteristics make this area an example for the application of integrated assessments of agricultural development scenarios *i.e.* low soil fertility, yield limitations by water, specialized farm, low technological level, subsidies for agricultural production, *etc*. The scenarios were designed to integrate site-specific soil, climate and irrigation data and describe their effects on crop choice and crop management at the farm level. Decisions at the farm level were translated into crop distribution patterns at irrigation command area scale for analysis of scenario impacts. Results were aggregated to represent the landscape level of scenario impacts. Scenarios are developed for the year 2025, a time frame that is sufficiently long to allow for major changes in agricultural management including realistic predictions of climate effects and yield trends.

Materials and Methods

Description of the study area

Jharkhand is a state in eastern India and has a land surface area of 79,710 km^2, of which only 28% is agricultural land. The state's mineral soils are developed on granite gneiss and granite schists. The land surface being uneven is subject to sheet and gully erosion causing loss of soil and plant nutrients. Almost two-thirds of the agricultural soils are light to coarse in texture with a water holding capacity less than 150 mm. Agriculture is the main stay for the 80% of rural population. The agricultural economy of the state is characterized by inadequate irrigation facilities, dependence on rainfall, limited choice of crops and low investment due to high risk of farming. The response to inputs like fertilizers, pesticides, hybrid seeds and other external inputs are relatively low. Ground water is also very low due to little recharging by natural process.

The study area is located between 23°50′ to 24°10′ N latitudes and 86°20′ to 86°45′ E longitudes covering an area of about 39,854 ha (Fig. 1). There are two major streams *viz*., Barakar River and Maithan reservoir. It has a catchment area of 6294 km^2 at Maithon and 5403 km^2 at Balpahari dam site. The mean annual rainfall of Barakar catchment is about 1260 mm. About 82% of the rainfall occurs during the monsoon months from June to September. During the pre- and post-monsoon seasons, the rainfall in the catchment is about 8 and 7%, respectively, of the annual rainfall. April to May is the hottest months and December to January is the coldest months.

Analytical framework

Three steps were involved in assessment of land and irrigation capability for crop intensification. First step was the identification of indicators for scenario definition followed by analysis of the scenario effects on several economic, social and ecological aspects. The third step has presentation of the assessment results for implementation. Scenarios of future cropping practices were chosen based on their

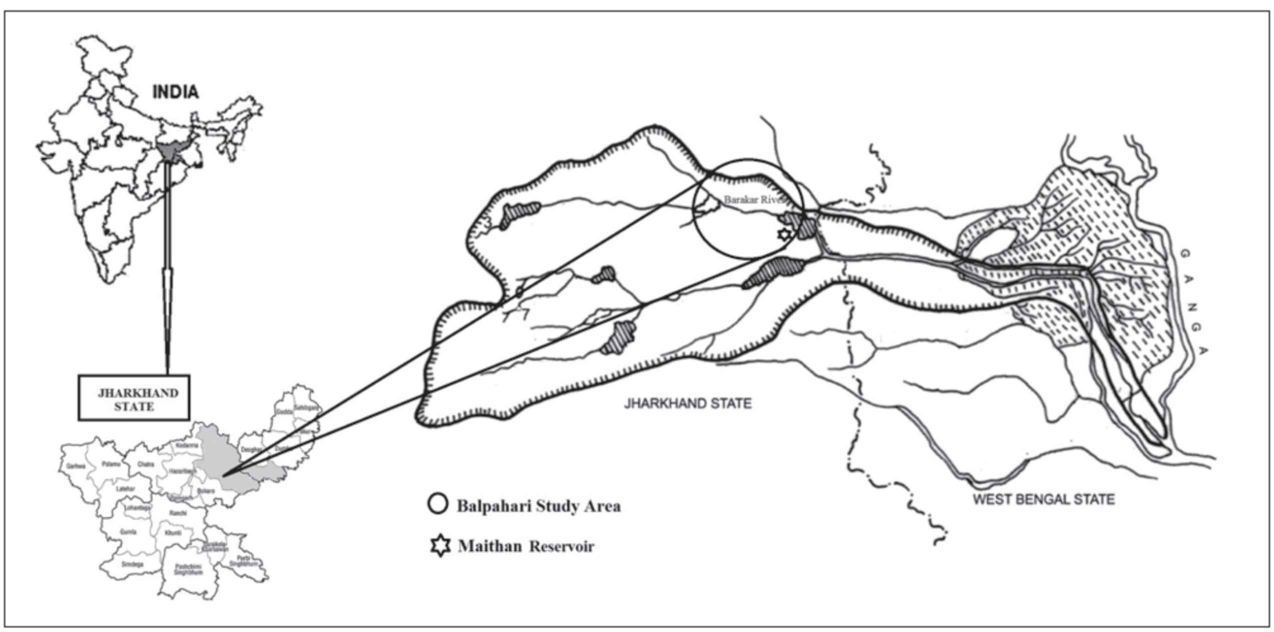

Fig. 1. Location of the study area (Balpahari, Jharkhand, India)

relevance to agricultural land use and sustainable development. They were based on the driving forces like market prices for agricultural produces, soil types, irrigation resources, rainfall trends, and government supported agricultural schemes. Three scenarios were constructed such as, soil scenario to support variety of crop cultivation; crop scenario in which multiple cropping system lead to further increase in the cultivation area; and an irrigation scenario in which crops of dry season can be irrigated.

Translation of scenario into crop distributions

To translate scenario assumptions into intensified crop management and cropping decisions, a 3-tier approach comprising of area map interpretation, field survey (farm structures, site characteristics, markets and agricultural schemes), and laboratory investigations was adopted. It was assumed that farmers make their cropping choices mainly by optimizing net farm income within the existing farm resources. The approach used existing crop production data for each of soil type representing different levels of soil fertility, crop calendar and irrigation water availability. It also incorporated additional expert assessments of inputs and outputs for important cropping practices, including irrigation, yield development as influenced by climate and management improvements. Crops were compared for their net margin based on local cost figures. Assumptions and constraints were (i) constant food grain requirements of farmers, (ii) use of manure and fertilizer in the cropping systems, (iii) constant level of market-based cropping systems, and (iv) adherence to crop rotation plan. On this basis, the suggested cropping system can maximize the total net margin of the study area by allocating part of the area of each land category to the best performing cropping practices, taking the restrictions into account.

For the assessment of the scenario, soil fertility, land capability and land irrigability map were prepared, and cropping system as per land classes was drafted taking into account the total area share of each crop as derived from the study. The approach implements the idea to distribute a list of crops and its proportions of the agricultural area according to the suitability of the land at a certain location unit for each crop. The result was a land suitability-based crop distribution for the area of study.

Indicators and analysis methods

In this study, 10 indicators were used based on their sensitivity to crop management practices, ability to describe major land classification processes, and significance of increasing productivity (agronomic) and protecting environmental soil functions. The selected indicators include rooting soil depth, texture, slope, surface flooding, drainage, pH, available nitrogen (N), available soil phosphorus (P), available potassium (K) and crop-water requirement. Soil depth, slope and texture reflect the suitability of soil physical conditions for plant growth. Soil pH, available N, P and K show the nutrient status of the soil for plants. Soil flooding and drainage determine the irrigation water demand. These factors have therefore been adopted to reflect the various aspects of land capability, soil water availability and crop suitability in the study area.

Topography, land use pattern, drainage and relief pattern were studied from toposheets and physical verification of the study area. The soil profile, existing cropping pattern and socio-economic status of farmers were studied through physical field survey. Soil resource mapping was undertaken using the Soil Survey Field Manual (Sehgal *et al.* 1989). During traverse and field observations, three to four sample strips, each covering an area of 100 ha, was marked on the contour map. These cover majority of the landform units in the study area. Altogether 12 soil units were identified and shown in the map of study area (Fig. 2). The area of each unit with existing land use distribution is given in table 1. From each strip, 2 to 3 soil profile observations were taken up randomly to a depth of 150 cm (or less in shallow soils) covering

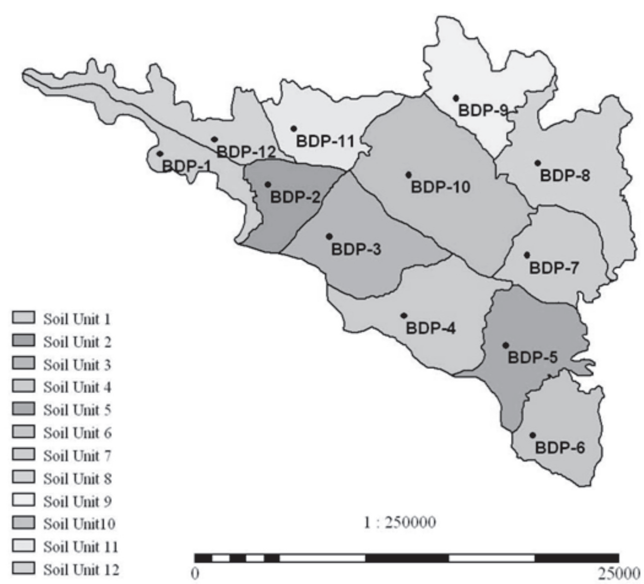

Fig. 2. Soil unit map of the study area (Balpahari, Jharkhand, India)

Table 1. Area of soil units as per land use of the study area

Soil unit	Total area (ha)	Area under reserved forest (ha)	Area inhibited by the population (ha)	Area under water bodies (ha)	Area under cultivation (ha)
BDP - 1	2073	311	52	0.33	1709.7
BDP - 2	2005	561	89	6.11	1348.9
BDP - 3	3676	317	147	28.2	3183.8
BDP - 4	3965	329	140	50.6	3445.4
BDP - 5	3360	769	136	27.3	2427.7
BDP - 6	2514	78	82	77.6	2276.4
BDP - 7	2723	0	112	16.3	2594.7
BDP - 8	4740	0	248	59.5	4432.5
BDP - 9	3231	0	104	1.39	3125.6
BDP - 10	6357	0	273	77.8	6006.2
BDP - 11	2530	3	89	13.1	2424.9
BDP - 12	2680	100	73	4.37	2502.6
Total	39854	2468	1545	362.6	35478

Note: The above area calculated as per the available toposheet (Survey of India) of study area using GIS techniques (ILWIS software).

a total cultivation area of about 35,478 ha. Horizonwise soil samples were collected for laboratory analysis. The soil samples of master profiles were analyzed for various physical and chemical properties following the standard laboratory methods (Sarma *et al.* 1987). Based on landform analysis, field surveys, laboratory analysis and field reviews, various thematic maps were prepared on 1:250,000 scale for scenario analysis.

The crop water requirement (CWR) was calculated using Modified Penman Method (Doorenbos and Pruitt 1975). The ETo values of the IMD station (India Meteorological Department) which is near the study area was considered for the calculation of the CWR. As per climate data, the percolation loss for the ponded crop was considered as 3 mm per day for the total crop period of rice. In case of other crops, as there is very small winter rainfall and the irrigation water applied is very low and it remains in the root-zone, percolation loss was not considered. The effective rainfalls and crop evapotranspiration of various crops for the study area were computed using the CROPWAT8.0 model (Smith 1991). Net Irrigation requirement (NIR) was obtained by adding percolation losses and subtracting effective rainfall from the crop evapotranspiration.

Field irrigation requirement (FIR) was calculated using formula:

$$\text{FIR} = \frac{\text{NIR} \times 100}{\text{Field efficiency}}$$

The field efficiency of 85% was adopted for ponded crops like rice and 65% for non-ponded or irrigated crops.

Gross irrigation requirement (GIR) was calculated using formula:

$$\text{GIR} = \frac{\text{FIR} \times 100}{\text{Conveyance efficiency}}$$

Conveyance efficiency value was adopted as 60% which is applicable for an unlined distribution system.

Results and Discussion

Soil scenario: Soil type and fertility

Soil elements which influence crop production were used to analyse soil fertility, including soil depth, texture, erosion, surface flooding and drainage (FAO 2007). Effective soil depth is an important soil parameter, which governs the root development and also is a source of moisture and nutrient supply to the plants (FAO 2005). The length and gradient of slope influence soil formation, soil depth, process of erosion, land use and its development. Erosion is the major soil degradation process which depends on variation in land slopes. Surface flooding is considered as one of the most serious limitations for crop production (Blum 2013). The flooding classes, which causes great damage to crops, are moderate and severe flooding. A real extent and visual theme under each class of soil depth, extent of slope and surface flooding is given in table 2 and fig. 3. Majority of soil were deep (70%) with moderate slope (60.1%) and having slight surface flooding (78.7%).

Soil texture is nearly a permanent soil characteristic having an important role for crop production. It mainly controls soil-water-nutrient

Table 2. Soil depth, soil slope and soil surface flooding of the study area

Class	Soil units	Cultivable area (in ha)
Soil depth		
Shallow (25-50 cm)	BDP-5, BDP-7	5022 (14.2%)
Moderate (75-100 cm)	BDP-3, BDP-11	5609 (15.8%)
Deep (100-150 cm)	BDP-1, BDP-2, BDP-4, BDP-6, BDP-8, BDP-9, BDP-10, BDP-12	24847 (70%)
Soil slope		
Gentle (>3-8%)	BDP-7, BDP-9, BDP-10, BDP-11	14151 (39.9%)
Moderate (>8-15%)	BDP-1, BDP-2, BDP-3, BDP-4, BDP-5, BDP-6, BDP-8, BDP-12	21327 (60.1%)
Soil surface flooding		
No flooding	BDP-9	3126 (8.8%)
Slight	BDP-1, BDP-2, BDP-3, BDP-4, BDP-5, BDP-6, BDP-7, BDP-10, BDP-11, BDP-12	27920 (78.7%)
Moderate	BDP-8	4432 (12.5%)

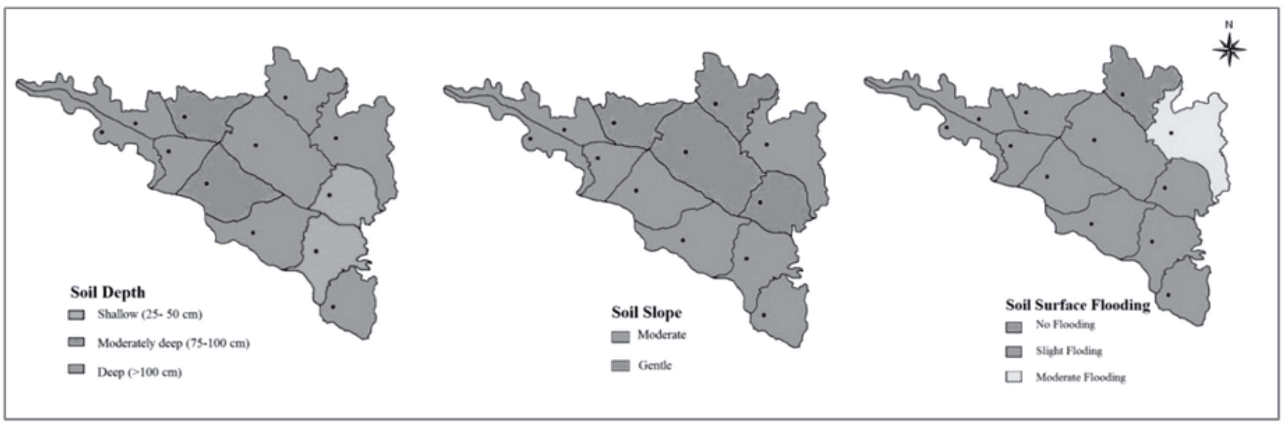

Fig. 3. Soil depth, soil slope and soil surface flooding map of the study area (Balpahari, Jharkhand, India)

retention and availability, work ability of soil, infiltration and drainage conditions. The textural groups used are clayey, sandy clay, sandy clay loam, clay loam, loam and sandy loam. Drainage is of two kinds *viz.*, surface and internal which is governed by soil texture, slope and depth of groundwater table. This influences soil-air-water relationship, the redox potential and hence the availability of air as well as nutrients (Kozlowski 1985). Since, the root growth is related to aeration, the drainage can be a limiting factor for evaluating soil productivity for many crops (FAO 2003). Based on the field observations, each class of soil texture, soil drainage and soil pH is presented in table 3 and fig. 4.

Table 3. Soil texture, soil drainage and soil pH of the study area

Class	Soil units	Cultivable area (in ha)
Soil texture		
Sandy loam	BDP-1, BDP-2, BDP-9, BDP-10, BDP-11, BDP-12	17118 (48.3%)
Loamy and clay loam	BDP-3, BDP-5, BDP-6, BDP-7, BDP-8,	14915 (42%)
Sandy clay and sandy clay loam	BDP-4	3445 (9.7%)
Soil drainage		
Imperfect	BDP-3, BDP-5, BDP-6, BDP-8, BDP-9, BDP-10, BDP-11	23877 (67.3%)
Moderately well	BDP-1, BDP-2, BDP-4, BDP-7, BDP-12	11601 (32.7%)
Soil pH		
Moderately acidic (pH 5.6-6.0)	BDP-1, BDP-2, BDP-3, BDP-4, BDP-5, BDP-7, BDP-8, BDP-10, BDP-11	27574 (77.7%)
Strongly acidic (pH 5.1-5.5)	BDP-6, BDP-9, BDP-12	7904 (22.3%)

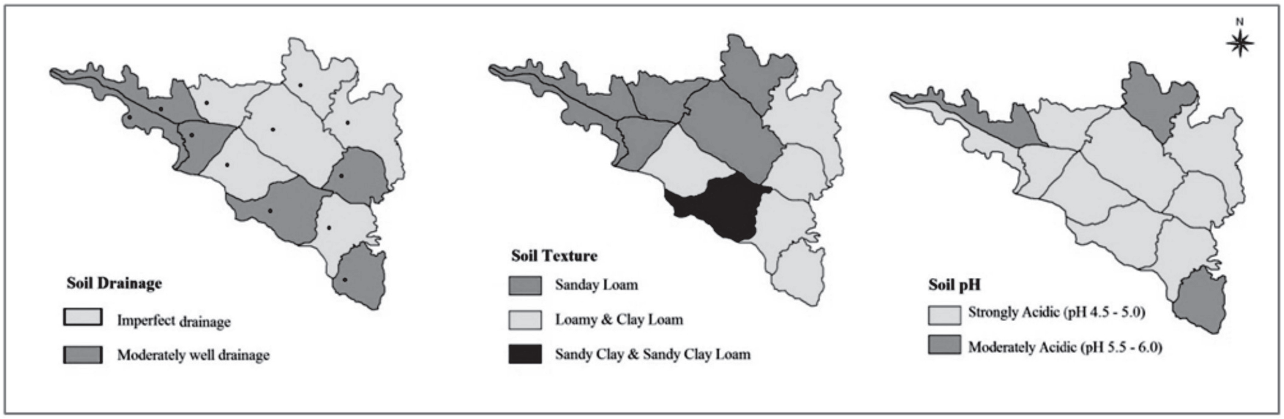

Fig. 4. Soil drainage, soil texture and soil pH map of the study area (Balpahari, Jharkhand, India)

The soil texture of the study areas ranges from sandy loam (48.3%) to sandy clay loam (51.7%). The soil pH measured in soils varied from moderately acidic (77.7%) to strongly acidic (22.3%). It is indicative that the pH range was optimum for many crops, but proper management is required to reduce the acidity hazards (Nweke and Nsoanya 2013). About 67% soils is affected by imperfect drainage condition.

Majority of surface soils (0-30 cm) were poor in N (<250 kg ha^{-1}), K (<120 kg ha^{-1}) and P (<22.4 kg ha^{-1}) content. The soils were found low to moderate in organic carbon (OC) content (1.7 to 6.5 g kg^{-1}). The distribution of N and P is presented in fig. 5. The sub-surface soil horizons were red or yellow in colour with evidence of accumulation of oxide iron.

Based on the soil and land attributes, the study area were classified into land capability subclasses as given in table 4 and shown in fig. 6. The suitability of each soil unit was evaluated on the basis of soil fertility composite index, which accumulates each element of this soil unit. The higher the accumulated numerical value is, the more suitable the soil is for crop growth (Qiu *et al.* 2002). Three subclasses *i.e.* IIes, IIIs and IVes were derived on the basis of their degrees of suitability or limitations to the crop growth. Soils under capability sub class IIes/IIIes with light to medium texture are good cultivable land but susceptible to erosion during high rainfall or over irrigation (Sys *et al.* 1991). Apart from other agriculture inputs, these soils primarily need multiple cropping systems to improve the soil condition.

From the view of soil scenario, the study area is liable-drought plateau area, with sufficient or moderate soil moisture, plain or slightly uneven terrain, thick soil body, no or mild erosion and moderately rich nutrients, and suitable for growing many profitable agricultural crops to support the livelihood of small and marginal farmers.

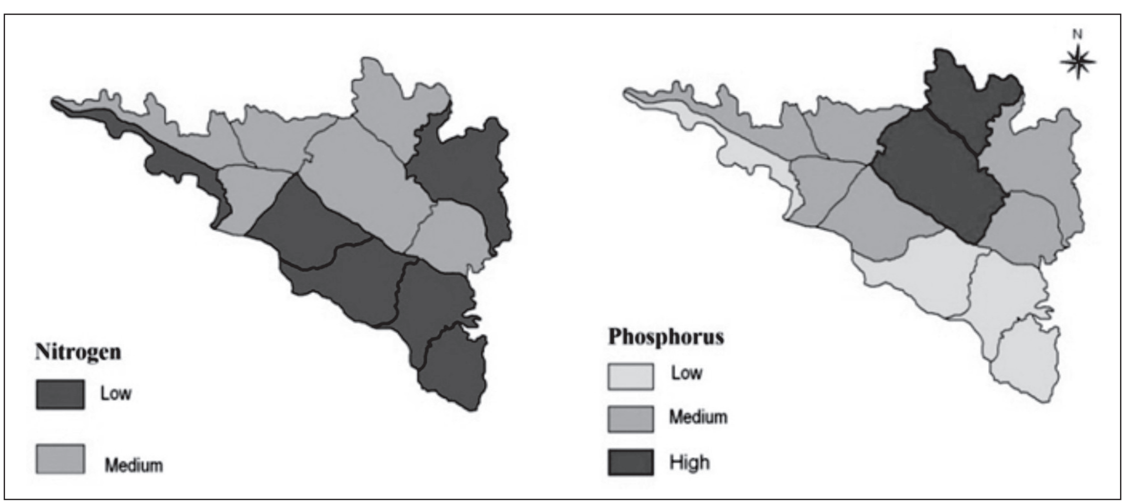

Fig. 5. Soil nitrogen and phosphorus of the study area (Balpahari, Jharkhand, India)

Table 4. Land capability and irrigability subclass of the study area

Class	Map/Soil Unit	Area (in ha)	Limitation
Land subclasses capability			
IIes	BDP-1, BDP-2, BDP-3, BDP-4, BDP-6, BDP-12	14467	Good for cultivation with due care for erosion control and irrigation management.
IIIs	BDP-5, BDP-7, BDP-9, BDP-10, BDP-11	16579	Cultivation of only those crops which are suitable under sandy loam and shallow to medium soil depth.
IIIes	BDP-8	4432	Suitable for cultivation with due care for soil fertility management and erosion control.
Land Irrigability subclasses			
A	BDP-1, BDP-2, BDP-4, BDP-6, BDP-9, BDP-10, BDP-12	20415	Soil texture- sandy loam to loam
B	BDP-3, BDP-8, BDP-11	10041	Soil texture- Loamy Sand, Soil depth: <1 m
C	BDP-5, BDP-7	5022	Soil depth < 0.5 m

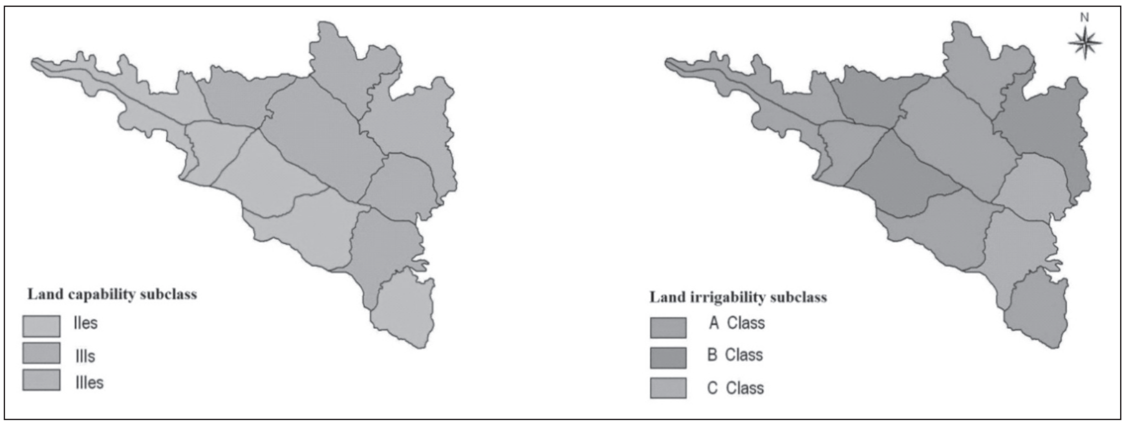

Fig. 6. Soil capability and irrigability subclasses of the study area (Balpahari, Jharkhand, India)

Irrigation scenario: Water availability and demand

Water is the most limiting factor to stabilize and increase yields due to crop-specific irrigation periods, climatic water balance, soil water storage capacity, soil water content at the start of the irrigation period, and rooting depth (Pescod 1992). The culturable area of 35,478 ha was considered in which the irrigation is required. The study area were classified into three irrigability subclasses (Table 4) on the basis of important soil characteristics like soil texture, soil depth, available moisture holding capacity, infiltration rate, permeability, coarse fragments, erosion and drainage (Fig. 6).

As per soil and climate data, the evapotranspiration (ETo), rainfall, crop-water requirement, irrigation requirement and flow of water supply for potential crops of the study area are given in table 5. The irrigation water requirement (IWR) calculations showed that, to achieve an unconstrained biomass and yield accumulation, the summer crops need comparatively more irrigation water than the winter crops (Steduto *et al.* 2012). The reason is that the time period for irrigation stretches from early March until the first week of June in summer, whereas for winter starts only from early November until the end of January. The variation in IWR was related to the precipitation pattern and evapotranspiration (ETo) rate within the study area and to the crop-soil balance related yield potential (Cohen *et al.* 2014).

Crop scenario: Crop suitability

The soil, climate, topography and water availability are essential and needed for determining crop suitability. Land suitability for growing crops consists of three main qualities *viz*., nutrient availability, rooting conditions and soil drainage system (FAO 1976; Sys *et al.* 1991). Most of the plant species need well drained, moderately fine to medium texture soils, free of salinity or acidity and having optimum physical environment (Gardner *et al.* 1999). As per current cropping system, maize, millets, black gram and vegetables are grown in upland and

Table 5. Irrigation water requirement of major crops in the study area

Crop (season)	ETo (mm/crop period)	CWR (ETm)	Rainfall (mm/period)		Irrigation requirement (mm)	FWS (l/s/ha)
			Total	Effective		
Potato (Winter)	491.8	136.3	6.5	6.3	129.9	0.17
Pulses and Oilseeds (Winter)	385.6	81.1	3.1	3.0	78.1	0.12
Wheat (Winter)	507.2	79.1	3.6	3.5	75.6	0.10
Vegetables (Winter)	375.0	87.9	4.4	4.2	83.6	0.15
Pulses (Summer)	552.5	138.0	40.8	33.0	104.9	0.19
Vegetables (Summer)	577.8	105.4	53.1	38.4	66.9	0.12
Upland maize (Rainy)	576.0	89.4	191.1	115.6	2.6	0.00
Upland groundnut (Rainy)	591.5	24.1	47.8	28.9	1.3	0.00

CWR: Crop water requirement; FWS: Field water supply assuming continuous supply and the 50% Irrigation Efficiency

Table 6. Potential cropping system as per land capability and irrigability classes in the study area

Season (month)	Rainy (June-October)		Winter season (November-March)		Summer season (April-June)	
Soil unit	BDP-1 to 4, 6,12	BDP-5, 7 to 11	BDP-1 to 4, 6,12	BDP-5, 7 to 11	BDP-1 to 4, 6,12	BDP-5, 7 to 11
Land Situation	LCC-IIes	LCC-IIIs+es	LCC-IIes	LCC-IIIs+es	LCC-IIes	LCC-IIIs+es
Upland	Maize Groundnut Black gram	Maize Groundnut Black gram	Mustard Lentil Vegetables	Mustard Lentil Berseem	Dhaincha	Dhaincha
Medium Land	Maize Black gram Cowpea Rice	Maize Black gram Cowpea Groundnut	Wheat Potato Mustard Lentil Vegetables	Potato Mustard Lentil	Green gram Vegetables Linseed	Green gram Linseed
Lowland	Rice	Rice	Wheat, Vegetables	Wheat Vegetables	Green gram Vegetables	Green gram Vegetables

medium land whereas rice is taken in lowland as main crop during rainy season. During winter season, only wheat and potato are cultivated in lowland using irrigation water. Upland and medium land remain fallow during summer and winter seasons.

Soil resource maps based on several parameters of this study provided information to predict the behaviour and suitability of soils for growing number of field crops, horticultural crops and other plantation crops as per the land suitability criteria. The major cropping pattern of field crops, which is suitable in different soil units of the study area is given in table 6. The length of growing season and development stages of crops in the existing agro-ecological situation of the study area are given in table 7. Based on the crop suitability criteria, mustard and lentil can

Table 7. Length of growing season and development stages of crops in the study area

Crop	Sowing date	Maturity date	Stages duration (days)				Irrigation frequency
			I	II	III	IV	
Rice	20 June	20 Oct.	30	31	31	30	00
Maize	20 June	10 Nov.	20	31	31	20	15
Groundnut	20 June	10 Nov.	20	31	31	20	15
Wheat	01 Nov.	20 Mar.	20	31	59	20	20
Black gram	30 Oct.	20 Feb.	20	36	36	20	15
Mustard	30 Oct.	20 Feb.	20	36	36	20	15
Linseed	30 Oct.	20 Feb.	20	36	36	20	15
Potato	20 Oct.	28 Feb.	20	41	41	28	20
Green gram	10 Mar.	12 June	20	26	26	20	15

be grown in addition to wheat and potato in upland and medium land during winter season (Johansen *et al.* 2000; Singh *et al.* 2014). Green gram, vegetables and linseed can be taken up in the existing fallow area of medium land and low land (Kar *et al.* 2006).

The stakeholder discussions on potential cropping system of study area revealed the fact that adequate involvement of farmers and perception of scientific findings are prerequisites for a systematic appraisal of the results. Diversity of interests plays an important role while addressing the changes in cropping practices.

Conclusions

The application of a series of indicators for comprehensive assessment of soil, crop and irrigation capability revealed the potential of land for cultivation of multiple crops and irrigation for increasing and stabilizing yields. In the study area, the most of the soils were shallow to moderately deep and sandy loam to clay loam in texture with slight to moderate erosion. The soils were strongly to moderately acidic in reaction with moderate organic matter and P content. Three irrigability classes A, B and C and two land capability classes (Class II and Class III) with two limitations *i.e.* slope and erosion (se) and soil problem (s) were identified. Around 14,467 ha (LCC-II) area is found to be suitable for growing wide range of crops besides rice during rainy season. In winter and summer season, vegetables, oilseeds along with some pulse crops can be grown in such type of land. About 21,011 ha (LCC-III) area is suitable for short duration variety of mustard and potato during winter and vegetables in summer with proper management of land, fertilizer and water. Crop rotation like rice-potato-green gram and rice-mustard/lentil/wheat-vegetable/linseed in lowland and medium land, and maize/groundnut-mustard-green manuring and black gram-lentil/mustard-green manuring in upland are found to be most feasible cropping system. The study is useful to generate knowledge of land capability, crop suitability and efficient soil-crop-water management system for bringing sustainability of agriculture. The information may be important for both at farm level for farmers' decision making on agricultural management and at regional level for policy decision on agriculture sustainability.

References

Beek, K.J., De Bie, K. and Driessen, P. (1997) Land information and land evaluation for land use planning and sustainable land management. *Land Chatham* **1**, 27-44.

Blum, Winfried E.H. (2013) Soil and land resources for agricultural production: general trends and future scenarios-a worldwide perspective. *International Soil and Water Conservation Research* **1**, 1-14.

Cohen, I. Sanchez, Arriaga, G. Esquivel, Velasquez Valle, M.A., Ibarra, Marco A. Inzunza, Villalobos, Arcadio Muñoz and P. Bueno Hurtado (2014) Climate based risk assessment for maize producing areas in rainfed agriculture in Mexico. *Journal of Water Resource and Protection* **6**, 1228-1237.

Doorenbos, J. and Pruitt, W.O. (1975) *Crop Water Requirements*. Irrigation and Drainage Paper No. **24**, FAO, Rome, Italy.

FAO (1976) *A framework for land evaluation. Soil Bulletin* No. **32**, Food and Agriculture Organization, Geneva.

FAO (2005) *Drought-resistant soils: Optimization of soil moisture for sustainable plant production*. FAO Land and Water Bulletin No. 11, Rome, Italy.

FAO (2003) *Optimizing soil moisture for plant production*. FAO Soil Bulletin No. **79**, Rome, Italy.

FAO (2007) *A framework for land evaluation.* FAO Soil Bulletin No. 6, Rome, Italy.

Gardner, Catriona M.K., Laryea, K.B. and Unger, P.W. (1999) *Soil physical constraints to plant growth and crop production*. AGL/MISC/24/99, FAO, Rome, Italy.

Johansen, C., Duxburv, J.M., Virmani, S.M., Gowda, C.L.L., Pande, S. and Joshi, P.K. (2000) *Legumes in rice and wheat cropping systems of the Indo-Gangetic plain - constraints and opportunities*. International Crops Research Institute for the Semi-Arid Tropics, pp. 230.

Kar, G., Verma H.N. and Singh, R. (2006) Effects of winter crop and supplemental irrigation on crop yield, water use efficiency and profitability in rainfed rice based cropping system of eastern India. *Agricultural Water Management* **79**, 280-292.

Merolla, S., Armesto, G. and Calvanese, G. (1994) A GIS application for assessing agricultural land. *ITC Journal* **3**, 264-269.

Kozlowski, T.T. (1985) Soil aeration, flooding, and tree growth. *Journal of Arboriculture* **11**, 85.

Nweke, I.A. and Nsoanya, L.N (2013) Soil pH an indices for effective management of soils for crop production. *International Journal of Scientific and Technology Research* **2**, 132-134.

Pescod, M.B. (1992) *Wastewater treatment and use in agriculture - FAO irrigation and drainage paper* No. 47, FAO, Rome, Italy.

Qiu, Bingwen, Zhou, Yong and Li, Xueyuan (2002) Dynamic assessment of regional land resource suitability based on geographical information system. *Acta Pedologica Sinica* **39**, 301-306.

Rao, M.V., Suresh Babu, V., Chandra, Suman and Chary, G. Ravindra (2016) *Integrated land use planning for sustainable agriculture and rural development*. Apple Academy Press, Canada.

Sarma, V.A.K., Krishnan, P. and Budihal, S.L. (1987) *Laboratory methods -soil resource mapping of different stales in India*. Technical Bulletin NBSS Pub. 14. NBSS&LUP (ICAR), Nagpur, 49p.

Sathish, A. and Niranjana, K.V. (2010) Land suitability studies for major crops in Pavagadataluk, Karnataka using remote sensing and GIS techniques. *Journal of Indian Society of Remote Sensing* **38**, 143-151.

Sehgal, J.L., Saxena, R.K. and Vadivelu, S. (1989) *Field Manual –Soil resource mapping of different States.* 2nd edition, Technical Bulletin **13**, NBSS&LUP, Publication, Nagpur, India.

Singh, A.K., Chakraborti M. and Datta, M. (2014) Efficient use of soil moisture and nutrients in rice based cropping systems under mid-tropical plain zone of India. *Rice Science* **21**, 299-304.

Smith, M. (1991) *CROPWAT:* Manual and Guidelines. FAO of UN, Rome, Italy.

Steduto, Pasquale, Hsiao, Theodore C., Fereres, Elias, Raes Dirk (2012) *Crop yield response to water*, FAO irrigation and drainage paper No. 66, FAO, Rome, Italy.

Swaminathan, M.S. (1996) *Sustainable agriculture: Towards an evergreen revolution*. Delhi: Konark Publishers Pvt. Ltd.

Sys, I.C., Van, R. and Debaveye, J. (1991) *Principles in land evaluation and crop production calculations. Land evaluation*, **Part-I**, International Training Centre for Postgraduate Soil Scientist, University of Ghent.

Tillman, D., Cassman, K.G., Matson, P.A., Naylor, R. and Polasky, S. (2002) Agricultural sustainability and intensive production practices. *Nature* **418**, 671-677.

Revised received 29 January 2017; Accepted 20 May 2017