Characterization and crop planning of *rabi* fallows using remote sensing and GIS

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Rice is the principal crop during *kharif* (rainy) season in eastern India, which occupies 26.8 M ha accounting for 63.3% of the total rice-growing areas of the country. However, this area is not fully utilized for crop production in the subsequent *rabi* (post-rainy) season and kept fallow due to a number of biotic, abiotic and socio-economic constraints. If this *rabi* fallow area can be effectively utilized, it will help in improving the economy of this region, which is yet to be benefited from the green revolution. The objectives of the present study include: (i) delineation of *rabi* fallow areas of eastern India using remote sensing and GIS technique; (ii) characterization of soil resources of the *rabi* fallow regions, and (iii) suggesting site-specific crop planning for this region. It was estimated that about 12.54 M ha area in the *rabi* season is left fallow in eastern India. The soil properties like soil texture, soil moisture retention at field capacity and permanent wilting point, saturated hydraulic conductivity, soil pH, electrical conductivity, soil organic carbon, etc. were determined at the representative profiles distributed in different agro-ecological sub-regions (AESRs) of this region and mapped in a GIS environment. Using water balance studies, site-specific crop planning based on available residual soil moisture has been suggested. In most of the AESRs, pulses and oilseeds like green gram, black gram, Sesamum and mustard can be grown successfully on residual soil moisture content. Crops which suffer from water deficit during maturity stages can also be grown during *rabi* season with one or two supplemental irrigations, wherever possible. If the site-specific constraints to crop production can be alleviated and these fallow lands can be brought under cultivation through proper crop planning as suggested, poverty in this resourceful region can be eradicated to a great extent.

Keywords: Crop planning, *rabi* fallow, remote sensing and GIS, water balance.

EASTERN India comprises Eastern Uttar Pradesh (UP; 85,844 sq. km), undivided Bihar and Jharkhand (173, 877 sq. km), Assam (78,438 sq. km), Chhattisgarh (144,422 sq. km), Odisha (155,707 sq. km) and West Bengal (88,751 sq. km)[1]. The total geographical area of eastern India is 73.66 M ha, which accounts for 22% of the total geographical area of the country. The net cultivated area in this region is only 45% (33.6 M ha). This region contributes to 34.6% of the total national food production. The food-grain productivity in this region is highest in West Bengal followed by Eastern UP, Bihar, Assam, Odisha, Jharkhand and Chhattisgarh. The cropping intensity in West Bengal, Odisha, Eastern UP, Assam, Bihar, Jharkhand and Chhattisgarh is 177%, 152%, 151%, 145%, 142%, 118% and 115% respectively. This region is inhabited by 38% of the total national population (Census of India, 2011). However, agricultural development is much below its potential in this region. As a result, employment opportunity in the agricultural sector is limited, forcing a large portion of the population to remain below poverty line and suffer from malnutrition. The per capita availability of the net cultivated area in this region is the lowest in the country. Most of the farm holdings are marginal to small and highly fragmented hampering the adoption of mechanization. This region is rich in rain, surface and groundwater resources. The average annual rainfall ranges between 1100 and 1200 mm, which is sufficient to meet the agricultural water requirement of many crops. However, there is a large spatial and temporal variation in the rainfall, which causes instability in agricultural productivity and production.

Rice is the principal crop during *kharif* (rainy) season in this region, which occupies 26.8 M ha accounting for 63.3% of the total rice-growing areas. However, this area is not fully utilized for crop production in the subsequent *rabi* (post-rainy) season and kept fallow. The major constraints to crop production during *rabi* fallow in this region have both technical and socio-economic dimensions[2]. If through proper research, planning and extension efforts, these areas can be brought under double cropping with proper utilization of carryover residual soil moisture and by providing supplemental irrigation, it can solve the food and nutritional security problem and benefit millions of poverty-ridden people of this region solely dependent on agriculture for their livelihood.

Multi-temporal remote sensing data are widely acknowledged as having significant advantages over single-date imagery for studying dynamic phenomena[3]. Use of

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multi-temporal data is especially advantageous in areas where vegetation or land-use changes rapidly. This offers opportunities for better vegetation characterization than could be achieved with a single-date image. Multi-temporal remote sensing data provide an opportunity to characterize agricultural land-use at the regional level. Vegetation indices (VIs) have been extensively used for monitoring and detecting vegetation and land-cover change[4]. Among the vegetation indices, the normalized difference vegetation index (NDVI) has been popular because of its simple calculation and established relation with vegetation parameters[5]. Vegetation indices are especially advantageous with multi-date datasets. Various multi-date vegetation indices are clustered to classify broad areas (usually at continental scale) according to the seasonalities of their green up/senescence sequences. Several studies have characterized vegetation phenology at continental scales using time series of vegetation indices obtained from satellite data.

With this backdrop, the objectives of the present study include: (i) delineation of *rabi* fallow areas of eastern India using remote sensing and GIS technique; (ii) characterization of the soil resources of *rabi* fallow regions, and (iii) suggestion of site-specific crop planning for the eastern region.

Materials and methods

Study area

The study area comprises the Eastern region of India situated between lat. 17.778°–28.403°N and long. 80.214°–89.830°E. This region includes Eastern UP, Bihar, Jharkhand, Chhattisgarh, Odisha and West Bengal as mentioned earlier. The base map of study area with district and state boundaries was prepared using GIS software Arc GIS (ver. 10) as shown in Figure 1.

Delineation of rabi fallow areas

The vegetation instrument on-board SPOT4 offers a valuable tool for vegetation mapping at the regional scale. The maximum value composite (MVC) products of NDVI with 1 km spatial resolution, available from the vegetation sensor on-board SPOT4, play a significant role in discriminating the vegetation types[6]. The compositing procedure attempts to eliminate measurements that are strongly influenced by atmospheric and aerosol scattering, which reduce NDVI values due to differential scattering effects in red and near-infrared bands[7]. More details about the sensor and data products are available in the VGT User's Guide (1999). To delineate *rabi* fallow areas of eastern India using ten-day MVC of SPOT NDVI during June 2012 to May 2013, data about 36 images were downloaded from the VGT free data product site (http://free.vgt.vito.be) (Figure 2). These data were georeferenced and stacked to a single file. It was then masked to select only the eastern India region (comprising Eastern UP, Bihar, Jharkhand, Chhattisgarh, West Bengal and Odisha). As these temporal data products carry noise, before analysing them further for agricultural land-use, corrections were made using FASIR (Fourier adjusted sun zenith angle corrected interpolated and reconstructed) techniques. NDVI data from a satellite sensor are primarily related to vegetation changes and follow an annual cycle of growth and decline. Clouds and poor atmospheric conditions usually depress NDVI values causing a sudden drop in them, which is not compatible with the gradual process of vegetation growth; it is considered as noise and removed. Using available land-use/land-cover map of India, only agriculture area was masked for further classification. As the conventional technique has its own limitation in classifying temporal data products, a recently developed approach called spectral angle mapper classification technique was used to retrieve agricultural land-use pattern. The image processing was done using ENVI (ver. 4.8).

Characterization of soils of rabi fallow areas

Soil samples of 26 dominating sub-groups belonging to five soil orders, viz. Entisols, Inceptisols, Alfisols, Vertisols and Mollisols of different AESRs of all the states of

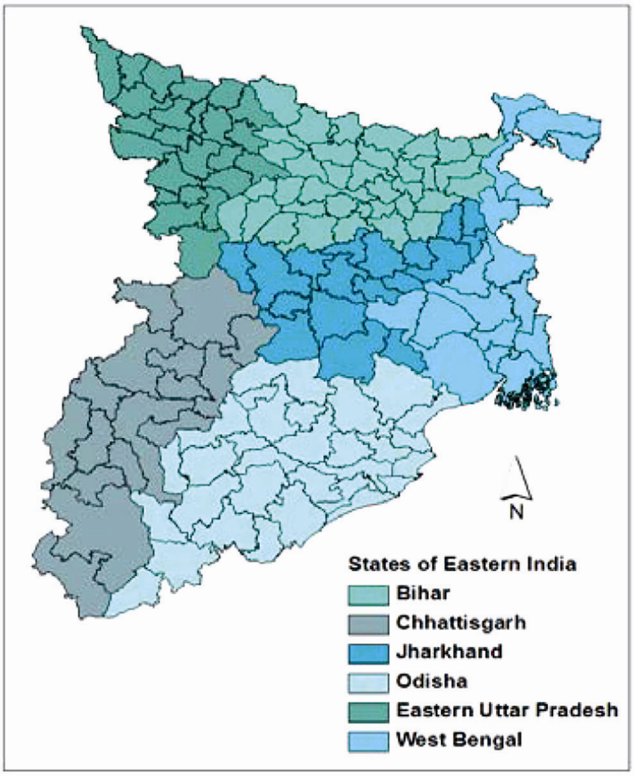

Figure 1. States of eastern India with district boundaries.

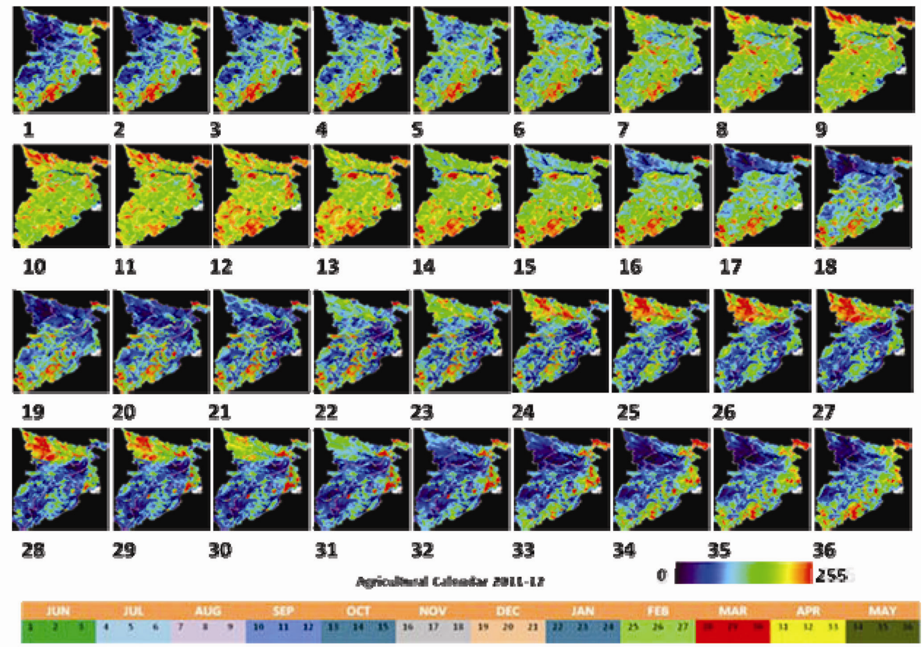

Figure 2. Temporal variation in SPOT NDVI image during agricultural calendar period indicating crop growth dynamics.

eastern India excluding Assam were used in the present study. Three profiles were dug for each soil subgroup at each site and soil samples collected from 0 to 30, 30 to 60 and 60 to 90 cm depths of each profile were analysed for important physico-chemical characteristics. Mechanical composition of the soil samples was determined following international pipette method[8]. Water retention characteristics were determined in undisturbed soil samples collected using metal cores of 5 cm diameter from all these depths using pressure plate apparatus[9]. Water retention at 10 kPa tension was considered as field capacity value for light textured soils and that at 33 kPa tension for medium and heavy textured soils. Difference between the soil moisture retained at field capacity and permanent wilting point (1500 kPa) was computed as available water capacity. Saturated hydraulic conductivity was determined in undisturbed soil cores of 4.2 cm diameter and 5.8 cm height by constant head percolation method[10]. Soil pH and soil organic carbon content were determined using standard analytical technique[11]. Erosion indices, i.e. dispersion ratio and erosion index were determined following the procedures of Middleton[12] and Sahi *et al.*[13] respectively. Soil map of the eastern region taken from National Bureau of Soil Survey and Land Use Planning (NBSS and LUP) has been digitized and thematic layers of different soil properties were prepared in GIS environment using the software Arc GIS.

Computation of residual soil moisture and crop planning

Eastern India receives major portion of the rainfall from June to mid-October during the southwest monsoon. The earliest period of onset of monsoon is between 1 and 20 June and that of withdrawal is between 15 September and 5 October. Rice is the major crop grown during *kharif* season in this region and is harvested between 15 October and 15 November. After harvest of rice, the *rabi* season crops are sown by 15 November on residual soil moisture. The evaporation loss from the bare plot was calculated following Gardner[14] and the crop water requirement for different *rabi* crops was computed following Doorenbos and Pruitt[15]. The evaporation losses were deducted from the plant available water content (water retained between 0.33 and 1.5 MPa tension) to obtain the residual soil moisture available to the *rabi* crops. Simulation of residual soil moisture dynamics and evapo-transpiration under different crops is based on the soil moisture dynamics in the crop root zone.

If the water requirement for a crop is equal to or less than the residual soil moisture, then taking that crop in *rabi* season was assumed to be successful without any additional irrigation. If the residual soil moisture fulfiled 75–80% of the crop water requirement, then the crop cultivation was assumed to be successful with the application of one irrigation. If the residual soil moisture fulfiled 55–60% of the crop water requirement, then the crop cultivation was assumed to be successful with the application of two irrigations at critical growth stages[16].

Results and discussion

Delineation of rabi fallow areas

Pattern of agricultural land-use was revealed from time-series NDVI images. The temporal NDVI profile given in

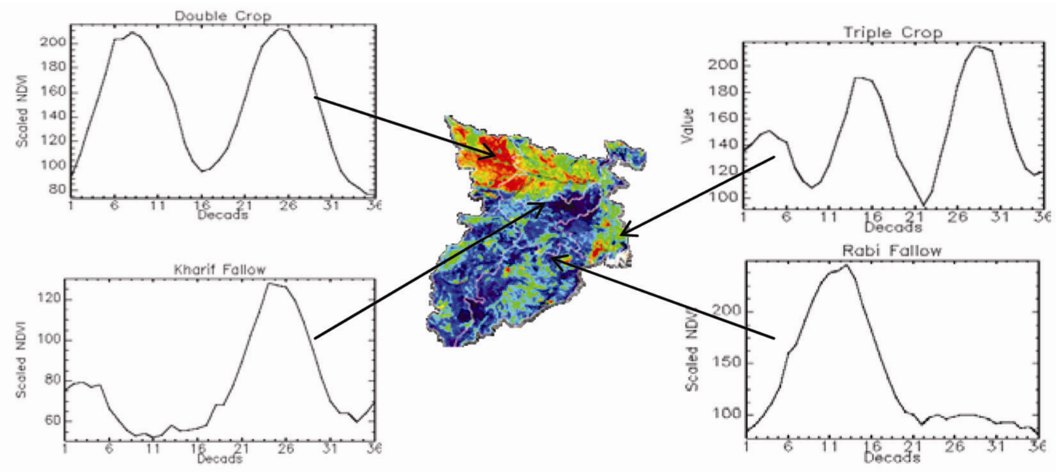

Figure 3. NDVI image with temporal NDVI profile showing major agricultural land-use in eastern India.

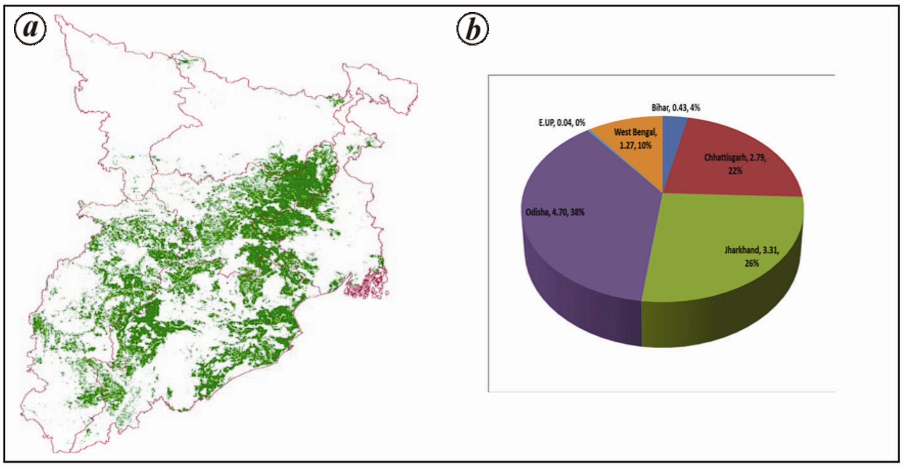

Figure 4. ***a***, Distribution of *rabi* fallow area of eastern India derived from time-series remote sensing data; ***b***, their coverage in different states.

Figure 2 shows major land-use patterns such as *kharif* fallow, *rabi* fallow, double and triple crops. The bimodal distribution of the temporal variation in NDVI was identified as double-cropped area and trimodal distribution as triple-cropped area, whereas the region with unimodal distribution of NDVI was identified as *rabi/kharif* fallow area (Figure 3). The NDVI profile of *rabi* fallow area was used in spectral angle mapper classification technique to map the area (Figure 3).

It was found that nearly 12.54 M ha area was being kept fallow during *rabi* season in the eastern states. This includes both land kept fallow after rice (rice fallow) and land kept fallow after other *kharif* crops (Figure 4). So this is higher than the rice fallow area (9.84 M ha) reported by Subbarao *et al.*[17]. The present study was conducted using coarser resolution remote sensing data (1 km data) to generate area statistics, which could be further improved using moderate or fine-resolution sensors.

Characterization of soil resources of the rabi fallow areas

The soils of the eastern region mainly constitute six orders, viz. Inceptisols, Entisols, Alfisols, Vertisols, Mollisols and Ultisols. Among them, Inceptisols is the dominant soil order covering approximately 34 M ha area. In general, 22–75% of the area in different states is under Inceptisols. Soils of Eastern UP, West Bengal and Odisha have more than 50% area under Inceptisols. Alfisols cover approximately 20 M ha area, which accounts for 10–50% area in different states of the Eastern region. The third major soil order in this region is Entisols, covering an area of 14.5 M ha. The area covered by Vertisols and Ultisols accounts for 3 and 0.39 M ha respectively (Figure 5). The spatial distribution of different soil orders in eastern India is depicted in Figure 5 *a* and *b*. Spatial analysis of *rabi* fallow under different soil orders was done overlaying soil order map on *rabi* fallow layer (Figure 6 *a*).

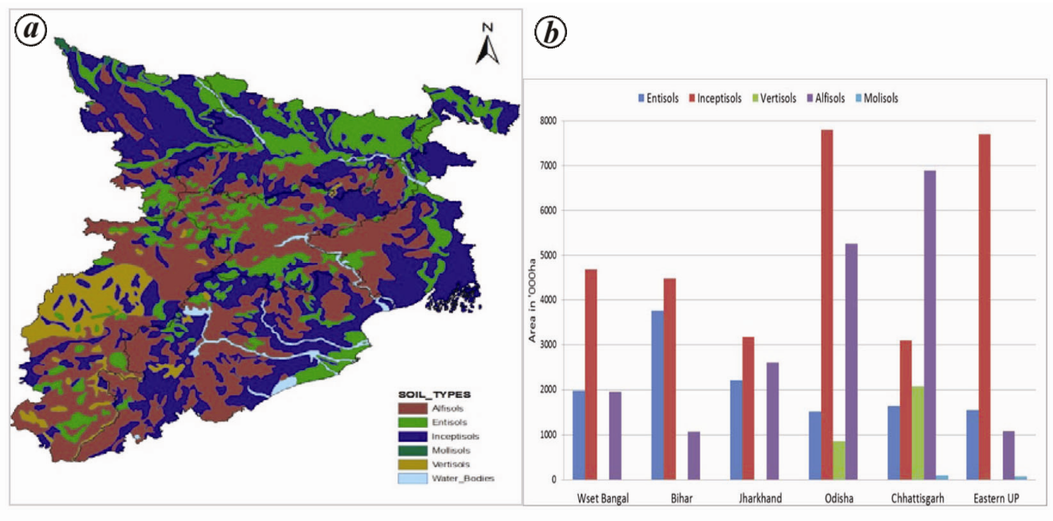

Figure 5. ***a***, Major soil orders prevailing; ***b***, their area distribution in different states in eastern India.

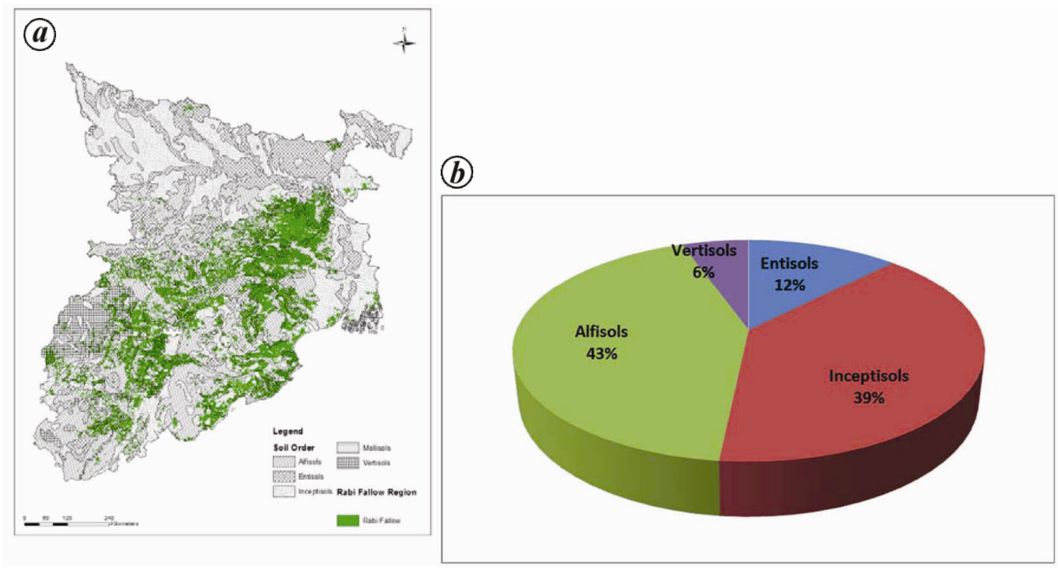

Figure 6. ***a***, Distribution of *rabi* fallow under different soil orders in eastern India; ***b***, coverage under different soil orders.

The results indicate that maximum area under *rabi* fallow was found under Alfisols in Odisha and under Entisols in Bihar. Among the *rabi* fallow areas, maximum area was coming under Alfisols (43%), followed by Inceptisol (39%), Entisols (12%) and Vertisols (6%; Figure 6 *b*).

The physical properties of the major sub-groups of this region are presented in Table 1. It was observed that soil texture varied from sandy loam to clay loam in the region. Most of the fine textured soils belong to Inceptisols, Vertisols and Mollisols and coarse textured soils belong to Alfisols and Entisols sub-groups (Table 1). All the soil sub-groups of Entisols and most of the Inceptisols have very high erosion index (Table 1), indicating that these soils are prone to erosion. So soil conservation measures should be taken up on priority basis in these soils. At 33 kPa tension and 1500 kPa tension, highest water was retained by Typic Haplustepts and lowest by Typic Ustipsamments[18]. Thus highest available water at all depths was found in Typic Haplustepts and lowest in Typic Ustipsamments. The distribution of available soil moisture in the eastern region is shown in Figure 7. In comparison to Alfisols and Entisols, more water was retained by Inceptisols, Vertisols and Mollisols at 33 and 1500 kPa tension. This helps conserve and carry over moisture in these types of soils. In general, the hydraulic conductivity is low in the soils of this region indicating poor drainage conditions. Among the different soil subgroups, the highest saturated hydraulic conductivity was

Table 1. Soil texture, water content at field capacity, wilting point, available water capacity and saturated hydraulic conductivity of some of the dominating sub-groups of eastern India

Soil sub-order	Soil texture	Water content at 33 kPa ($cm^3\ cm^{-3}$)	Water content at 1500 kPa ($cm^3\ cm^{-3}$)	Available water ($cm^3\ cm^{-3}$)	Available water capacity ($cm\ m^{-1}$)	Saturated hydraulic conductivity ($cm\ h^{-1}$)	Erosion index
Entisol							
Aeric Fluvaquent	c to cl	0.333–0.578	0.186–0.309	0.147–0.269	14.7–26.9	0.003–0.009	36.79
Typic Ustipsamments	ls to scl	0.107–0.238	0.041–0.120	0.066-0.118	6.60–11.80	0.328–0.428	36.58
Typic Ustorthents	l to cl	0.291–0.407	0.129–0.208	0.162–0.199	16.2–19.9	0.030–0.074	25.95
Lithic Ustorthents	cl	0.389–0.401	0.174–0.202	0.199–0.215	19.9–21.5	0.072–0.089	27.59
Inceptisols							
Aeric Tropaquepts	c	0.415–0.464	0.169–0.215	0.246–0.249	24.6–24.9	0.01–0.027	22.15
Aeric Haplaquepts	sl to c	0.297–0.409	0.101–0.173	0.196–0.236	19.6–23.6	0.146–0.361	29.35
Typic Ustochrepts	c	0.516–0.609	0.238–0.286	0.278–0.323	27.8–32.3	0.016–0.027	19.16
Vertic Haplaquepts	c	0.452–0.557	0.231–0.315	0.221–0.242	22.1–24.2	0.011–0.021	15.20
Vertic Tropaquepts	scl	0.152–0.294	0.071–0.109	0.081–0.185	8.1–18.5	0.051–0.091	32.83
Typic Ustropepts	scl to c	0.328–0.432	0.136–0.198	0.192–0.234	19.2–23.4	0.011–0.900	20.77
Typic Tropaquepts	c	0.450–0.497	0.201–0.272	0.225–0.249	22.5–24.9	0.007–0.021	16.03
Vertic Ustochrepts	sl to sc	0.210–0.377	0.07–0.196	0.140–0.181	14.0- 18.1	0.014–0.102	38.52
Typic Haplustepts	cl to c	0.331–0.453	0.176–0.267	0.155–0.186	15.5–18.6	0.302–0.411	33.59
Alfisols							
Ultic Paleustalfs	sl to scl	0.170–0.259	0.060–0.139	0.110–0.120	11.0–12.0	0.695–0.793	10.15
Typic Paleustalfs	scl to c	0.298–0.395	0.134–0.229	0.164–0.166	16.4–16.6	0.601–0.892	13.89
Rhodic Paleustalfs	sc to c	0.269–0.330	0.126–0.189	0.141–0.143	14.1–14.3	0.701–0.847	8.74
Typic Rhodustalfs	scl to sc	0.216–0.408	0.084–0.200	0.132–0.208	13.2–20.8	0.410–0.574	13.89
Typic Ochraqualfs	cl to c	0.379–0.453	0.184–0.242	0.195–0.211	19.5–21.1	0.015–0.062	18.74
Aeric Ochraqualfs	l to c	0.336–0.462	0.098–0.235	0.227–0.238	22.7–23.8	0.038–0.309	21.80
Typic Haplustalfs	scl to cl	0.365–0.442	0.159–0.183	0.206–0.259	20.6–25.9	0.074–0.124	19.93
Kandic Paleustalfs	scl to c	0.243–0.501	0.139–0.250	0.104–0.251	10.4–25.1	0.149–0.713	17.70
Vertisols							
Typic Chromusterts	c	0.382–0.492	0.201–0.271	0.181–0.221	18.1–22.1	0.021–0.905	12.83
Chromic Haplusterts	c	0.359–0.401	0.191–0.208	0.168–0.193	16.8–19.3	0.035–0.102	27.91
Typic Haplusterts	c	0.387–0.467	0.184–0.237	0.203–0.230	20.3–23.0	0.141–0.322	35.19
Mollisols							
Lithic Haplustolls	scl to c	0.243–0.442	0.082–0.173	0.161–0.269	16.1–26.9	0.361–0.871	28.41

C, Clay; l, Loam; sl, Sandy loam; ls, Loamy sand; scl, Sandy clay loam; sc, Sandy clay; cl: Clay loam.

observed in Typic Ustipsamments and lowest in Aeric Fluvaquents. Soils of this region are low in soil organic carbon and are mostly acidic in reaction.

Crop planning for the rabi fallows of different agro-ecological subregions of Eastern India

The NBSSP & LUP has divided India into 20 AESRs based on soil, crop, climate, physiography and length of growing period (LGP)[19]. The eastern region of India falls under 16 of these sub-regions, as shown in Figure 8. The residual soil moisture for different AESRs was computed by water balance method considering the available water capacity of the soil and evaporation that took place after harvest of the *kharif* crop (Table 2). The percentage of crop water requirement for different *rabi* season pulses and oilseeds, viz. gram, lentil, groundnut, mustard, green gram, black gram, sesamum and horse gram, that can be fulfiled by the residual soil moisture is shown in Table 3. The crop planning for different AESRs of eastern India is given in Table 4.

In AESR 9.2, which is dominated by Alfisols, Inceptisols and Entisols, maximum evaporation (6.29 cm/m) takes place from Alfisols leaving 17.31 cm/m available residual soil moisture, which can be effectively utilized by *rabi* crops. This residual soil moisture is adequate to meet the water requirement of mustard, green gram, black gram, sesamum and horse gram in Alfisols and mustard and horse gram in Inceptisols and Entisols (Table 4). However, by providing one life-saving irrigation at critical growth stages, gram and groundnut crops can be grown successfully on Alfisols, and lentil on Inceptisols and Entisols. There is the possibility of gram and groundnut cultivation on Inceptisols and Entisols, if provision of two irrigations is made. This AESR is characterized as sub-humid dry with LGP between 150 and 180 days, out of which about 100–110 days are utilized by rice cultivation and the remaining 40–70 days can be utilized for *rabi* crops. Therefore, short-duration varieties of suggested pulses and oilseeds can be successfully grown in this region to bring the *rabi* fallow under cultivation.

In the hot–moist sub-humid AESR 12, LGP varies from 150 to 210 days with rainfall of 1200–1700 mm and mean temperature of 25–28°C. This region can support a number of crops through residual soil moisture and effective rainfall. This zone can be subdivided into three sub-regions, i.e. 12.1, 12.2 and 12.3. In sub-region 12.1, Alfisols, Entisols, Inceptisols and Vertisols retain 9.88, 14.04, 15.84 and 15.03 cm/m residual soil moisture respectively. With the availability of residual soil moisture, horse gram can be grown in Inceptisols and Vertisols, and mustard and horse gram in Entisols. However, provision of one irrigation can help in the cultivation of lentil and with two irrigations, a number of pulses and oilseeds can be grown (Table 4). In AESR 12.2, Alfisols, Inceptisols and Entisols can retain 10.33, 20.20 and 13.97 cm/m residual soil moisture respectively, which can help in successful cultivation of mustard, green gram, black gram, sesamum and horse gram crops in Inceptisols. However, residual soil moisture retained in Alfisols and Entisols is not adequate to meet the water demand of any of the proposed *rabi* crops without irrigation. In AESR 12.3, Alfisols and Inceptisols retain 9.88 and 13.51 cm/m residual soil moisture respectively, which is sufficient to meet the water requirement of mustard, black gram, sesamum and horse gram crops on Alfisols. None of the proposed *rabi* crops can meet the water requirement without provision of one or two irrigations. Provision of one irrigation at critical growth stages can help horse gram, green gram, black gram and sesamum crops complete their life cycle. Under adequate water availability to provide two irrigations, gram, lentil and groundnut can be cultivated successfully.

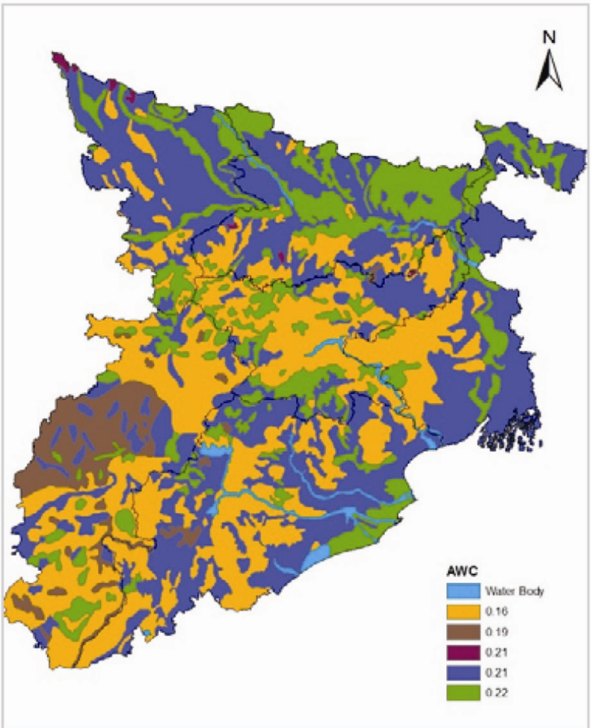

Figure 7. Spatial distribution of available water capacity of eastern India.

The moist, sub-humid AESR 13 consists of two sub-regions, i.e. hot dry–moist (13.1) and warm hot–moist (13.2). This sub-region is dominated by Inceptisols and Entisols with pockets of Mollisols. This sub-region receives 1200–1500 mm rainfall, with effective rainfall during *rabi* season being 51.5 mm. The residual soil moisture retention of this region was respectively, 9.74, 11.82 and 11.26 cm/m for Inceptisols, Entisols and Mollisols with evaporation values of 6.86, 5.58 and 6.94 cm/m. Residual moisture retained by Incetptisols is adequate for cultivation of horse gram and by Entisols to grow mustard, black gram, sesamum and horse gram, while Millisols can support complete growth of mustard and horse gram crops with residual soil moisture. Provision of one irrigation on Inceptisols and Mollisols can facilitate successful cultivation of green gram, black gram and sesamum, whereas provision of two irrigations can assure the cultivation of gram, lentil and groundnut on Inceptisols and Mollisols. The LGP of this sub-region ranges from 80 to 100 days. So *rabi* crops of 80–100 days duration can be grown either solely on residual soil moisture or by applying one or two irrigations at critical growth stages. Moreover short, medium and late-medium duration varieties of the aforesaid crops can be grown on medium textured soils of this region.

The AESR 15 is characterized by sub-humid to humid and perhumid climate. This sub-region is dominated by Inceptisols with considerable coverage of Alfisols and Entisols. This region is divided into four sub-regions, i.e. 15.1, 15.2, 15.3 and 15.4. In AESR 15.1, Alfisols, Inceptisols and Entisols retain 10.45, 10.29 and 15.91 cm/m residual moisture with evaporation of 6.65, 5.41 and 5.39 cm/m respectively. The residual soil moisture can meet the water requirement of mustard, black gram, sesamum and horse gram on Alfisols and Inceptisols and lentil, mustard, green gram, black gram, sesamum and horse gram on Entisols. In sub-regions 15.2, 15.3 and 15.4, Inceptisols retain 11.3, 12.94 and 10.46 cm/m residual water with evaporation amounting 6.0, 6.26 and 5.94 cm/m respectively. Available residual soil moisture in sub-regions 15.2, 15.3 and 15.4 in Inceptisols can meet the water requirement of mustard and horse gram crops. Green gram, black gram and sesamum crops can also complete their life cycles on Inceptisols of sub-regions 15.2 and 15.4 with the available soil moisture. With application of two supplemental irrigations, it is possible to grow gram, lentil and groundnut crops in sub-regions 15.2 and 15.4. In sub-region 15.3, green gram, black

Table 2. Computation of residual soil moisture in different agro-ecological sub-regions (AESRs) of eastern India by water balance approach

AESR	Dominating soil order	Moisture content at 33 kPa (cm^3/cm^3)	Moisture content at 1500 kPa (cm^3/cm^3)	Available water capacity (cm^3/cm^3)	Available water capacity (cm/m)	Water lost through evaporation (cm/m) during 5 October to 15 November	Residual soil moisture (cm/m) on 15 November
9.2	Alfisols	0.351	0.115	0.236	23.6	6.29	17.31
	Inceptisols	0.286	0.115	0.171	17.1	3.99	13.11
	Entisols	0.320	0.144	0.176	17.6	4.92	12.68
11	Alfisols	0.294	0.159	0.135	13.5	6.71	6.79
	Entisols	0.338	0.150	0.188	18.8	4.39	14.41
	Inceptisols	0.514	0.274	0.240	24.0	7.61	16.39
	Vertisols	0.414	0.218	0.196	19.6	4.60	15.00
12.1	Alfisols	0.317	0.161	0.156	15.6	5.72	9.88
	Entisols	0.348	0.160	0.188	18.8	4.76	14.04
	Inceptisols	0.504	0.264	0.240	24.0	8.16	15.84
	Vertisols	0.414	0.218	0.196	19.6	4.57	15.03
12.2	Alfisols	0.322	0.162	0.160	16.0	5.67	10.33
	Inceptisols	0.518	0.264	0.254	25.4	5.20	20.20
	Entisols	0.358	0.169	0.189	18.9	4.93	13.97
12.3	Alfisols	0.316	0.159	0.157	15.7	5.82	9.88
	Inceptisols	0.307	0.133	0.174	17.4	3.89	13.51
13.1	Inceptisols	0.323	0.157	0.166	16.6	6.86	9.74
	Entisols	0.301	0.127	0.174	17.4	5.58	11.82
13.2	Mollisols	0.332	0.150	0.182	18.2	6.94	11.26
15.1	Alfisols	0.356	0.185	0.171	17.1	6.65	10.45
	Inceptisols	0.291	0.134	0.157	15.7	5.41	10.29
	Entisols	0.314	0.101	0.213	21.3	5.39	15.91
15.2	Inceptisols	0.334	0.158	0.176	17.6	6.30	11.30
15.3	Inceptisols	0.328	0.136	0.192	19.2	6.26	12.94
15.4	Inceptisols	0.340	0.176	0.164	16.4	5.94	10.46
16.1	Inceptisols	0.297	0.142	0.155	15.5	6.62	8.88
16.2	Inceptisols	0.303	0.151	0.152	15.2	5.28	9.92
17.1	Alfisols	0.356	0.185	0.171	17.1	5.53	11.57
18.4	Inceptisols	0.452	0.231	0.221	22.1	5.54	16.56
	Entisols	0.342	0.168	0.174	17.4	4.76	12.64
18.5	Inceptisols	0.442	0.231	0.211	21.1	5.47	15.63
	Entisols	0.352	0.178	0.174	17.4	4.79	12.61

gram and sesamum crops can be successfully cultivated with only one irrigation and gram, lentil and groundnut can be cultivated with two irrigations (Table 4). The LGP in this sub-region is 210–300 with rainfall of 1200–1500 mm, including seasonal effective rainfall of 93–219 mm during *rabi* season. After harvest of rice in *kharif* season, a large number of pulses and oilseeds can be grown in this region. Also the crop varieties of short, medium and long duration can be grown in this region.

The eastern Himalaya warm per-humid AESR 16, dominated by Inceptisols, is divided into two sub-regions, i.e. 16.1 (hot per-humid) and 16.2 (warm per-humid). This sub-region is characterized by LGP > 300 days with high rainfall of 2500–3000 mm. In some parts, temperatures are low and range between 13°C and 15°C. Because of high LGP and high rainfall, a large number of crops can be cultivated in this region. However, topography and high rainfall also limit the choice of the crops. Inceptisols can retain 8.88 and 9.92 cm/m residual soil moisture with evaporation of 6.62 and 5.52 cm/m in sub-regions 16.1 and 16.2 respectively. No crop cultivation is possible with the residual soil moisture among proposed *rabi* pulses and oilseeds in sub-region 16.1, whereas horse gram can be grown successfully in sub-region 16.2. Application of one irrigation can help gram and lentil crops to complete their life cycle and with two irrigations groundnut can be grown in the sub-region 16.2. In AESR 16.1, mustard and horse gram crops can be grown with one irrigation and black gram, green gram and sesamum with two irrigations.

In the northeastern warm pre-humid AESR 17.1, LGP varies between 270 and 300 days with >2500 mm annual precipitation, 1500–1600 mm potential evaporation and 16–240°C mean temperature. This is also considered as a resource-rich region due to great possibilities of *rabi* crop cultivation. Though the topographical features and large area under forests limit the choice of the crops, a large number of pulses and oilseed crops can be cultivated in this region on residual soil moisture. This sub-region is mainly dominated by Alfisols, which can retain 11.57 cm/m residual soil moisture with evaporation of 5.53 cm/m. The residual soil moisture is sufficient to

Table 3. Water requirement (%) fulfilled by residual soil moisture in different AESRs of eastern India

	Crop water requirement fulfilled by residual soil moisture content (%)							
AESR	Gram	Lentil	Groundnut	Mustard	Green gram	Black gram	Sesa mum	Horse gram
Alfisols								
9.2	69	86	60	155	138	136	140	185
11	19	23	17	36	29	30	32	41
12.1	30	37	25	63	54	54	54	73
12.2	28	35	24	59	50	51	51	67
12.3	34	43	29	80	68	72	72	93
15.1	61	65	37	147	97	105	122	128
17.1	73	95	63	192	164	166	161	222
Inceptisols								
9.2	49	62	42	105	93	94	94	123
11	46	57	40	86	76	77	77	95
12.1	47	58	42	93	86	83	81	104
12.2	63	79	55	130	107	108	114	151
12.3	50	63	43	112	97	102	101	131
13.1	42	54	36	91	78	79	79	103
15.1	58	63	35	141	92	101	118	127
15.2	55	69	48	122	103	105	108	144
15.3	53	65	45	106	91	92	93	123
15.4	59	72	50	128	106	108	113	151
16.1	37	46	31	78	69	69	68	90
16.2	79	98	68	182	154	162	161	217
18.4	45	54	38	83	74	74	73	95
18.5	51	62	44	107	90	91	93	125
Entisols								
9.2	51	63	44	103	91	93	91	117
11	53	65	46	95	84	85	85	109
12.1	54	64	46	107	91	91	93	123
12.2	41	51	35	83	73	74	73	93
13.1	53	66	46	112	102	100	103	133
15.1	98	104	59	236	151	161	198	214
18.4	33	40	28	63	55	56	56	71
18.5	35	42	30	69	61	61	60	78
Vertisols								
11	48	59	41	91	79	79	79	100
12.1	50	62	42	99	90	90	88	114
Mollisols								
13.2	50	62	44	107	94	94	94	125

support growth and development of mustard, green gram, black gram, sesamum and horse gram crops. With the application of one irrigation lentil can be grown in this sub-region, while with two irrigations, crops like gram and groundnut can be grown.

In AESR 18, characterized as sub-humid dry (18.4) and sub-humid moist (18.5) climate, LGP ranges from 180 to 270 days with mean annual rainfall of 1200–1800 mm, potential evaporation of 1400–1700 mm and mean temperature of 26–270°C. After rice harvest, 80–170 days of LGP can be utilized for cultivation of *rabi* crops. Soils of this region are fertile and can support a number of crops. In the eastern coastal plains, hot, dry sub-humid (18.4) and moist sub-humid (18.5) climate prevails and is mostly dominated by Inceptisols and Entisols. In AESR 18.4, residual available soil moisture in Inceptisols and Entisols is 16.56 and 12.64 cm/m respectively. The above residual soil moisture is not enough to meet the water requirement of any of the proposed oilseeds and pulses (Table 4). However, application of one irrigation can help in the cultivation of mustard and horse gram in Inceptisols, while two irrigations at critical growth stages can help in the production of most of the *rabi* pulses. In AESR 18.5, Inceptisols and Entisols retain 15.63 and 12.61 cm/m residual soil moisture with evaporation values of 5.47 and 4.99 cm/m respectively. Residual soil moisture retained by Inceptisols can be utilized by mustard and horse gram crops to fulfil their complete water requirement, but on Entisols no crop can be grown with the residual soil moisture only. On Inceptisols, green

Table 4. Possibilities of growing different crops on residual soil moisture (without irrigation) and with one or two irrigations in different AESRs and soil types in eastern India

AESR	Climate (average rainfall, mm)	Length of growing period (days)	Dominating soil order	Possible crops		
				Without irrigation	With one irrigation	With two irrigations
9.2	Sub-humid dry (1000–1200)	150–180	Alfisols	Mustard, green gram, black gram, Sesamum, horse gram	Lentil	Gram, groundnut
			Inceptisols	Mustard, horse gram	Green gram, black gram, Sesamum	Lentil
			Entisols	Mustard, horse gram	Green gram, black gram, Sesamum	Lentil
11	Sub-humid dry/ moist (1200–1600)	150–180	Alfisols			Mustard, horse gram
			Inceptisols		Mustard, horse gram	Green gram, black gram, Sesamum
			Entisols	Horse gram	Mustard, green gram, black gram, Sesamum	Lentil
			Vertisols	Horse gram	Mustard, green gram, black gram, Sesamum	
12.1	Sub-humid moist (1400–1700)	180–210				
			Alfisols			Mustard, horse gram
			Inceptisols	Horse gram	Mustard, green gram, black gram, Sesamum	Lentil
			Entisols	Mustard, horse gram	Green gram, black gram, Sesamum,	Lentil
			Vertisols	Horse gram	Mustard, green gram, black gram, Sesamum	Lentil
12.2	Sub-humid moist (1200–1600)	180–210	Alfisols			Horse gram
			Inceptisols	Mustard, green gram, black gram, Sesamum, horse gram		Gram, lentil
			Entisols		Mustard, horse gram	Green gram, black gram, Sesamum
12.3	Sub-humid dry (1200–1500)	150–180	Alfisols		Mustard, Horse gram	Green gram, black gram, Sesamum
			Inceptisols	Mustard, Black gram, Sesamum, horse gram	Green gram	Lentil
13.1	Sub-humid dry/moist (1200–1500)	180–210	Inceptisols	Horse gram	Mustard, green gram, black gram, Sesamum	
			Entisols	Mustard, Green gram, black gram, Sesamum horse gram		Lentil
13.2	Sub-humid moist (1400–1500)	180–210	Mollisols	Mustard, horse gram	Green gram, black gram, Sesamum	Lentil
15.1	Sub-humid moist (1300–1600)	210-240	Alfisols	Mustard, black gram, Sesamum, horse gram	Green gram	Gram, lentil

(*Contd*)

Table 4. (*Contd*)

AESR	Climate (average rainfall, mm)	Length of growing period (days)	Dominating soil order	Possible crops		
				Without irrigation	With one irrigation	With two irrigation
			Inceptisols	Mustard, black gram, Sesamum, horse gram	Green gram	Lentil
			Entisols	Lentil, mustard, green gram, black gram, Sesamum, Horse gram	Gram	Groundnut
15.2	Humid (1600–2000)	240–270	Inceptisols	Mustard, green gram, black gram, Sesamum, horse gram		Lentil
15.3	Perhumid (2000–3200)	270–300	Inceptisols	Mustard, horse gram	Green gram, black gram, Sesamum	Lentil
15.4	Perhumid (2500–3000)	>300	Inceptisols	Mustard, Green gram, black gram, sesamum, horse gram	Lentil	Gram
16.1	Perhumid (2600–3000)	270–300	Inceptisols		Horse gram	Mustard, green gram, black gram, Sesamum
16.2	Perhumid (2500+)	>300	Inceptisols	Mustard, green gram, black gram, Sesamum, horse gram	Lentil	Gram, groundnut
17.1	Perhumid (2500+)	270–300+	Alfisols	Mustard, green gram, black gram, Sesamum, horse gram	Lentil	Gram, Groundnut
18.4	Sub-humid dry (1200–1500)	180–210	Inceptisols		Horse gram	Mustard, green gram, black gram, Sesamum, lentil
			Entisols			Mustard, horse gram
18.5	Sub-humid moist (1200–1500)	240–270	Inceptisols	Mustard, horse gram	Green gram, black gram, Sesamum	Lentil
			Entisols			Mustard, horse gram

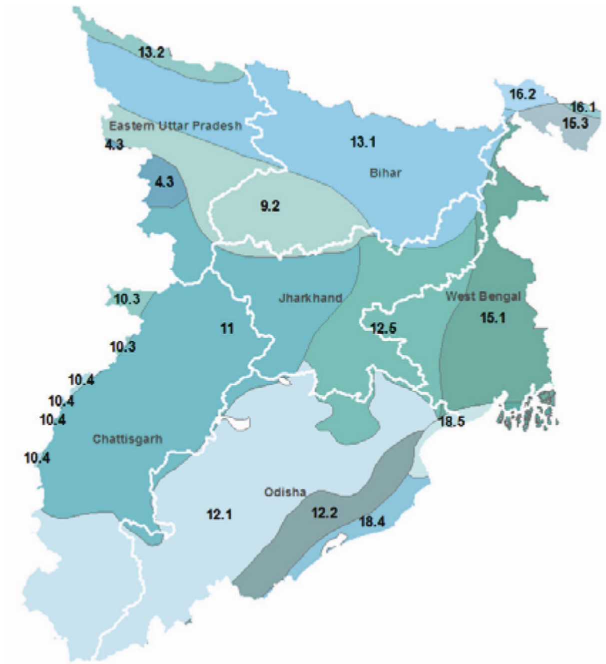

Figure 8. Agro-ecological sub-regions of eastern India with state boundaries.

gram, black gram and sesamum can be grown with one irrigation, and gram and lentil can be grown with two irrigations at critical growth stages. Similarly, in Entisols, mustard and horse gram crops can be grown with two irrigations.

Conclusions

Thus from the present study it may be concluded that an estimated area of 12.54 M ha in the *rabi* season is left fallow in eastern India, though this region is gifted with fertile soil and good rainfall. The main constraints for keeping this land fallow are due to both technical and socio-economic reasons. Among the technical constraints, low residual soil moisture coupled with lack of irrigation, poor soil and crop management are important, whereas among the socio-economic constraints, labour shortage, poor economic status of farmers, poor extension services, lack of availability of inputs and fragmented land size are important. Based on the seasonal water balance study, it was suggested that in most of the AESRs of eastern India, pulse and oilseed crops like green gram, black gram, sesamum, mustard can be grown successfully on residual soil moisture content. Crops that suffer from water deficit during maturity stages can also be grown during *rabi* season with one or two supplemental irrigations, wherever possible. If the site-specific constraints to crop production can be alleviated and these fallow lands can be brought under cultivation through proper crop planning as suggested, poverty in this resourceful region can be removed to a great extent.

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