



# Agricultural Area Diversification and Crop Water Demand Analysis: A Remote Sensing and GIS Approach

B. U. Choudhury · Anil Sood · S. S. Ray ·  
P. K. Sharma · S. Panigrahy

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**Abstract** Large scale adoption of input intensive rice–wheat cropping system in the centrally located Jalandhar district of Indian Punjab has led to over-exploitation of ground water resources, intensive use of chemical fertilizers and deterioration of soil health. To overcome these shortfalls, in the present study, agricultural area diversification plan has been generated from agricultural area and crop rotation maps derived from remote sensing data (IRS P6-AWiFS and RADARSAT ScanSAR) along with few agro-physical parameters in GIS environment. Cropping system indices (area diversity, multiple cropping and cultivated land utilization) were also worked out from remote sensing data. Analysis of remote sensing data (2004–05) revealed that rice and wheat individually remained the dominant crops, occupy 57.8% and 64.9% of total agricultural area (TAA), respectively. Therefore, in the diversified plan, it is suggested that at least 39% of the

current 40% TAA under rice–wheat rotation should be replaced by other low water requiring, high value and soil enriching crops, particularly in coarse textured alluvial plain having good quality ground water zones with low annual rainfall (<700 mm). This will reduce water requirement to the tune of 15,660 cm depth while stabilizing the production and profitability by crop area diversification without further degradation of natural resources.

**Keyword** Crop diversification · Water requirement · Agro-physical parameters · Remote sensing and GIS · Cropping system indices

## Introduction

Crop area diversification essentially advocates moving away from growing a single crop (food/non-food grains) to a number of crops in different combinations in the same piece of land. It has been recognized as an effective strategy for achieving the objectives of food and nutritional security, income growth, judicious use of land and water resources, increase in external input use efficiency and thus, sustainable agricultural development and environmental improvement. The necessity of crop diversification, however, in the case of Indian Punjab is an ecological compulsion primarily to arrest the further deterioration of already overexploited natural resources particularly ground water, reduction/increase in use efficiency of external inputs

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B. U. Choudhury (✉)  
Division of Soil Science,  
ICAR Research Complex for NEH Region,  
Umiam, Meghalaya 793103, India  
e-mail: burhan3i@yahoo.com

A. Sood · P. K. Sharma  
Punjab Remote Sensing Centre,  
Ludhiana 141004, India

S. S. Ray · S. Panigrahy  
Agricultural Resources Group,  
Space Applications Centre, ISRO,  
Ahmedabad 380015, India

(e.g. fertilizers, irrigation water, pesticides etc.), increase in farm incomes by reducing cost of cultivation while increasing profitability and sustainability of soil and environmental health. The state has steered an unprecedented growth both in terms of area and production of food grains particularly cereal based input intensive rice–wheat mono-cropping system during the green revolution era and has been contributing significantly to the national pool of food grains since then, i.e. around 50% and 70% of total rice and wheat production. In the post green revolution phase, area under rice–wheat cropping system has been increasing consistently. This expansion of rice–wheat system (RW) was encouraged by discriminatory domestic policies of the successive governments of Indian Punjab such as, subsidies for inputs, free electricity for ground water pumping, availability of short-duration and high-yielding varieties of rice and wheat and setting up well organized marketing outlets with high remuneration for the produce through minimum support prices. Presently, rice–wheat system occupies more than 84% of the total cultivated area (Sood et al. 2009) and is encroaching even in non-rice growing areas, particularly in central parts of the state with light textured soils having annual rainfall of <700 mm, which are by and large, unfit for lowland rice cultivation. This unprecedented expansion is happening only at the cost of significant decline in crop areas from other diversified low input intensive/and soil enriching crops like kharif pulses, maize, cotton, millets etc. to gain by rice while grams, rape seed and mustard, barley, vegetables etc. by wheat during rabi season (Sood et al. 2000, 2009). As a result, more than 78% area of the state is facing a problem of decline in water table at the rate of 30 cm per year (Hira et al. 2004) while half of the area is having poor quality of ground water (saline to sodic).

Usually, rice is transplanted into puddled soil and farmers try to maintain ponded water on the surface throughout the crop growth periods. Besides being one of the highest guzzlers of irrigation water, this practice of (lowland) rice production degenerate the physical structure of the soil, which may have negative implications for the ensuing aerobic crops too (Timsina and Connor 2001; Choudhury et al. 2007). Under such circumstances, crop area diversification can overcome these shortfalls associated with the mono-cropped rice–wheat production system. Since sustainability of cropping systems of an area is governed by various

agro-physical input parameters (like local climate, physiography, soil, water quantity and quality, existing cropping pattern and prevalent management practices etc.). Therefore, to suggest/device a sustainable diversification plan alternate to the existing one, all these factors of production/input parameters must be integrated in a holistic approach. Use of multi-temporal and multi spectral satellite remote sensing data along with geographic information system (GIS) is indeed an exceptional tool to study the existing cropping system as well as in generating alternate diversified cropping system by integrating all these agro-physical information with due consideration to the regional/local effects in spatial domain (Ray et al. 2005). Keeping in view these implications, present study was conducted in one of the centrally located districts of Punjab i.e. Jalandhar. In order to characterize the cropping system efficiency, multiple cropping, area diversity and cultivated land utilization indices were also worked out. An alternate diversified plan was suggested based on the information generated in GIS environment on the basis of existing physiography, annual rainfall distribution, soil texture, ground water quality and existing cropping pattern/system of the study area.

## Methodology

### Location and Description of the Study Area

Jalandhar, one of the centrally located districts of Punjab covers 5.29% area and 4.81% of the total food grain production of the state. It lies between the latitude of 30° 57' 35.4" to 31° 37' 18.99" north and longitude of 75° 4' 27.27" to 75° 57' 57.50" east. It is more or less a flat terrain, forming a part of Indogangetic plains. The various landforms in the area are alluvial plain (upper/lower), flood plain and paleochannels. Alluvial plain constitutes the major portion of the district. It is gently sloping from north-east to south-west. Part of the alluvial plain is subjected to local flooding and thus, has sufficient soil moisture content. River Sutluj is flowing along the southern side of the district. The climate of the area is semiarid with an average annual rainfall of 770 mm, 65% of which is received during the monsoon months of July to September. Agriculture occupies a special place in the economy of the district as nearly 90% of the TGA

is under cultivation with a cropping intensity of 173% (Sood et al. 2009). The district has nearly 100% irrigated agriculture with tube well being the major source of irrigation (>90%) while canal contributes less than 10% of the total irrigated area.

#### Data Source

Three dates composite (June 21st, July 16th and 9th August, 2004) of calibrated, speckle free and geo-referenced RADARSAT ScanSAR Narrow Beam B (SCNB) data with pixel spacing of 25 m was used for estimating rice acreage during *kharif* season. Using decision rule-based classification algorithm, three date composite data have been found suitable for rice crop monitoring and is operational in India for *kharif* rice crop acreage estimation (Panigrahy et al. 2000).

For maize, wheat, potato based vegetables and other crops covering all the three seasons (*kharif*, *rabi* and *summer*), multi-date optical remote sensing data of IRS-P6 AWiFS (September 5th, October 15th, November 13th, December 5th, 2004 and January 14th, February 21st, April 30th, 2005, respectively) were used. For monitoring the changes in cropping system, crop rotation maps of Punjab state prepared during the year 1998–99 (Panigrahy et al. 2003) were used as reference maps. Non-spatial data (land use, crop acreage and production, irrigation and fertilizer consumption statistics) were obtained from statistical abstracts of Punjab, published by Economic Advisor, Government of Punjab. The already digitized geo-referenced district and block boundaries were overlaid on the maps and the area of interest was extracted.

#### Dataset Preparation

Pre processed, geo-referenced data of previous year (2003) RADARSAT ScanSAR Narrow Beam B (SCNB) scene was used as master image for co-registering all the three dates of data (22nd June, 16th July and 9th August, 2004) using image to image registration. The three date composites of calibrated geo-referenced FCC of ScanSAR image was analyzed for rice acreage estimation during *kharif* season. In the similar manner, all the optical multi-date datasets were co-registered with the previous year's master image (already geo-referenced) using image-to-image registration. The image-to-image registration was done with sub-pixel accuracy (<0.5 root mean square error

in second order polynomial). All the dates were brought to 50 m resolution using cubic convolution interpolation technique for quick analysis and easy interpretation. Then the database for Jalandhar district was extracted by overlaying the district boundary.

#### Classification and Analysis Approach

##### *Generation of Cropping Pattern and Crop Rotation Maps*

Using ground truth information collected at the time of satellite pass for each individual scene corresponding to the peak season of crop growth and a two stage classification approach i.e. unsupervised iso-data followed by maximum likelihood supervised classification, a common agricultural mask covering all the three seasons (*kharif*, *rabi* and *summer*) was generated by overlaying district boundary of Jalandhar. The agricultural map was generated by masking out the non-agricultural area such as, urban, forest, water body, wasteland etc., using remote sensing data (Panigrahy et al. 2003). Using logistic modeling approach and by overlaying the agricultural mask on RADARSAT ScanSAR data, rice mask was generated. Using this rice and agricultural mask, other crops (maize, vegetables etc.) were segregated from the IRS-P6 AWiFS multi-date data for the month of September 5th, October 15th, 2004 and Nov 13th, 2005 and the *kharif* cropping pattern map was generated. Similarly, for *Rabi* season, using the agricultural mask, *rabi* crops like wheat, vegetables, potatoes etc. were segregated from IRS-P6 AWiFS multi-date data for the month of December 5th, 2004 and January 14th, February 21st, 2005 and finally the *rabi* cropping pattern map was generated. Following the similar approach, *summer* season cropping pattern map was generated from IRS-P6 AWiFS data for the month of April, 30th. Since the satellite data used in the present investigation was of coarser resolution (pixel spacing of 56 m), all other minor crops in the three seasons which couldn't properly segregated into individual classes, have been clubbed together as one class and named as other crops.

Seven dates' IRS AWiFS data, mostly representing one date for each month, were used for mapping cropping pattern and crop rotation. NDVI (Normalized

Difference Vegetation Index) images were generated using the following relationship.

$NDVI = (NIR - R) / (NIR + R)$ ; where NIR and R are DN (Digital Number) values in Near Infrared and Red bands, respectively of AWiFS data. A K-means classification was followed using NDVI values of the data to generate *kharif*, *rabi*, summer cropping pattern and crop rotation classes. The clusters were then assigned to a class based on ground truth data. This included knowledge about the crop-growing period and cropping pattern for *kharif* and *rabi* season and the field information collected during the field visit (Ray et al. 2005). The cropping pattern maps generated for *kharif*, *rabi* and *summer* seasons for the year 2004–05 were integrated to generate the crop rotation maps. A logical class-code combination algorithm was used to derive the crop rotation map (Panigrahy et al. 2003). The class codes used to designate the crop rotations is: Rice–Wheat means rice in *kharif* season and wheat in *Rabi* while Others–Wheat means moong/arhar/mash/soybean etc. in *kharif* season and wheat in *rabi* season. After generation of seasonal cropping pattern and crop rotation maps, acreage under each class was computed.

#### Accuracy Assessment

The accuracy of the area under different crops was verified with the data of Bureau of Economics and Statistics, Government of Punjab for the same year (2004–05), which was more than 90%. The accuracy in digital classification of area under different crops was further assessed by overlaying extensive georeferenced ground truth points in GIS (GCP's) collected over the study area during 2004–05 representing corresponding landuse/cropping system types.

#### Cropping System Indices

To evaluate the efficiencies of different multiple cropping systems in terms of land use and crop productivity, three indices namely multiple cropping, area diversity and cultivated land utilization indices, have been computed. Duration of each crop rotation was computed using high temporal resolution data of SPOT Vegetation (VGT) sensor. The remote sensing data used were 10-day composite of NDVI products derived from VEGETATION sensor of SPOT-4 satellite. Thirty-nine dates' data were used from 1st May 2004 to 31st May 2005. The NDVI profile for each

cropping system in the study area was fitted using a 5th order polynomial. From this fitted model the beginning and ending dates of cropping cycles were computed, which can be considered the spectral emergence and spectral maturity date. The component total duration (di) was computed using the NDVI profile (NDVI plotted against time) for each crop rotation, where 10 days were added at the beginning (15 days for rice) and 10 days at the end of each crop-growing period. These days account for the duration of field preparation, the gap between sowing and spectral emergence and the gap between spectral maturity and the harvest of the crop (Panigrahy et al. 2003).

To monitor the temporal changes in cropping system indices over a span of 5 years (1998/99 to 2004/05), corresponding indices of 1998–99 were compared which were computed by Panigrahy et al. (2003) following the similar approaches of 2004–05 from the remote sensing derived crop rotation maps.

#### Multiple Cropping Index (MCI)

This index measures the cropping intensity. It is calculated by the sum of the areas planted with different crops and harvested in a single year, divided by the total cultivated area times 100 (Dalrymple 1971).

$$MCI = \frac{\sum_{i=1}^n ai}{A} \times 100$$

Where, n = total number of crops; ai = area occupied of the *i*th crop planted and harvested within a year, A = total cultivated land area available. All these values were taken from seasonal cropping pattern statistics generated from the classification of AWiFS data.

#### Area Diversity Index (ADI)

Area diversity index measures the multiplicity of crops, which are planted in a single year by computing the reciprocal of sum of squares of the area occupied by each crop. The Area Diversity Index (ADI) can be defined as:

$$ADI = \frac{1}{\sum_{i=1}^n \left( ai / \sum_{i=1}^n ai \right)^2}$$

Where,  $a_i$  is the area under each crop. In order to depict season wise change in crop diversity,  $n$  was used as the number of crops grown in a season. ADI was computed individually for kharif ( $ADI_K$ ) and Rabi ( $ADI_R$ ) seasons as well as for the complete growing cycle (annual) of 2004–05 and was compared with the already calculated values for 1998–99 cropping seasons to see the change in the crop diversity over the periods (Panigrahy et al. 2003).

*Cultivated Land Utilization Index (CLUI)*

CLUI was computed by summing the products of land area planted to each crop, multiplied by the actual duration of that crop and divided by the total cultivated land area times 365 days. This index measures how efficiently the available land area has been used over the year.

$$CLUI = \frac{\sum_{i=1}^n a_i \cdot d_i}{A \times 365}$$

Where,  $n$  = total number of crops;  $a_i$  = the area occupied by the  $i$ th crop,  $d_i$  = days that the  $i$ th crop occupied  $a_i$ ,  $A$  = total cultivated land area available

during the 365 day period. Here, also, the  $a_i$  and  $A$  were computed from the crop maps, as the crop specific area and total agricultural area, respectively.

*Generation of Alternate Diversification Plan*

Crop diversification plans were generated using various agro-physical input parameters such as soil texture, physiography, rainfall (RF), ground water quality and the existing cropping pattern and rotation maps of the study area. Poor quality of ground water is the major concern for the state of Indian Punjab where more than 60% of the geographical area of the state has brackish ground water, loaded with excessive salts and sodicity. Since ground water through tube well is the major source of irrigation (>90%) in the study area (Jalandhar), therefore, the information on the quality of ground water was considered as an important input parameter for crop diversification plan (Table 1). Other parameters like soil texture (coarser or finer), physiography and the amount of rainfalls received in the study area are also given due consideration since they reflect a wide spatial variation as well as play a pivotal role in sustaining location specific cropping system. The spatial maps of these input parameters collected

**Table 1** Alternate diversification plan based on existing cropping pattern and few agro-physical parameters

| Physiography <sup>a</sup> | Soil               | Rainfall, mm | Water quality <sup>b</sup> | Suggested cropping system                                      |
|---------------------------|--------------------|--------------|----------------------------|--|
| OFp                       | –                  | –            | SLMS/MSHS                  | Rice–wheat/barley/mustard & rapeseed                           |
| OFp                       | Coarse/fine loamy  | >700         | Good                       | Sugarcane based  |
| FP                        | Coarse/fine loamy  | >700         | SLMS/MSHS                  | Rice–barley  |
| AP                        | –                  | >700         | MSHS/SLMS                  | Rice–wheat/Mustard   |
| AP                        | –                  | <700         | MSHS/SLMS                  | <sup>c</sup> Desi cotton-/wheat                                |
| AP                        | Sandy/Coarse loamy | <700         | Good                       | Maize–potato/onion   |
| AP                        | Coarse/fine loamy  | <700         | Good                       | Maize–wheat/barley   |
| AP                        | Coarse loamy       | >700         | Good                       | <sup>d</sup> Groundnut/moong–gram–potato                       |
| AP                        | Fine loamy         | 500–700      | Good                       | <sup>c</sup> Soybean/Moong–wheat                               |
| AP                        | sandy              | >700         | Good                       | <sup>d</sup> Cowpea–barley–vegetables; Sesamum–gram–vegetables |
| AP                        | –                  | –            | Good                       | <sup>c</sup> Moong/sesamum/mash–wheat                          |
| AP                        | Sandy              | >700         | Good                       | <sup>d</sup> Veg.–veg.–veg.                                    |
| AP                        | Sandy              | >700         | Good                       | <sup>d</sup> Bajra–potato–ground nut                           |
| AP                        | Sandy              | >700         | Good                       | <sup>d</sup> Maize–potato–onion/mentha                         |

<sup>a</sup> OFp: Old flood plain; FP: Flood plain & AP: Alluvial plain

<sup>b</sup> SLMS: Slightly low to moderate sodic; MSHS: Moderate to highly sodic

<sup>c</sup> Others–wheat

<sup>d</sup> Triple cropping (including vegetable based)

from various sources were digitized and rasterized using vector to raster module of Arc/Info. RF surfaces were generated from isohyets (rainfall contours) by kriging interpolation method for the entire state and the study area was extracted by overlaying district boundary. All these raster based spatial databases were created at 50-m grid size and were integrated with already generated agricultural area and crop rotation maps. The typical soil and climatic requirements for various crops proposed for Punjab/Jalandhar were collected from available literature. Using this information, a logical classification approach was followed to generate suitable alternate crop diversification plan (Panigrahy et al. 2003).

The suitability zone of the proposed crop rotation/cropping system based on the existing input sources has been shown in Table 1.

#### Quantification of Total Productivity and Profitability in Adoption of Alternate Plan

In order to quantify the impact of changes in crop acreage diversification on productivity and profitability in the district, we worked out total output production (yield) of major crop enterprises (e.g. rice, wheat, maize, potato-vegetables, pulses/oilseeds, sugarcane etc.), taking the average yield/productivity of the corresponding crops in Jalandhar for the same year 2004–05 (ESO, 2005–06). Then the total production output of both the existing and alternate plans was expressed in terms of rice equivalent yield (REY). To calculate REY, the total production value of major crops was computed using minimum support prices (MSP) of current year (2011–12) and the output yield

of corresponding crop was converted into relative rice yield. Finally, comparison was made between existing and alternate plan on total productivity as well as profitability at district level implementation.

## Results and Discussions

### Cropping Pattern and Crop Rotation

The district has a geographical area of 263.2 thousand hectares, 90.2% of them are under agricultural cultivation (TAA). In the kharif season (2004–05), rice was the major crop grown in more than half of the total agricultural area of the district (TAA: 57.8%, Table 2) and was distributed spatially in all parts of the district (Fig. 1). After rice, a significant proportion of the TAA (10.1%) had been brought under vegetables cultivation. Besides rice and vegetables, about one fourth of the remaining TAA (25.3%) of the district was grown under different types of minor kharif crops like arhar, mentha, ground nut, sesamum, linseed, sunflower, *susbania spp.*, fodder mixtures etc. Since, the satellite data used in the study was a bit of coarser resolution (spatial resolution: 56 m), therefore, segregation followed by individual class identification and mapping of these crops could not be accomplished. Hence, all of them had been clubbed together under a single group/class and represented as other crops.

Wheat was the major crop during rabi season, occupied nearly 65% TAA followed by vegetables mostly potatoes, with an area of 22.9% TAA of the district. Next to vegetables, sugar cane also cultivated in a significant proportion of TAA (5.4%) of the district.

**Table 2** Percent of total agricultural area under different crops/crop rotations estimated from remote sensing data of 2004–05

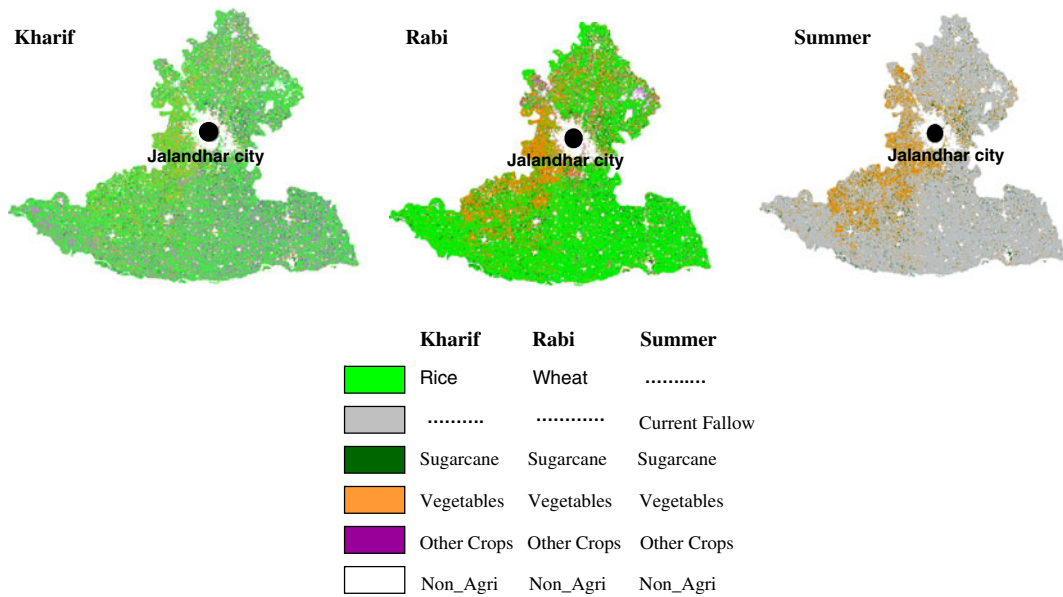
| Kharif              | % TAA <sup>a</sup> | Rabi                | % TAA | Summer                    | % TAA | Crop rotation   | % TAA |
|---------------------|--------------------|---------------------|-------|---------------------------|-------|-----------------|-------|
| Rice                | 57.8               | Wheat               | 64.9  | Current Fallow            | 79.0  | Rice–wheat      | 40.1  |
| Sugarcane           | 5.4                | Sugarcane           | 5.4   | Sugarcane                 | 5.4   | Rice–others     | 17.6  |
| Maize               | 1.3                | Vegetables/Potato   | 22.9  | Summer crops <sup>b</sup> | 15.6  | Others–wheat    | 25.4  |
| Vegetables          | 10.1               | Pulses              | 0.2   | –                         | –     | Maize based     | 1.3   |
| Others <sup>c</sup> | 25.4               | Others <sup>d</sup> | 6.6   | –                         | –     | Sugarcane based | 5.4   |
| –                   | –                  | –                   | –     | –                         | –     | Triple cropping | 10.2  |

<sup>a</sup> Total agricultural area = 237.49 thousand hectares

<sup>b</sup> Potato, sunflower, mentha, summer maize and fodder mixtures

<sup>c</sup> Minor crops (fodders, moong, arhar, *susbania spp.* etc.)

<sup>d</sup> Rapeseed & mustard, sunflower and fodder mixture



**Fig. 1** Cropping pattern and crop rotation maps of Jalandhar derived from remote sensing data of 2004–05

Like kharif season, owing to the limitation of satellite data used with coarser resolution, the remaining areas occupied with other minor rabi crops could not be segregated and mapped separately (Fig. 1). However, from current season ground truth and past land use statistics, the other minor Rabi crops grown were identified as pulses (grams, massar), oilseeds (rape-seed and mustard, sunflower), fodders etc. occupied a remarkable area of the TAA of the district (6.7%). During summer season, most of the agricultural land (79% of TAA) remained fallow (Table 2 and Fig. 1). The remaining areas (21%), however, were grown with summer vegetables and sugar cane, which occupied 15.6 and 5.4% of the TAA, respectively. The accuracy of estimated crop area was more than 90% when verified with the landuse statistics of Bureau of Economics and Statistics, Government of Punjab for the season 2004–05.

The dominant crop rotation was rice–wheat, occupied 40% of the TAA of the district (Table 2) and was spatially distributed throughout except the central western part the district. The other major crop rotations identified in the district were others–wheat (moong/arhar/mash–wheat, soybean–wheat, groundnut–wheat), rice–others (rice–berseem, rice–winter maize, rice–cucurbits) and triple cropping (vegetables mostly potato based, potato–rice–wheat, rice/maize–potato–summer moong) which had significant presence of 24.8, 17.6 and 10.2% TAA of the district,

respectively. Besides these, sugarcane and maize based (maize–wheat/barley/potato/berseem) cropping system had also a remarkable presence, altogether occupied an area of more than 6.5% of the TAA (Table 2).

### Cropping System Indices

The three important cropping system indices viz. Area Diversity, Multiple Cropping and Cultivated Land Utilization were derived from high temporal resolution RS data to adjudge the efficiency of the existing cropping systems with respect to diversification over a span of 5 years (1998–99 to 2004–05) (Table 3).

It was found that during both the seasons of kharif and Rabi, crop area diversification in the district

**Table 3** Temporal changes in different cropping system indices over a span of 5 years (1998/99 to 2004/05) derived from remote sensing data

| Indices <sup>a</sup> | 1998–99 | 2004–05 | Gain (%) |
|----------------------|---------|---------|----------|
| ADI <sub>k</sub>     | 1.60    | 2.43    | 51.9     |
| ADI <sub>R</sub>     | 1.47    | 2.17    | 47.6     |
| ADI <sub>A</sub>     | 2.88    | 3.75    | 30.2     |
| MCI (%)              | 190     | 210     | 10.5     |
| CLUI (%)             | 75.0    | 81.4    | 8.5      |

<sup>a</sup> Index abbreviations are explained in the text

increased remarkably. The ADI in Kharif ( $ADI_K$ ) and Rabi ( $ADI_R$ ) seasons of 2004–05 were increased by 51.9 and 47.6% over 1998–99. This reflected that the district is at the inception in switching over again to multiple cropping from mono-cropping pattern. This may be due to the incentives provided by the State Government through crop diversification programme as well as contract farming. Relatively higher value of  $ADI_K$  than  $ADI_R$  was due to the significant sharing of other kharif crops (like vegetables, sugar cane, maize, and other crops) besides rice. In Rabi season, although vegetables mostly potato had considerable presence, yet, wheat crop alone occupied nearly 2/3rd of the TAA (Table 2). Due to the prevalence of rice–wheat, vegetables/potato based, non-rice and non-wheat based rotations, the annual ADI value also increased from 2.88 to 3.75 (net gain of 30%) over the same period.

Similarly, multiple cropping index (MCI) increased from 190% (in 1998–99) to of 210% (in 2004–05), a net gain of over 10%. MCI value of more than 200% indicated that most of the area in the district was under double cropping and even in some selected areas, vegetables/potato based triple cropping were also practiced. This reflects that the number of crops grown in a unit area in a single crop calendar also increased.

Temporal increase in the ADI and MCI value in the district was corroborated from the corresponding increase in cultivated land utilization index (CLUI) value. CLUI increased over 8% for the same period. In the existing cropping system practices, land was occupied by crops for more than 295 days in a year (81% of the total year). CULI can further be increased by taking more short duration, low water loving, soil enriching and high value crops.

## Decadal Changes in Irrigation Water and Fertilizer Consumption

Remarkable increase in food grain production of Punjab could be possible primarily due to the intensive use of two most important inputs i.e. irrigation water and inorganic fertilizers (nutrients). The net irrigated area (NIA) of Punjab increased from 3.81 million hectares in 1994–95 to 4.02 million hectares in the year 2003–2004, which was 96% of the net sown area. Over the same period, Jalandhar district showed marginal increase of 3% and attained nearly 100% of the net sown area under irrigation (Table 4). Private tube wells were the main source of irrigation over the years and its contribution increased from 87% to nearly 99% of NAI over the decades (1994–95 to 2003–04). This increase in tube well irrigated area was only at the expanse of significant decline in canal irrigated area from 13% to 1.3% of NIA for the same period. Due to the dominance of water intensive rice based cropping systems and an average annual low, erratic rainfall distribution (<800 mm), farmers were compelled to over-exploit the ground water resources by excessive pumping through tube wells to meet the demand of high water requirement of rice-wheat systems. Availability of free electric power further caused a big boost in the number of electrically operated tube wells in the district alike to other parts of the state. Over-pumping of this poor quality, shallow brackish ground water will have serious implication on the sustainability of soil health as well as system productivity on long run.

Besides grave concern on quantity and quality of irrigation water, extensive adoption of rice based cropping system also increased intensive consumption of inorganic fertilizers in Jalandhar district of Punjab.

**Table 4** Decadal changes in input use of irrigation water and fertilizer consumption (1994–95 to 2004–05) per unit of TAA

|  | 1994–95  | 2004–05   | Net gain/loss (%) |
|--|----------|-----------|-------------------|
| Irrigation   |          |           |                   |
| Govt. canals   | 13.0     | 1.3       | –11.7             |
| Tube wells   | 87.0     | 98.7      | +11.7             |
| Per cent of NAI to NAS                               | 97.7     | 100.0     | +2.3              |
| Fertilizer consumption ( $\text{kg ha}^{-1}$ of TAA) |          |           |                   |
| Nitrogen (N)   | 237.9    | 284.5     | +19.6             |
| Phosphorous (P)                                      | 64.3     | 75.3      | +17.1             |
| Potash (K)   | 12.9     | 33.5      | +159.7            |
| NPK  | 315.1    | 393.3     | +24.8             |
| N:P:K  | 18.5:5:1 | 8.5:2.3:1 |                   |

TAA total agricultural area; NAI net area irrigated; NAS net area sown



Inorganic fertilizers like nitrogen (N), phosphorous (P) and potash (K) consumption together was over 315 kg ha<sup>-1</sup> in 1994–95 itself, which was nearly 300% higher than the national average. Over the decades, the rate of total fertilizer (N, P &K) consumption increased further by 25%. Nitrogenous fertilizer alone accounted for more than 70% of total N,P and K consumption. The consequence of this monotonous application of single type of fertilizer (nitrogenous) had its bearing on the proportion of N: P: K ratio. In 1994–95, the ration was 18.5:5:1 as against the standard recommend proportion of 4:2:1. On long run, it will cause perilous impact on availability of other macro and micro nutrients, mineral stability and soil fertility restoration, soil quality components and ultimately the crop growth and production *vis a vis*. However, over the decades, this ratio narrowed down to 8.5:2.3:1 (Table 4). This could be possible, mostly due to the significant reduction in rice cultivated area from 72.8% to the current 40% over the same period. This ratio needs to be narrowed down further. Therefore, it is imperative to diversify some of the area under water intensive rice based cropping systems to low-inputs (eg. water and fertilizers) requiring, soil enriching and high remunerative cropping systems.

### Derivation of Crop Area Diversification Plan

The study area had an average annual rainfall of 770 mm, 80% of which was received in the monsoon months (July to September) with wide spatial inter-annual variability. Total annual potential evapotranspiration loss is 3 times higher than the total annual rainfall received. As a result, climatologically, annual water deficit exceeds 1,330 mm and even in kharif season (June to October), water balance of the district is negative (−95 mm). Majority of the area in the district is coarser in soil texture with an annual average rainfall of less than 800 mm, moderate to severe prone to water erosion and poor (saline to sodic) ground water quality. Under such circumstances, large scale adoption of input intensive rice based cropping system is not advisable since the water requirement of low-land rice followed by wheat crop in Indo-gangetic Plains of India exceeds 2,000 mm (Choudhury et al. 2007). To support rice based cropping systems, large quantity of water from external sources (either ground or canal) is needed and presently the farmers of this region are practicing this. They are over pumping poor quality ground water along with extensive application of inorganic fertilizers (inappropriate proportion) to support rice based cropping systems even in coarse

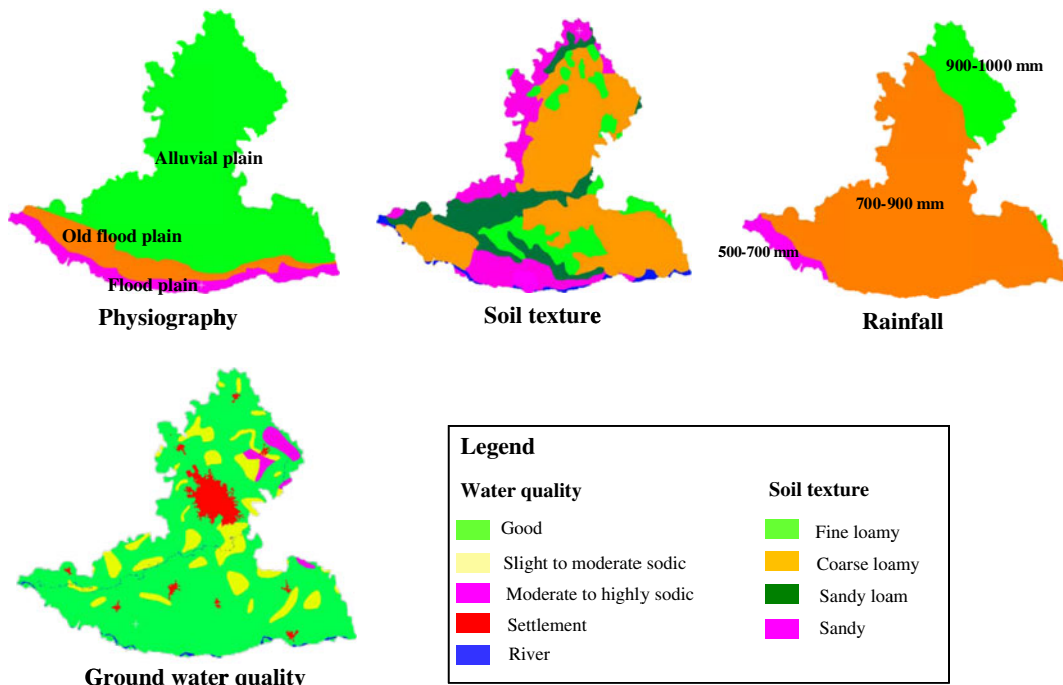
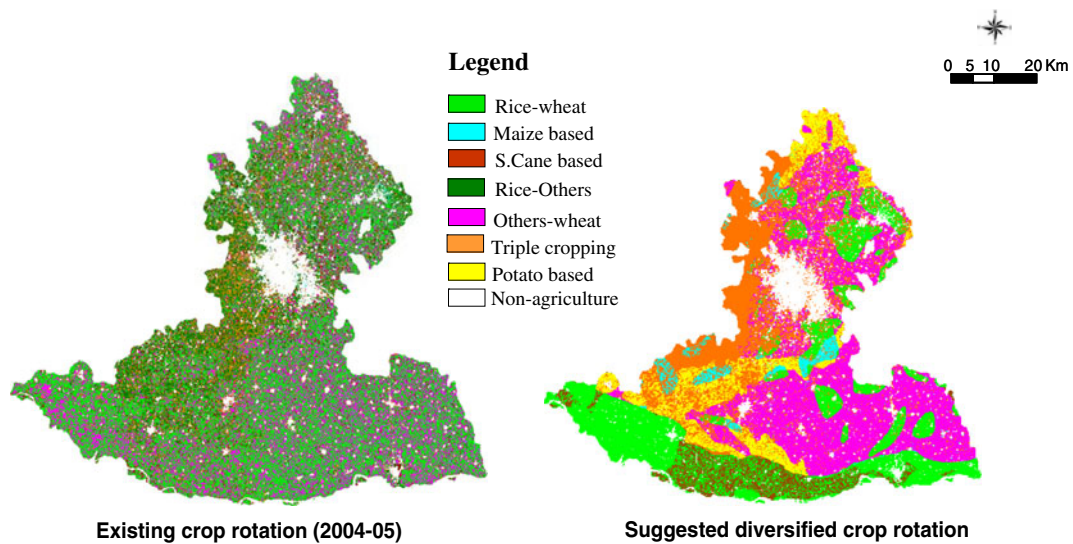


Fig. 2 Agro-physical input parameters in spatial data format used to derive crop diversification plan



**Fig. 3** Existing crop rotation and suggested diversified crop rotation plan for Jalandhar district of Punjab

textured soils. As a result, sustainability of soil health, natural resources, productivity stabilization and profitability are at great risk.

Therefore, generation of crop diversification plan based on important agro-physical input parameters is essential. Four important agro-physical input parameters like physiography, soil texture, rainfall distribution pattern and groundwater quality along with existing cropping pattern at spatial scale were generated (Fig. 2) to derive alternate crop area diversification plan (Fig. 3). During the process of generation, logical classification approach was followed to demarcate crop suitability zones (Table 1). As per the diversified plan, it is suggested that area under rice and wheat should be reduced from the current 137 and 154 thousand hectares to 58 and 132 thousand hectares, respectively (Table 5). At the same time, area under low water requiring maize and

vegetable crops should be increased by 120% and 60% from the present level (Table 5). On cropping system basis, rice–wheat rotation should be substituted significantly by maize and other low water requiring and soil enriching pulses/oilseeds/vegetable based systems (Table 6 and Fig. 3). Taking minimum water demand for different crops (at lower side) under Punjab conditions (Panigrahy et al. 2003), adoption of diversified plan can reduce the water requirement by more than 15,600 cm depth (Table 4), without any penalty to the total productivity rather increasing the profitability. Successful implementation of this plan, thus, may help in overcoming several major shortfalls (such as soil health denegation, degradation/over-exploitation of natural resources and yield/productivity stagnation followed by decline) associated with lowland rice–wheat cultivation.

**Table 5** Crop-wise change of area (, 000 ha) as per the alternate diversified cropping pattern plan

| Crop                   | Area, 000 ha          |           | Gain/loss% | Crop water requirement, cm | Water saving in alternate plan, cm |
|------------------------|-----------------------|-----------|------------|----------------------------|------------------------------------|
|                        | Existing <sup>a</sup> | Alternate |            |                            |                                    |
| Rice                   | 137.08                | 57.9      | −57.8      | 200                        | 15,836                             |
| Wheat                  | 154.12                | 132       | −14.4      | 44                         | 973                                |
| Maize                  | 3.13                  | 6.9       | 120.4      | 50                         | −189                               |
| Sugarcane              | 12.88                 | 13.6      | 5.6        | 170                        | −122                               |
| Vegetables             | 24.24                 | 41.0      | 69.1       | 50                         | −838                               |
| Pulses/oilseeds        | marginal              | 44.0      | —          | —                          | —                                  |
| Total water saving, cm |                       |           |            |                            | 15,660                             |

<sup>a</sup>Source: Remote sensing data (2004–05)

**Table 6** Suggested changes in percent area under major cropping systems as per the alternate plan

| Cropping system                   | (% of total agricultural area) |           | Gain/loss (%) |
|-----------------------------------|--------------------------------|-----------|---------------|
|                                   | Existing*                      | Alternate |               |
| Rice–Wheat                        | 40.1                           | 24.4      | –39.2         |
| Rice–others                       | 17.6                           | 0.0       | –100.0        |
| Maize based                       | 1.3                            | 2.9       | 120.4         |
| Sugarcane based                   | 5.4                            | 5.7       | 5.6           |
| Others–Wheat                      | 24.8                           | 31.2      | 25.6          |
| Triple cropping (Veg. based)      | 10.2                           | 17.3      | 69.1          |
| Triple cropping (pulses/oilseeds) | –                              | 18.5      | 100.0         |

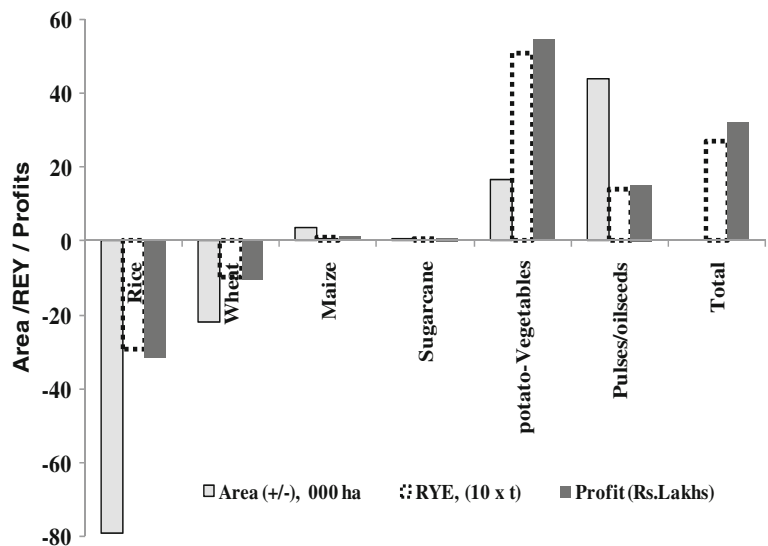
\*Source: Remote sensing data (2004–05)

**Comparative Analysis of Total Productivity and Profitability in Adoption of Alternate Plan**

Considering the changes (gain/loss) in crop acreage under suggested diversified plan, (Table 5), total productivity of the existing and alternate plan has been calculated and compared in terms of rice equivalent yield (REY), considering MSP of 2011–12 (Fig. 4). Total productivity (REY) revealed that a change in acreage under major crops as per suggested diversified plan, despite a reduction of 392.0 t from rice and wheat (Fig. 4), the overall total productivity (REY) of the district will be boosted up by a net gain of 269.0 t, mostly from the cumulative gain from potato/vegetables (505.9 t), pulses/oilseeds (138.8 t), maize (10 t) and sugarcane (5.9 t) based systems (Fig. 4). In terms of monetary benefit, the profit of

margin only from the output production will be at the tune of Rs.29.0 lakhs (Fig. 4) at district level implementation. Consumption of fertilizers in rice–wheat system in Punjab alone exceeds 400 kg ha<sup>-1</sup> (N: 284 kg ha<sup>-1</sup> & P<sub>2</sub>O<sub>5</sub>: 118 kg ha<sup>-1</sup>) (Sharma et al. 2004) and an additional burden of 20–25% higher electricity consumption in the exchequer of the state comes from the over pumping of ground water for irrigating the input intensive rice–wheat system (Johl 2002). Other non-quantifying primary and secondary adverse consequences (like depletion of ground water table at the rate of 30 cm year<sup>-1</sup>, secondary soil salinization, soil health degradation and deterioration of structural re-generation, pollution of ground water and environment) (Hira et al. 2004; Sood et al. 2009) of large scale adoption of rice–wheat rotation in the existing system can pose a severe threat to the

**Fig. 4** Comparative analysis of total productivity and profitability in suggested diversified plan



endurance and even sustainability of agricultural production system and economy of the state (Johl 2002; Dhillon et al. 2010). Majority of these shortfalls, however, can be addressed by adopting the present suggested alternate plan at district level and its further implementation at state level.

## Conclusion

In the central parts of Indian Punjab, input intensive lowland rice followed by wheat encroached even in areas not suitable for growing rice (average annual rainfall of <700 mm and sandy textured soils with medium to poor quality ground water zones). As a result, farmers had to solely depend on over-exploitation of limited ground water resources to meet the crop water demand and excessive use of high energy chemical fertilizers (>390 kg NPK/ha) to sustain productivity. However, with the successful implementation of agricultural area diversification involving low water requiring, short duration, soil enriching and high value crops instead of extensive adoption of rice–wheat rotation can effectively overcome these shortfalls. Satellite based multi-sensor, multi-spectral, medium resolution (56 m) remote sensing data in monitoring cropping pattern changes along with few selected agro-physical parameters (e.g. physiography, rainfall, soil texture and ground water quality) in spatial format gives a cutting edge in deriving location specific agricultural area diversification plan. Use of more finer resolution satellite data in deriving existing cropping pattern maps (including minor crops) along with due consideration to spatial variability in all the agro-physical parameters including management practices related to sustainable agricultural production system can further improve the adaptability of agricultural area diversification without any penalty to the productivity potential and profitability of the system.

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