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Using remote sensing technologies to enhance resource conservation and agricultural productivity in underutilized lands of South Asia

Parvesh Chandna [a,c,*], J.K. Ladha [a], U.P. Singh [b], Milap Punia [c], Raj Gupta [d], B.S. Sidhu [e]

[a] International Rice Research Institute (IRRI), NASC Complex, DPS Marg, PUSA, New Delhi 110012, India
[b] Banaras Hindu University, Varanasi 221002, India
[c] Department of Geography, CSRD/SSS, Jawaharlal Nehru University, New Delhi 110067, India
[d] International Maize and Wheat Improvement Centre, (CIMMYT), NASC Complex, New Delhi 110012, India
[e] Government of Punjab, Department of Agriculture, Chandigarh-160022, Punjab, India

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A B S T R A C T

Satisfying the food demands of an ever-increasing population, preserving the natural resource base, and improving livelihoods are major challenges for South Asia. A large area of land in the Middle and Lower Gangetic Plains of South Asia remains either uncultivated or underused following the rice harvest in the kharif (wet) season. The area includes “rice-fallow,” estimated at 6.7 million ha, flood-prone riversides (“*diara* lands,” 2.4 million ha), waterlogged areas (4.9 million ha), and salt-affected soils (2.3 million ha). Bringing these lands under production could substantially improve the food supply and enhance livelihoods in the region. This paper describes a methodological case study that targeted resource-conserving technologies in underused lands of the Ballia District of eastern Uttar Pradesh (India) using multispectral remote-sensing images. Classification of temporal satellite data IRS-P6 in combination with Spot VGT 2 permitted the identification of all major categories of underused land during the post-rainy rabi/winter season, with an average accuracy of 89%. Based on three-year averages of field demonstrations, farmers gained an additional income of \$63 ha^{-1} by introducing raised beds in salt-affected soils; \$140 and \$800 ha^{-1} by introducing deepwater rice varieties (monsoon) and boro rice (winter) in waterlogged areas; and \$581 ha^{-1} by introducing zero-till lentil (winter) in rain-fed fallow lowland. Timely wheat planting through zero-tillage implies an additional income of \$147 ha^{-1} and could increase wheat production by 35,000–65,000 tons in the district. The methodologies and technologies suggested in the study are applicable to more than 15 million ha of underutilized lands of the Indo-Gangetic Plains of South Asia. If the technologies are precisely applied, they can result in more than 3000 million US \$ of additional income every year to these poverty prone areas.

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Introduction

The Indo-Gangetic Plains (IGP) are the major food-producing region of South Asia. The rice–wheat system, a major cropping system in the IGP, supports more than 450 million people and contributes more than 80% of the total cereal production in these countries (Ladha, Pathak, & Gupta, 2007). The Eastern Gangetic Plains (EGP), with 34.64 million ha, supports more than 300 million people (Chandna et al., 2009). The intensively cultivated irrigated rice–wheat (RW) system is fundamental to the employment, income, and livelihood of the people of this region. Productivity of the RW system appears to have plateaued because of natural resource degradation (Ladha et al., 2003). Approximately 6.7 million ha of potentially productive land in the EGP remain fallow during the rabi/winter season after the kharif/monsoon rice crop (Subbarao et al., 2001), with the unavailability of irrigation water as the most common cause. Moreover, flood-affected lands cover more than 2 million ha in Bihar (Chandna et al., 2010; Padmanabhan, 2008), where waterlogging or excessive moisture (Choudhary et al., 2008; Pandey, Singh, & Nathawat, 2010) either causes a delay in the planting of a rabi crop or causes the land to remain uncultivated. Wheat is an important winter food crop in the EGP, but at least 60% of the wheat is planted late (Chandna et al., 2007, pp. 31–37; Chandna et al. 2010). The late planting of wheat reduces yield and leads to poor water-use efficiency. For example, a linear decline in

* Corresponding author. International Rice Research Institute (IRRI), NASC Complex, DPS Marg, PUSA, New Delhi 110012, India. Tel.: +91 11 25843802 (office), 91 9350935943 (mobile).
E-mail address: p.k.chandna@cgiar.org (P. Chandna).

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yield of 1–1.5% d^{-1} is observed when wheat is planted after mid-November (Ortiz-Monasterio, Dhillon, & Fischer, 1994; Ortiz-Monasterio & Lobell, 2007).

Improved resource-conserving technologies (RCTs) such as zero-tillage provide options for more timely planting, thereby potentially leading to higher productivity, input-use efficiency, and profitability (Gupta & Sayre, 2007; Gupta and Seth 2007; Ladha et al., 2009; Ladha et al., 2007). The surface seeding of wheat, in which presoaked wheat seeds are broadcast in excessively wet soils, is a simple technology for resource-poor farmers to achieve higher yields through timely planting (Hobbs, 2001). Laser-assisted precision land leveling saves irrigation water, nutrients, and agro-chemicals (Jat, Chandna, Sharma, Gill, & Gupta, 2006, 48pp; Rajput, Patel, & Agarwal, 2004). The raised bed planting of crops improves yields in partially reclaimed alkali soils (Connor, Gupta, Hobbs, & Sayre, 2003, pp. 103–109; Humphreys et al., 2010). However, any single technology may not be suitable for all situations, suggesting that technologies should be targeted to their most appropriate niche (de Graaff et al., 2008). This requires information on the distribution and extent of lands with specific problems such as a shortage of soil moisture, excessive wetness or salt, and flood occurrence. Assessing target zones for promising technologies facilitates out-scaling in a fast and cost-effective manner (Chandna et al., 2011; Erenstein, Hellin, & Chandna, 2010). Remote-sensing options provide spatial-temporal synoptic resource data in different electromagnetic spectral windows. These remote-sensing based datasets can be used to generate information on the extent and location of problem areas and potential target areas for more efficient use of natural resources (Rozenstein and Karnieli, 2011; Shalaby & Tateishi, 2007). Such information can help target promising RCTs in a focused and precise manner on a regional scale. The objective of the current study was to assess the scope of remote-sensing and geographical information systems for targeting RCTs for increasing crop productivity of underutilized lands in the eastern IGP of India.

Materials and method

Site description

The Ballia District of Uttar Pradesh, situated in the EGP (Fig. 1) between 25°33′ and 26°11′N and 83°40′ and 84°38′E, is bound on the north by the Ghagara River, on the south by the Ganges River, on the east by the Sharn and Bhojpur districts of Bihar, and on the west by the Mau District of Uttar Pradesh. The district covers 3,29,023 ha. Because of its saucer-shaped topography, the study area has numerous natural physiographic features such as *tals* (water bodies), oxbow lakes, point bars, cutoff meanders, and buried channels. These physiographic features create conditions of excessive moisture, sodicity, and waterlogging.

The rice *(Oryza sativa)*-wheat (*Triticum aestivum*) cropping system is the dominant cropping system in Ballia (Fig. 1). Other cropping systems are maize (*Zea mays* L)-wheat, wheat-mungbean (*Phaseolus aureus* Roxb.), rice-mustard (*Brassica juncea)*, maize-potato (*Solanum tuberosum*), rice-cucurbit (*Cucumis sativus*), and rice-lentil (*Lens culinaris* Medic). Sugarcane (*Saccharum officinarum* L.) is grown in the Ghagara River belt and in parts of Rasra Block in the northwest part of Ballia. Pigeon pea (*Cajanus cajan* Milsp.) is grown in uplands and chickpea (*Cicer arietinum* L.) and lentil in lowland and *tal* areas. In *diara* lands, wheat is grown during the winter season (November–March), followed by boro rice (March–June).

Soils of the Ballia District originate from alluvium deposits of the Ghagara and Ganges rivers. The soils are deep, well-drained,

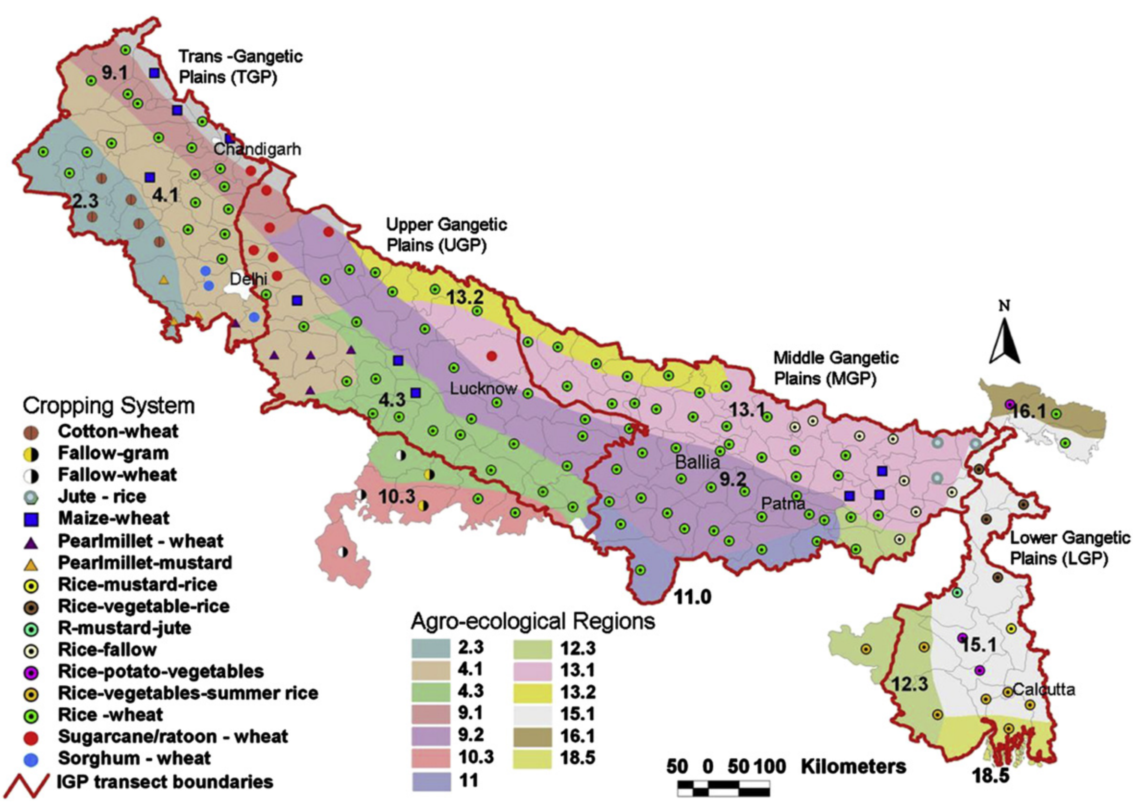

Fig. 1. District-wise major cropping systems, agro-climatic zones (transects), and agroecological zones of Indian part of IGP. (Source: Velayutham, Mandal, Mandal, & Sehgal, 1992 (for agroecological zones), Yadav, Subba, & Rao, 2001(for cropping systems), Narang & Virmani, 2001 (for agro-climatic zones)).

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