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Cropping systems and crop residue management in the Trans-Gangetic Plains: Issues and challenges for conservation agriculture from village surveys

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ABSTRACT

Conservation agriculture practices are being advocated to help sustain crop productivity gains and secure environmental sustainability in the Trans-Gangetic Plains, India's Green Revolution heartland. The paper illustrates the use of village surveys as a quasi-quantitative system analysis tool to derive implications for agricultural research and development. Drawing from village surveys in 170 communities, the paper assesses current crop residue management practices in Punjab and Haryana's rice–wheat, basmati–wheat and non-rice–wheat cropping systems. The prevalence of wheat as the winter crop implies an intensive collection, trading and use of wheat straw as basal feed for dairy livestock; which contrasts with the diverse crop residue management of the monsoon crops. The increased use of combine harvesters has spurred the rapid advent of mechanical wheat straw reapers whereas the bulk of combine harvested rice straw is burned *in situ*. Present crop residue management practices are largely incompatible with year-round mulch retention despite significant biomass production. The research and development community faces the challenge of evening out straw use and management over seasons to ensure at least partial residue retention if its calls for conservation agriculture in this important sub-region are to succeed. The paper also reiterates the worrying decline of groundwater tables associated with the rice–wheat system.

1. Introduction

The 20th century Green Revolution—combining high yielding wheat and rice varieties with complementary fertilizer and irrigation technologies in a supportive policy environment (Hazell, 2009)—has transformed the semi-arid Trans-Gangetic Plains (TGP, comprising Indian Punjab and Haryana States) into India's granary, producing 21% of the nation's food grains on only 3% of its area (Erenstein et al., 2007b). The agricultural research & development (R&D) community faces the challenge of sustaining the crop productivity gains and securing the environmental sustainability in this strategically important sub-region (Fujisaka et al., 1994; Timsina and Connor, 2001). The stagnation of productivity growth in these intensive cropping systems has lead to a strong advocacy for conservation agriculture based technologies to rebuild soil health (FAO, 2007; Gupta and Sayre, 2007; Hobbs, 2007; Hobbs et al., 2008). The conservation agriculture principles—minimal soil disturbance, retention of crop residue mulch and a rational use of crop rotations, along with profitability at the farm level—are increasingly recognized as essential for sustainable agriculture in this region.

To date, most significant progress has been made with addressing the challenge of reducing tillage for wheat in the TGP's rice–wheat systems—particularly zero tillage wheat, aided by significant costs savings as well as potential wheat yield increases (Erenstein et al., 2007a; Erenstein and Laxmi, 2008). In these systems, zero tillage is typically only applied to the wheat crop—with the subsequent rice crop still puddled and transplanted—and also does not necessarily imply the retention of crop residue as mulch or the use of crop rotations. From a soil health perspective this is a critical shortcoming, as the benefits accrued in the wheat season from zero-tillage and leaving some residues is lost if the same is not done for the subsequent crop—particularly when applying the traditional system of puddling soils and transplanting rice. Even in zero tillage wheat fields farmers generally do not purposively leave mulch and typically burn the straw of the preceding rice crop in combine harvested fields—although even after burning the remaining anchored straw may be considerable and may satisfy the conservation agriculture requirements of residue mulch. This suggests farmers unpacked the conservation agriculture technological components using only those that were particularly attractive or easy to use vis-à-vis the opportunities, constraints and trade-offs they face. Moving these systems towards more complete models of conservation agriculture implies *inter alia* tackling the challenge of rice establishment and year-round crop residue retention, the latter calling for a better understanding of current crop residue management practices.

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Crop residue management has long been relatively neglected by the R&D community but has recently received increased attention in the quest for sustainable agriculture and its potential contribution to soil fertility, soil organic matter, soil structure and soil health (Bijay-Singh et al., 2008; Dawe et al., 2003; Felton et al., 1987; Gupta et al., 2004; Hatfield and Stewart, 1994; Kumar and Goh, 2000; Mohanty et al., 2007; Moldenhauer et al., 1994; Prasad et al., 1999; Samra et al., 2003; Verma and Bhagat, 1992; Yadvinder-Singh et al., 2005). Most published crop residue management research in South Asia and elsewhere relates to experimental work—with limited rigorous survey based documentation of the crop residue management on the farm, a notable exception being the National Crop Residue Management Surveys in the USA (CTIC, 2010).

Crop residues are an integral part of rural livelihoods in South Asia (Devendra, 2007; Erenstein and Thorpe, 2010a; Rao and Birthal, 2008). Their utilization provides coherence to the prevailing smallholder crop–livestock systems, being important sources of livestock feed for the dominant species in the region—cattle, buffaloes, small ruminants—and sometimes having other productive uses such as fuel and construction material. Alternate crop residue uses likely imply trade-offs vis-à-vis their retention as mulch as advocated under conservation agriculture. One would expect such trade-offs to be particularly problematic where crop residues have considerable scarcity value—as in semi-arid rainfed areas (Erenstein, 2003; Unger et al., 1991). The competing use of crop residues has indeed been posited as a critical constraint to the adoption of conservation agriculture in sub-Saharan Africa (Giller et al., 2009; Wall, 2009). *A priori*, one would expect crop residues to have limited intrinsic value in intensive irrigated cereal systems and the residue retention trade-offs to be inherently limited.

India's vast Indo-Gangetic Plains show some marked agro-ecological gradients with rice–wheat systems predominant in the northwest which is characterized by a prevalence of irrigation, high yields of cereal grain and crop residues—hereafter referred to as straw in the case of rice and wheat—and a commercial orientation (Erenstein et al., 2007b; Erenstein and Thorpe, 2010b). However, these earlier accounts also provided contradictory signs of both straw scarcity and straw surplus, particularly in the TGP. In part this reflects the unraveling of crop–livestock interactions as crop production intensified whereas livestock intensification lagged and straw remained the basal feed. The TGP's seasonal biomass production also poses challenges to handling and retaining straw as mulch—particularly as the prevailingly tined zero tillage drills are relatively poor in trash handling (Samra et al., 2003). For better or worse, this was not a major issue so far in view of the limited biomass remaining in rice–wheat systems after the current rice crop and straw management practices (Erenstein and Laxmi, 2008).

Cropping systems in the TGP are primarily irrigated, double cropped and wheat-based, with wheat grown during the winter season and rice (non-basmati), basmati rice or non-rice (e.g. coarse cereals, legumes, cotton) as the subsequent monsoon crop. Basmati rice—referred to as basmati hereafter, with normal non-basmati rice being referred to as rice—has a high market value due to its aromatic (fragrant) long-slender grains (Bhattacharjee et al., 2002). It also takes a longer time to mature, is relatively low yielding and is primarily produced for export—with Haryana being India's leading basmati exporting state. We hypothesize that the variations in the prevailing monsoon crop (rice vs. non-rice; normal rice vs. basmati) will have a marked influence on farmers' wheat and rice straw management practices.

The primary objective of the paper is to assess how the wheat and rice straw management practices vary over the TGP's cropping systems and assess the implications thereof—particularly with the advent of, and strong advocacy for, conservation agriculture based technologies. An earlier review indeed concluded with the call for more multidisciplinary, integrated and system approach efforts to address crop residue management in the prevailing cropping systems so as to enhance both agricultural productivity and sustainability (Kumar and Goh, 2000). The present paper thereby builds on earlier work in the region. Diagnostic surveys in the 1990s focused on tillage and crop establishment (Fujisaka et al., 1994; Harrington et al., 1993), but Harrington et al. (1993) do mention that fodder sources included wheat straw and basmati straw, whereas rice straw from modern varieties was rarely used in their Haryana study areas. Household surveys in the 2000s focused on zero tillage adoption, but also reported some marked divergences in rice and basmati crop and straw management (Erenstein et al., 2007a). However, both these studies focused on the basmati–wheat areas in Haryana. Another study characterized the meso-level agro-ecological gradients and their implications for crop–livestock interactions across the Indo-Gangetic Plains (Erenstein and Thorpe, 2010a), including a narrow sample of 18 villages in contrasting agro-ecologies in the TGP (Erenstein et al., 2007b). The present paper revisits the TGP study area but drawing from a much larger and more representative sample to better understand the sub-regional diversity and its implications for conservation agriculture.

A secondary objective of the paper is to illustrate the use of village surveys as agricultural system analysis tool for R&D. Village surveys as used here have been defined as "rapid quasi-quantitative community studies—i.e. a hybrid between quantitative and qualitative social science approaches to study a defined group of people or aspect thereof. They combine quantitative elements of sample surveys—such as a rigorous sampling design to ensure representativeness and the inclusion of substantial village numbers and comparable quantifiable indicators to facilitate quantitative analysis and contrasts—with a community level focus (i.e. for the entire village or target group) using key informants and group discussions" (Erenstein, 2010). Village surveys have already been variously used to monitor technology uptake (Erenstein, 2010) and meso-level agro-ecological characterization (Erenstein and Thorpe, 2010a,b). The next section presents the study area and the village surveys that were used as primary data source. A number of cropping systems and straw management indicators are subsequently presented and contrasted, which is followed by a discussion and conclusion.

2. Materials and methods

2.1. Study area

The study area encompasses the Trans-Gangetic Plains (TGP) in India, comprising the two contiguous states of Punjab and Haryana—the Green Revolution heartland in the north-west Indo-Gangetic Plains. Erenstein et al. (2007b) have characterized the sub-region and this is summarized hereafter. Rural livelihoods based on irrigated wheat-buffalo farming systems prevail. Wheat has traditionally been, and continues to be, the mainstay of food security and is grown in the cool and dry winter season. Over the last 30 years there has been widespread adoption of rice which is primarily grown in the hot and wet monsoon season. This has made rice–wheat the predominant cropping system—comprising 35% of the rice–wheat system area in the Indo-Gangetic Plains, with Punjab alone contributing 26.5% (Sharma et al., 2004). Farm size is relatively high for regional standards and the area has witnessed a rapid mechanization. Buffalo (dairy) increasingly dominate the bovine population—making the TGP the most densely buffalo populated area of India—whereas there has been a sharp decline in draft animals and small ruminants. Agricultural