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Potential of conservation agriculture (CA) for climate change adaptation and food security under rainfed uplands of India: A transdisciplinary approach

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ABSTRACT

Rainfed agro-ecosystems, the purported grey patches untouched by the Green Revolution or most technological advances, occupy a prominent position in Indian agriculture. Cropping intensities and crop yields are low and unstable in these areas due to unpredictable patterns of rainfall, a host of biotic and abiotic stresses and adherence to traditional farm practices. This precarious food security situation is especially dangerous in the central Indian tribal belt (also known as the poverty belt) which is a typical rainfed area dominated by tribal communities. More than 90% of the tribal people are totally dependent on agriculture and produce much of what they eat. Small land holdings and their low productivity, along with uncertainties in rainfall patterns, increases economic and social risks for these farmers. With degraded soils and unreliable weather patterns, return on investment is uncertain and likely to be much lower overall than under irrigated conditions with better soils. Under such conditions, one approach to achieve improved crop production is to minimize soil and other natural resource degradation by adopting a set of crop-nutrient-water-land system management practices, such as conservation agriculture (CA). To assess the effect of introduced technology under local ecological and socio-economic conditions, the study focused on two ecosystem services: a) provisional, and b) regulatory through five treatments consisting of farmers' traditional practice (FP) which was conventional tillage with broadcast of local variety maize (*Zea mays* L.); and four CA treatments viz., conventional tillage with sole cropped maize using line sowing of the improved maize cultivar 'Nilesh' (CT-M); conventional tillage with maize intercropped with the improved cowpea (*Vigna unguiculata* L. cultivar 'Hariyalli Bush') (CT-M + C); reduced tillage with sole cropped maize (MT-M); and reduced tillage with maize + cowpea (MT-M + C). After harvest of maize and cowpea, mustard was planted as a post rainy season crop and all the mustard plant residues were returned to their respective plots as residue cover except FP. Under provisional ecosystem services, performance of CA on crop yield, and profitability was assessed through maize equivalent yield and partial budget analysis, respectively. Results showed that reduced tillage combined with maize-cowpea intercropping (MT-M + C) followed by mustard residue retention had higher system productivity and net benefits, an increase of 200% and 230%, respectively over FP. Under regulatory ecosystem services, the soil quality was assessed through calculation of soil quality index (SQI) which was highest under MT-M + C followed by mustard residue retention and lowest under farmers' practices. In terms of CA treatment preference, 35% of the farmers indicated a strong preference for MT-M + C compared to 14% for FP. Combined, these results clearly demonstrate the potential of CA to simultaneously increase yield, diversify crop production and improve soil quality which should support a move towards sustainable intensification of crop production to improve future household income and food security. Additionally, using a transdisciplinary approach fully engaged all stakeholders in co-designing the CA treatments appropriate for the farmers and local environmental conditions leading to significant impacts on economic livelihoods, environmental sustainability and food security.

1. Introduction

Food security has become increasingly important globally as well as on domestic fronts as global supply, income growth and access is not keeping pace with increasing population in developing countries. Rapid population growth and economic development severely degrades

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the environment through industrialization and expanding of agricultural production into marginal lands. Increasing resource degradation problems such as groundwater depletion, water logging, salinization, soil erosion, loss of biodiversity and invasive species further add to food security challenges (Oliver and Gregory, 2015). In many developing countries like India, food security of the poor will be at risk, as they would face more severe resource and economic constraints due to the above world average population growth and limited arable land. In certain regions of India, like Bihar and Odisha, low agricultural productivity and output, and high poverty rates leave millions, especially those in rural areas, undernourished (Kumar, 2003). The situation is further complicated by decreasing per capita availability of arable land and slow climate change adaptation, which will lower food supply, compounding the challenge of meeting food demand. While climate change may affect the entire world, its impact especially in the rainfed regions of India is more severe because of the dependency of the majority of the people in the region. Rainfed agriculture in India currently accounts for about two-thirds of the total cropped area and nearly half of the total value of agricultural output (Roul et al., 2015). Nearly half of all food grains are grown under rainfed conditions, and hundreds of millions of the rural poor depend on rainfed agriculture as the primary source of their livelihood. Low-input subsistent agriculture in these regions is generally coupled with reduced crop yield and degrading soil conditions. Excessive and inappropriate tillage increases soil degradation and erosion (Cerda et al., 2009), reducing soil productivity and soil organic carbon (Lal, 2004). Thus, agricultural intensification is needed in these regions without further degrading the natural resource base. Furthermore, in the Indian context, average farm size is very small and average household member size is large, with poverty and food insecurity prevalent among small land-holders (Pradhan et al., 2015). Therefore, introduction and implementation of a new agricultural production system should be viewed in the context of enhancing farm productivity, environmental quality and profitability of agriculture while also improving household food and nutritional security.

Food security in India is linked to poverty and sustainability. With the country unable to lower the population growth rate to below 1% per annum, poverty remains an issue. Low caloric intake, poor health, low agricultural productivity and low income are perennial forces in the vicious poverty cycle in India (Varadharajan et al., 2013). The issue is not only the availability of food but of its affordability by vulnerable populations in adequate quantity and quality. It is not a question of whether we can increase food production to meet the needs of the rising population, but whether we can do so in a sustainable manner. It is imperative to develop a long-term strategy that would reduce the vulnerability of the farming community and sustainably intensify agricultural productivity while minimizing the degradation of land and natural resources being used.

Therefore in order to ensure food security on a sustainable basis, a suitable cropping system and land use needs to be implemented and adopted, based on principles to restrict land degradation and conserve the natural resource base as well as increase food and nutritional security through crop diversification and optimal rotation. Among many sustainable cropping systems available, conservation agriculture (CA) is the one that can reverse soil degradation, improve crop production, and enhance the socio-economic condition of small land-holder farmers.

The goal of this study was to identify entry points for improvement of farmers' economic livelihoods through conservation agriculture (CA) in the face of stresses caused by human activities and climate. Specifically, the objectives were to:

1. Evaluate the effect of CA on system productivity and profitability;
2. Evaluate the effect of CA on soil quality;
3. Compare farmer preferences before and after practicing CA to quantify the impacts of on farm action research; and
4. Provide recommendations for stakeholders regarding CA suitability.

2. Why a transdisciplinary approach?

Conservation agriculture strategies and practices have been developed and promoted to reduce risk and improve natural resource conditions such as soil quality, as well as address the combination of low yields, production risks and poor natural resource conditions typically seen in developing areas in Africa and south Asia (Stevenson et al., 2014). CA embodies three main principles: reduced or zero soil disturbance, permanent organic soil cover to reduce soil loss, and crop diversification (FAO, 2013). Currently, CA is being practiced on over 125 million hectares world-wide (Friedrich et al., 2012) and has several reports of reduced production costs, improved water use efficiency, and sustained or increased crop productivity across the globe (Hobbs, 2007; Erenstein et al., 2008; Govaerts et al., 2009; Kassam et al., 2009; Wall, 2009; Thierfelder and Wall, 2009, 2010). In addition, there are reports of erosion control and soil water conservation from implementation of CA (Scopel et al., 2005; Hobbs et al., 2008). Crop diversification with intercropping and rotation improve the nutritional security of the farm households and reduces the risk of total crop failure in unfavorable or erratic weather (FAO, 2013). Labor requirements can be reduced by about 50% for male-driven work of soil tillage but CA can increase female-driven work of weeding (Bishop-Sambrook, 2003).

Despite the documented benefits, the broad applicability of CA to diverse cropping systems around the globe remains contested (Pittelkow et al., 2015; Giller et al., 2009). Furthermore, implementation and adoption of all the three principles of CA in resource poor and vulnerable smallholder farming systems face various issues and challenges, most notably the retention of crop residues due to its strong competition as livestock feed (Giller et al., 2009). Considering various arguments on justifying the implementation of CA, it must obviously be adapted to local agro-ecological conditions and farmer capabilities and preferences. CA is best conceptualized as an integrated production system that is universally applicable but must be locally adapted. Careful consideration of farmer capabilities and preferences is just as important as understanding the production capabilities of the agro-ecological system. Therefore, successful introduction of CA depends upon adapting and tailoring the basic CA principles to the local context.

In order to enhance and promote CA adoption, a transdisciplinary approach was undertaken to evaluate CA in the rainfed uplands of Odisha, India. A transdisciplinary approach is arguably superior for the introduction of CA technology to smallholder farmers in India as it involves complex human and natural systems. The transdisciplinary approach attempts to embody scientific knowledge that is created and assimilated by different disciplines while engaging multiple stakeholders for their inputs in the co-design and implementation of field experiments and demonstrations. This approach builds strong partnerships among researchers, farmers, communities and global audiences, facilitating greater adoption of innovative technologies, and achieving sustainable outcomes. The framework to smoothly transition from CA production system creation to sustainable outcomes involves four stages (Table 1). The first stage involves co-design and research definition of CA. Interdisciplinary researchers engaged farmers, villagers, and local universities and extension/NGO personnel to explain CA technology and potential outcomes to farming systems. Potential experimental designs to evaluate CA production systems were determined after multiple engagements with stakeholders on local practices and cropping preferences. Experimental outcome indicators were developed collaboratively. The second stage was data collection. Once CA treatments were determined from stage 1, an experimental design for treatment assessment was developed. Farmers and villagers were provided with training on implementing; managing the field experiments, and the universities and NGO collected the data. The district government and funding agencies were informed of the experiments. The third stage encompassed data analysis, determination of relevancy and interpretation of outcomes. After data analysis by researchers, the relevancy of the results was discussed and interpreted among the