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Identifying viable nutrient management interventions at the farm level: The case of smallholder organic Basmati rice production in Uttarakhand, India

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ABSTRACT

Smallholder farmers may gain notable livelihood benefits by participating in organic value chains. However, whether there are enough resources available to maintain organic production sustainably on smallholder farms in resource-poor regions is of concern. If not balanced by sufficient inputs, continual nutrient export via commodity crops will result in nutrient mining, and livelihood improvements gained by participating in profitable value chains could be negated by soil degradation in the long term. The objectives of this study were to test an integrated approach for understanding the farm-level impacts of subsystem nutrient management actions and to identify locally viable interventions for increased nutrient supply and recycling. We employ a systems analysis methodology to address the nutrient gaps on smallholder farms in Uttarakhand, India producing organic Basmati rice for an international value chain. Farmers here rely on few livestock (three to five head of cattle ha^{-1}) to supply nutrient inputs and are achieving smaller than potential Basmati yields. We surveyed 42 small farms (< 3.5 ha, average annual income around \$1000 $year^{-1}$) and analyzed available manure stocks for nutrient contents in order to trace the farm-level flow of manure nutrients, identify vectors of avoidable nutrient loss, and systematically identify locally relevant and feasible improvements. The interventions identified as viable were reducing nutrient losses through simple and relatively cheap manure management modifications (i.e. using straw bedding to capture livestock urine, covering farmyard manure stockpiles with plastic sheeting, enclosed biogas slurry storage, and using biogas slurry for improved compost production), in situ green manuring, and purchasing farmyard manure. Cost–benefit analyses predicted that proposed interventions could increase farmers' net profit by up to 40% while also addressing problematic nutrient gaps. While our results pertain specifically to Uttarakhand, we found that our integrated research approach worked well to address the problem of nutrient gaps on resource-poor smallholder organic farms, and believe that the strategy could be used with equal success to address similar problems in other regions.

1. Introduction

The state of Uttarakhand is on the forefront of promoting organic agriculture in India (Panneerselvam et al., 2012) and is one of the few places in the world where Basmati rice (*Oryza sativa* 'Basmati') is grown. Situated along the Western Himalayan foothills, Uttarakhand's major cropping system is a rice–wheat rotation, where coarse-grain paddy rice is grown in the rainy *kharif* season (approximately June–October) and wheat in the dry *rabi* season (approximately November–March). The number of farmers adopting high-value Basmati in place of coarse-grain paddy has notably increased, and India's export of Basmati grew by 56% between 2010 and 2015 (APEDA, 2016; Jena and Grote, 2012).

An agricultural development project led by HELVETAS Swiss

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Intercooperation in collaboration with Intercooperation Social Development India (ICSD) targets smallholders in Uttarakhand's Nainital District with potential for joining an organic and fair-trade Basmati value chain, aiming to improve smallholder livelihoods through sale of the in-demand product (Eyhorn, 2017). Participants receive extension support in the transition to grow organic Basmati, and gain access to a reliable marketing scheme. Farmers in the project are generally solely dependent on farming for income and rely on their few livestock (three to five head of cattle ha^{-1}) to supply the bulk of the nutrient inputs used in their organic systems. As in other resource-poor regions of the world, a concern is whether there are enough resources available on smallholder farms to maintain profitable organic production sustainably. A willingness to adopt organic practices does not necessarily imply that farmers are able to employ best organic management, as many are constrained by the availability of essential resources, namely water and organic soil amendments. If not balanced by sufficient inputs, continual nutrient export via commodity crops will result in nutrient mining, and livelihood improvements gained by participating in a profitable value chain could be negated by soil degradation in the long term.

Many farmers in the region achieve lower than potential yields, for various reasons. To achieve sustainable intensification of these systems and thereby magnify the social and economic benefits of farmers' involvement in the organic and fair-trade scheme, the issue of insufficient nutrient supply must be addressed. Since livestock manure is the primary source of nutrient inputs to crop fields, manure management is an essential focus for identifying potential improvements to farm-level nutrient management that are within reach of resource-poor farmers. How manure is managed after excretion and during collection, storage, and field application can result in varying degrees of nutrient losses; these directly affect both the quantity and composition of manure, which in turn affect soil quality and crop yield.

Farmers in the Uttarakhand hills use two primary methods of manure management: farmyard manure (FYM), the practice of collecting animal manures and other organic farm wastes in minimally managed stockpiles, and vermicomposting (VC), the practice of using earthworms to compost animal manures and organic wastes. Some farmers have installed biogas plants, which produce combustible gas (principally CH_4) through anaerobic digestion of animal manures. Biogas is harvested for household use, and spent manure slurry is released from the digestion tank as liquid effluent. Farmers with biogas plants utilize this effluent (biogas slurry, BGS) as a fertilizer. We hypothesize that across all three management practices there is potential for system improvements that are economically, socially, and environmentally acceptable. In addition, there are farmers who have adopted in situ green manuring (GM) with *Sesbania aculeata* between *rabi* and *kharif* seasons, and we hypothesize that this practice improves farm nutrient status.

Smallholder farms may be viewed as composed of multiple intertwined subsystems, the management of which influence whole-farm performance. To investigate adequately the farm-level impacts of different subsystem management actions, an integrated systems approach is needed (Alvarez et al., 2014; Fonte et al., 2012); we adopt such an approach in this study. Furthermore, while useful knowledge can be gained by testing interventions at experiment station field trials, farm-level realities and trade-offs are not always accounted for in the development of management solutions. Diversity among smallholder farmers' production systems and socio-economic constraints necessitates a site-specific approach to ensure that unique and complex interplays of social and ecological factors inform the development of system improvements (Giller et al., 2011). For this reason, we applied our research approach to a case study.

The objectives of this study were: (i) to test the effectiveness of an integrated research approach for assessing the farm-level impacts of subsystem nutrient management actions on smallholder mixed crop–livestock farms; and (ii) to systematically identify locally relevant and feasible solutions to increase nutrient supply and recycling at the farm level in the case study context.

2. Materials & methods

2.1. The study area

The research was conducted in the Nainital District in the hilly southeast region of Uttarakhand, India. Average annual rainfall and temperature here are 1648 mm and 18 °C, respectively. Soils are loamy and shallow to medium-deep with poor water-holding capacity (Srivastava and Singh, 2009). The Nainital District hosts a primarily agriculture-based economy, with > 70% of landholdings < 1 ha (Tuteja, 2013). Commonly cultivated crops include paddy rice, soya, wheat, pulses, tomato, onion, and ginger, as well as a wide variety of herbs and vegetables grown for home consumption. Farmers raise nondescript local hill breeds of cattle and buffalo for milk, manure, and draught power. Farm households typically rely on an average annual income of 69,700 INR (approximately $1065) (Eyhorn et al., 2018). The farms targeted for this study were located in the Patkote, Kotabagh, and Betalghat village areas, and were already participating in the aforementioned organic Basmati development project. A common cropping sequence on these farms was Basmati, coarse-grain paddy, and soya in *kharif*, followed by wheat, tomato, and pulses in *rabi*.

In a field trial at the nearby Govind Ballabh Pant University of Agriculture and Technology (GBPUAT) in Pantnagar, the impact of a suite of organic management practices on the yield performance of Basmati rice is being tested. Data from the experiment station field trial, both published and unpublished, were used to calculate several parameters in our study (see Table 1). For a description of the field trial, see Singh et al. (2016).

2.2. Methods

The research followed the four-phase DEED methodology described by Giller et al. (2011) and inspired by Kolb's experiential learning cycle (Kolb, 1984), in which the research phases are named (1) Describe, (2) Explain, (3) Explore, and (4) Design (Fig. 1). The cyclical nature of the methodology facilitates an iterative approach where knowledge gained from the research can lead to positive action relevant to the actual conditions and concerns of the stakeholders involved. A description of the objectives and methods employed in each research phase follows.

2.2.1. Describe

In the first research phase, we described farmers' actual manure management and GM practices, manure availability, manure application rates, and Basmati crop performance. Data collection activities were organized around a conceptualization of manure management in mixed crop–livestock systems described by Rufino et al. (2006). In this conceptual model (Fig. 2), whole-farm manure nutrient availability and losses are understood as the products of management activities in four farm subsystems: 1. Livestock; 2. Manure collection and handling; 3. Manure storage and composting; and 4. Soil nutrient availability, crop capture, and crop conversion (Rufino et al., 2006).

2.2.1.1. On-farm surveys. Forty-two farmers were surveyed in February–April 2016. The survey was designed to understand farmers' practices in each of the four management subsystems described in Fig. 2, and covered farm size, livestock holding, manure production and collection, allocation of manure to different storage and processing methods, green manuring practices, manure application rates, and Basmati yield. Respondents were purposively selected using stratified sampling to achieve representation of farmers practicing each of four nutrient management practices: FYM, VC, BGS, and GM. At the end of each survey, farmers were asked to describe qualitatively what they perceived as the advantages and disadvantages of their nutrient