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Increasing yield stability and input efficiencies with cost-effective mechanization in Nepal

Alex G. Park[a,*], Andrew J. McDonald[b], Mina Devkota[b], Adam S. Davis[a]

[a] Department of Crop Sciences, University of Illinois at Urbana-Champaign, S-306 Turner Hall, 1102 South Goodwin Avenue, Urbana, IL 61801, USA
[b] CIMMYT-Nepal, Singh Durbar Plaza Marg, Kathmandu, Nepal

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ABSTRACT

Nepal is at a crossroads of diminishing farm-labor and inadequate investment into farming operations that, among other factors, have stagnated domestic wheat yield. Cultural and economic constraints have hindered the widespread adoption of more expensive precision agriculture technologies like zero-till that have the capacity to improve labor and farm input efficiencies. To capture the benefits from added precision of application but with the ability to fit within the current semi-mechanized seed bed preparation and tillage system, we introduced a low-cost, chest mounted seed and fertilizer. We found that simple mechanization caused yield efficiencies to be positive and significant for nitrogen and phosphate. Seed rates using this method were positively associated with seedling density. This led to both yield and profit being more predictable for farmers. Conversely, hand-applied inputs caused a disassociation between inputs and end of season yield and therefore added a large measure of risk to their farming operations.

1. Introduction

Nepal has the lowest cereal yield per hectare among the south Asian countries that provide the region with its domestic source of grain. The cause of Nepal's low yields has been attributed to a stunting of agricultural intensification caused by short-sighted development policies and socioeconomic crises (Karan et al., 1994; Sharma, 2006). Limited adoption of agronomic practices by farmers that increase yield are on a collision course with a diminishing labor market that will further undermine domestic food security if not addressed (Joshi et al., 2012; Seddon et al., 2002). Long-term solutions to these problems will require policy changes at the national level by the Nepali government, while more immediate solutions can be found by targeting appropriate technologies at ineffective agricultural practices. Here we document the effects of low-cost, simple mechanization (in the form of a chest-mounted seed and fertilizer spreader) on yield, yield variability, efficiencies and others metrics compared to the traditional hand application of inputs.

Stagnation of agricultural intensification in Nepal has exposed farmers to risk by preventing them from adopting better agronomic practices like appropriate management of soil fertility. Fertilizer rates for nitrogen (N), phosphate (P), and potassium (K) on the Terai of Nepal –the most productive and developed agricultural region adjacent India– are 40%, 26%, and 70% less, respectively compared to farmers in neighboring Bihar, India (Park et al., 2018). When fertilizer is applied, 75–80% of it comes from gray market sources from India (Pandey, 2014). The effects of inadequate supplies of affordable fertilizer to crop productivity in Nepal are compounded by decreasing availability of agricultural labor (Maharjan et al., 2013).

In response to limited opportunities for economic advancement in farming, agricultural laborers and farmers in the 1990s began leaving the sector en masse in search of more lucrative work abroad (Central Bureau of Statistics, 2009; Seddon et al., 2002). This trend has only accelerated, with 10% of the Nepali population working overseas in the remittance economy by 2014 (Kaphle, 2014; NIDS, 2018). This departure of farm labor was found to dramatically reduce the productivity of Nepali agriculture on a farm by farm basis. For every laborer that left a household in which they were part of the labor pool, total crop productivity dropped 11% (Maharjan et al., 2013). As labor becomes scarcer in the Nepali agricultural economy, labor bottlenecks have emerged as an increasing problem. Labor bottlenecks occur when there are labor shortages, and are especially problematic during critical times of agricultural operations (Pingali, 2007). Bottlenecks often occur around seed bed preparation, sowing, top dressing and harvesting. Delays in these operations have significant consequences to the productivity of the wheat system in Nepal and South Asia. A common

* Corresponding author.
E-mail addresses: Agpark2@illinois.edu (A.G. Park), A.McDonald@cgiar.org (A.J. McDonald), M.Devkota@cgiar.org (M. Devkota), asdavis1@illinois.edu (A.S. Davis).

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example of a labor bottleneck in Nepal is the late sowing of wheat. Delays in sowing can reduce yields by 0.7% for every day delayed past an optimum sowing window due to late season heat stress (Ortiz-Monasterio et al., 1994). Solutions to labor bottlenecks increasingly take the form of mechanization, or technology more broadly, in most global agricultural systems (Pingali, 2010).

Immediate solutions to the specific problems of labor and fertilizer scarcity can be undertaken using technology that increase efficiencies. A technological solution that focuses on improving efficiency of inputs and labor best reflects the reality that an increase of both inputs and labor in Nepal is unlikely to increase in the near future because of the long-term political and socioeconomic roots of these problems (Sharma, 2006). To have a realistic chance of adoption at scale, technological solutions must be low-cost, simple for easy maintenance, and capable of fitting within the status quo of agricultural practices of Nepal. These criteria are part of successful agricultural development projects in the past that adapted appropriate technologies to the constraints of the local agricultural systems (ATTRA, 2018). Past development projects in Nepal that leveraged advanced agricultural technologies have often failed in the long-term because the supporting manufacturing, machinery, and agribusiness sectors were unable to maintain complex equipment or processes after the initial support for the introduction of the technology was completed (Maharjan et al., 2013; Metz, 1995).

A source of inefficiency in Nepal ripe for improvement with an appropriate technological intervention is the traditional practice of applying farm inputs by hand. We believe this traditional practice is a principal source of within-field variability and, we hypothesize, a prime contributor to resource use inefficiencies and yield gaps. An intervention that increases the precision and speed of application of seed and fertilizer would improve both input and labor efficiencies. We therefore sought to test if a simple, chest-mounted spreader could improve the following aspects of the farming system in our study relative to traditional methods: 1) improve uniformity of wheat yield within fields, 2) improve fertilizer efficiency of nitrogen and phosphate with respect to yield and an independent measure of crop vigor, 3) increase seed efficiency to seedling establishment and yield, and 4) increase labor efficiency. We then assessed whether the net effect of mechanization provided meaningful improvements to a farmer's return on investments.

2. Methods

2.1. Overview

To test whether simple mechanization could improve fertilizer and seed efficiency compared to traditional hand applied methods on the Terai of Nepal, we split a group of 60 farmer participants into two treatment groups within a Completely Randomized Design. Thirty farmers received an application of farm inputs using a chest-mounted spreader, while the other 30 applied these inputs by hand.

2.2. Study location and timing

The study area was located near the town of Siddharthanagar in the district of Rupandehi in the Terai region of Nepal (27.5126 °N, 83.4816 °E) where the dominant annual cropping pattern is a rice-wheat rotation (Mahajan and Gupta, 2009). Trials began in November of 2016 with sowing and concluded in April 2017 when harvested. The study area climate is sub-tropical, with a mean annual temperature between 20 and 25 °C and an average annual rainfall of approximately 1400 to 2000 mm (WFP, 2010) which mostly falls during monsoon. All fields in the study received at least one irrigation during the wheat growing season.

2.3. Technological intervention and traditional practices

We selected a chest-mounted spreader as our intervention to apply the granular inputs of urea, diammonium phosphate, and seed to farmer's fields. The model chosen was a (*Model 2750, Manufacturer-EarthWay)* spreader, commonly used to fertilize lawns in America and Europe. An agitator feeds granular material from a top mounted nylon hopper to the distribution plate where it is spread in a fanning action of approximately 45° in front of the user's chest who controls rate of application through speed of cranking and a flow control mechanism. Inputs were applied by travelling along the perimeter of the field with the left side of the fan overlapping the right side of the previous pass (Wolf and Smith, 1979). The current price for a single unit sold in the United States at the time of publication was $35 USD. This simple device was compared to the traditional method of applying fertilizer and seed by hand. In the traditional method, fertilizer or seed is placed in a container, which is applied by hand as the laborer walks up and down a field applying the input as uniformly as possible. Under both mechanized and traditional treatments, the inputs were then incorporated by either a cultivator or rotovator.

2.4. Experimental design and input rates

Sixty farmers were selected at random for inclusion in a Completely Randomized Design trial, with the two treatments applied to 30 farms each. A single researcher applied farm inputs with the spreader, while farmers applied inputs to their own fields. Within each farmer's field, four 1 m^2 subsamples were randomly established to capture heterogeneity of response variables across the season. As these were on-farm trials, researchers only controlled different application techniques of seed and fertilizer. All farmers were provided 3.75 kg of diammonium phosphate, and 4 kg of urea after it was determined that many farmers in the trials would have no fertilizer to apply whatsoever because of inadequate access or funding, thereby making the experiment irrelevant. If farmers were able to afford fertilizer, they almost always added the amount we provided them to their own supply, thereby increasing their rates (information that we recorded). The rates of fertilizer in these trials for N and P are 21% higher than those in a recent production survey (Park et al., 2018), and reflect the combining of farmer fertilizer with that provided by researchers. Seed was provided by farmers and represented 12 unique varieties. Field sizes ranged between 0.014 ha to 0.11 ha, and averaged 0.04 ha.

2.5. Normalized difference vegetation index, end of season yield estimates, and seedling density

Normalized Difference Vegetation Index (NDVI) was recorded biweekly throughout the wheat season at all subsamples because of its strong relationship with both plant uptake of fertilizer (Teal et al., 2006) and end of season yield (Wiegand and Richardson, 1990). Time constraints at the time of harvest necessitated a four-step model approach to estimate yield at all subsamples in farmers' fields. First, we harvested a single random subsample from each of the 60 fields within the study for an estimation of real yield. The yield of this sample was corrected for moisture content using a *wile 55* moisture meter. Second, we fit a quadratic model to the seasonal NDVI curves with random effects in the intercept and linear term for each farm, and a random effect in the intercept for each subsample. Third, we estimated the seasonal maximum NDVI using these fitted curves for each subsample because of its strong relationship to end of season yield (Labus et al., 2002). Fourth, simple linear models were fit between maximum NDVI values and the real yield values from the harvested subsample stratified by variety to allow for adequate replication. The resulting predictions of final yield were used as the response variable in this study. Seedling density was determined by visual counts within each of the subsamples. Variability of seedling density was determined by calculating the