Europ. J. Agronomy 80 (2016) 154–167

Contents lists available at ScienceDirect

European Journal of Agronomy

journal homepage: www.elsevier.com/locate/eja

Fertilizers, hybrids, and the sustainable intensification of maize systems in the rainfed mid-hills of Nepal

K.P. Devkota[a,*], A.J. McDonald[b], L. Khadka[b], A. Khadka[b], G. Paudel[b], M. Devkota[b]

[a] Crop and Environmental Science Division (CESD), International Rice Research Institute (IRRI), Los Banos, Laguna, Philippines
[b] International Maize and Wheat Improvement Center (CIMMYT), South Asia Regional Office, Kathmandu, Nepal

ARTICLE INFO

Article history:
Received 8 March 2015
Received in revised form 8 July 2016
Accepted 1 August 2016
Available online 10 August 2016

Keywords:
Yield gap
Precision nutrient management
Sustainable intensification
Domain-specific recommendation

ABSTRACT

In the rainfed mid-hill region of Nepal, most fields receive 2–3 t ha^{-1} of organic compost application every year. Despite efficient recovery and use of organics in the mixed crop-animal systems that predominant in the mid-hills, depleted soil fertility is widely understood to be a significant constraint to crop productivity, with most farmers achieving maize grain yields below 2 t ha^{-1}. Increased use of fertilizer may arrest and even reverse long-term soil quality degradation, but few farmers in the mid-hills use them at present and existing recommendations are insufficiently responsive to site, varietal, and management factors that influence the productivity and profitability of increased fertilizer use. Moreover, policy makers and development practitioners often hold the perception that returns to fertilizer use in the mid-hills are too low to merit investment. In this study, on-farm experiments were conducted at 16 sites in the Palpa district, Nepal to assess the responsiveness of a maize hybrid (DKC 9081) and an 'improved' open-pollinated maize variety ('OPV', Manakamana-3) to four nitrogen (N) rates, i.e., 0, 60, 120 and 180 kg ha^{-1}, with each N rate response evaluated at 30:30 and 60:60 kg ha^{-1} rates of phosphorus (P_2O_5) and potassium (K_2O), respectively. With sound agronomy and high rates of fertilizer (180:60:60 kg N:P_2O_5:K_2O ha^{-1}), grain yields observed in the field experiments exceeded 8 t ha^{-1} with hybrids and 6 t ha^{-1} with OPV. Yield levels were lower for OPV than hybrid at every level of applied N, but both genotypes responded linearly to N with partial factor productivity for N (PFP_N) ranging from 14 to 19 for OPV versus 26–30 for hybrid, with improved N efficiencies obtained when P and K rates were significantly higher. Averaged across phosphorus (P) and potassium (K) levels, a $ 1 incremental investment in fertilizer increased the gross margin (GM) by $ 1.70 ha^{-1} in OPV and by $ 1.83 ha^{-1} in the hybrid. For the full response of N, requires higher rate of P_2O_5:K_2O and vice-versa and full response to P_2O_5:K_2O does not occur if N is absent. These results suggest that, i) degraded soils in the mid-hills of Nepal respond favorably to macronutrient fertilizers – even at high rates, ii) balanced fertilization is necessary to optimize returns on investments in N but must be weighed against additional costs, iii) OPVs benefit from investments in fertilizer, albeit at a PFP_N that is 36–47% lower than for hybrids, and, consequently iv) hybrids are an effective mechanism for achieving a higher return on fertilizer investments, even when modest rates are applied. To extend these findings across years and sites in the mid-hills, crop growth simulations using the CERES-maize model (DSSAT) were conducted for 11 districts with historical weather and representative soils data. Average simulated (hybrid) maize yields with high fertilizer rate (180:60:60 kg N:P_2O_5:K_2O ha^{-1}) ranged from 3.9 t ha^{-1} to 7.5 t ha^{-1} across districts, indicating a high disparity in attainable yield potential. By using these values to estimate district-specific attainable yield targets, recommended N fertilizer rates vary between 65 and 208 kg N ha^{-1}, highlighting the importance of developing domain-specific recommendations. Simulations also suggest the potential utility of using weather forecasts in tandem with site and planting date information to adjust fertilizer recommendations on a seasonal basis.

1. Introduction

Maize (*Zea mays* L.) is the second most important food crop in Nepal (0.85 million ha area and production of 1.99 million ton) and is the foremost staple in the mid-hills ranging from 300 to 2500 m altitude with 70% of the total maize area located in this region (CBS, 2015). In the mid-hills, maize has multiple uses as food,

* Corresponding author.
E-mail address: k.devkota@irri.org (K.P. Devkota).

http://dx.doi.org/10.1016/j.eja.2016.08.003
1161-0301/

feed, fodder, and fuel and is almost always cultivated under rainfed ('bari') conditions (Matthews and Pilbeam, 2005).

Under current crop management practices, maize productivity in the country is still low at 2.3 t ha^{-1} in 2013, growing at the very modest rate of 19 kg ha^{-1} $year^{-1}$ over the past three decades (FAOSTAT, 2015; Tiwari et al., 2009). Compared to the other south Asian countries, the maize yield gap in the mid-hill region of Nepal is large (>4.0 t ha^{-1}) (Devkota et al., 2015; Timsina et al., 2010) with the low and unbalanced application of chemical fertilizer (<20:5:0 kg N:P_2O_5:K_2O ha^{-1}) identified as a primary factor for low yields (Adhikari, 2000; Devkota et al., 2015; Shrestha et al., 2013; Tiwari et al., 2004). In Nepal, fertilizer use has increased over the past two decades, but the overall intensity of chemical fertilizer use lags behind many Asian countries and much of the increased usage has occurred in the Terai region and not in the mid-hills (Takeshima et al., 2016).

The current average annual growth rate for maize yield in Nepal is around 2% but the demand for maize production is estimated to grow by 5% per annum over the next two decades (FAOSTAT, 2015). The increased demand includes both use as food in the mid-hills as well as the demand for poultry and livestock feed as a result of the growing demand for milk, meat and meat products (DoA, 2014). Locally available sources of nutrients, mainly farm yard manures (FYM), are not sufficient to support high maize productivity (Ziadi et al., 2013). Intensified use of mineral fertilizers and adoption of hybrids represent major pathways to increase maize yields in the rainfed mid-hill region of Nepal (Devkota et al., 2015). Nevertheless, the current fertilizer recommendations for rainfed maize in Nepal (i.e. 60:30:30 kg N:P_2O_5:K_2O ha^{-1}) (GoN, 2015) are based on old data and applied across a broad geographic area, and hence is not responsive to the site and management factors that govern indigenous soil fertility, crop yield potential, or the efficiency of fertilizer recovery (Ziadi et al., 2013). Specific factors associated with defining economically-optimum fertility management practices included soil organic carbon (Kurwakumire et al., 2014), soil texture (Ziadi et al., 2013), climatic conditions (Pasuquin et al., 2014; Porter and Semenov, 2005), and agronomic management practices (Xu et al., 2014), including crop variety. In mid-hill region of Nepal, just before sowing of maize, farmers routinely apply approximately 10 t ha^{-1} of cured farm yard manure (Devkota et al., 2015), but these practices vary widely across farmers and also between fields on the same farm. Site-specific nutrient recommendations that account for these factors may increase crop production and enhance nutrient productivity (Kurwakumire et al., 2014), and ultimately contribute to efficiently closing yield gaps.

To complement field trials, dynamic simulation approaches can provide an inexpensive means of determining crop nutrient requirements under varied soil, management, and climatic conditions (Hoogenboom et al., 2015; Liu et al., 2012). The CSM-CERES-maize model of DSSAT can predict accurately the growth, phenology, yield and yield attributes of maize crop by accounting for the effect of Nitrogen (N) and Phosphorus (P) under diverse soil, weather, management, and crop cultivars choices (Gijsman et al., 2002; Hoogenboom et al., 2015; Jones et al., 2003; Porter et al., 2010). Besides N, the model considers P soil availability, uptake from the soil, and its effects on maize growth upon initialization of CENTURY model, however, the current version of CSM in DSSAT does not consider effects of K (Hoogenboom et al., 2015). In order to gain insights into efficient fertility management practices for maize in the mid-hills, the first objectives of this study were to characterize the responses of hybrid and OPV maize genotypes to N fertilizers at two levels of P and K. Secondly, to characterize the influence of soil, weather, and sowing date on efficient nutrient management practices using a companion simulation study on how these responses are likely to vary across years and sites in the mid-hill region.

2. Materials and methods

2.1. Field site characteristics

On-farm experiments were conducted in Palpa (Fig. 1), one of the mid-hill district of Nepal, with latitude 27.87° and longitude 83.54°in four rainfed sites within 35 km range during the 2012 and 2013 maize growing seasons. The soils of the field sites are dominantly haplaquept, ustochrepts and paralithic with silty loam texture (Table 1). The climate of the study region is warm-temperate, and during the maize growing season (April 1 to September 30) mean rainfall is 1410 mm with average daily maximum and minimum temperatures of 28.0 and 19.5 °C, respectively, and solar radiation of 14.38 MJ m^{-2} d^{-1} (Fig. 2).

2.2. Experimental design and treatments

On-farm experiments were conducted at three locations of Palpa (Laguwa, Chhandibhanjang and Harthog villages) in 2012 and 2013 (Table 2). The experiments were conducted in factorial randomized block design with N rate treatments (3 levels in 2012, 4 levels in 2013) layered with P + K rate (2 levels) with two crop genotypes, for a total of 12 and 16 factor combinations in 2012 and 2013, respectively. The two genotypes included an OPV (Manakamana-3) and a hybrid (DKC 9081). Nitrogen rates in 2012 were 60, 120 and 180 kg N ha^{-1} and 0, 60, 120 and 180 kg N ha^{-1} in 2013. Two levels of P and K were applied in both years (30:30 and 60:60 kg ha^{-1}). Maize was planted under strip-tillage conditions with a row-to-row distance of 60 cm with a target plant population of 58,000 ha^{-1}. Furrows for the strip-tillage were opened using mini-tiller and/or a bullock-drawn country plough. Seeding was done in the furrow using a punch-type planter. Plot sizes varied from 25 to 60 m^2 depending upon the geometry of the terrace.

2.3. Crop management

Shortly before maize sowing (2–5 days), round-up (Glyphosate) @ 5 ml L^{-1} was applied. All P and K fertilizers were soil-incorporated in the furrows as a basal application at sowing. After basal application of dia-ammonium phosphate (DAP), the remaining N fertilizer was top-dressed with urea fertilizer in two splits i.e., 60% in 1st topdressing and 40% in 2nd topdressing according to the respective N rate treatments (Table 2). Hand weeding (manual pulling) was carried out before the application of urea top-dressing.

2.4. Measurements on crop phenology, growth, yield and yield attributes

Maize phenology was recorded through visual observation by counting plants in the 3rd row from the North in all plots. Crop growth rates were estimated through destructive harvesting of three plants in each plot at 15–20 day intervals. The sampled plants were oven dried 72h at 65 °C until constant weight. In 2012, maize grain yield was determined by randomly harvesting 20 plants and estimated yield based on actual stand density. In 2013, a 9 m^2 area was harvested in the center of each plot. Grain yield is expressed on 14% moisture basis. Cob density (no. of cobs m^{-2}) was determined by counting all plants in the harvested area. Average grain weight was determined by oven drying 200 grains and expressed 1000 grain weight on an oven dry basis. Harvest index (HI) was calculated as the ratio of oven-dry grain yield to the total above-ground biomass and expressed in percentage.