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Research Paper

Effect of seven years of nutrient supplementation through organic and inorganic sources on productivity, soil and water conservation, and soil fertility changes of maize-wheat rotation in north-western Indian Himalayas

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ABSTRACT

Sloping croplands require different nutrient management practices than levelled lands in order to check soil degradation. In order to check erosion *vis-a vis* degradation, fertilization of maize (*Zea mays* L.)-wheat (*Triticum aestivum* L. emend Fiori & Paol.) crop rotation with organic manure supplemented with inorganic fertilizer is required. A seven year fixed plot field experiment under rainfed conditions was conducted comprising seven management practices in both maize and wheat crops: control (0), 100% NPK through inorganic fertilizers (100-0), 100% N through farmyard manure (FYM) (0–100), substitution of 50% N through four different organic manures viz., FYM (50 + 50 FYM), vermicompost (50 + 50 VC), poultry manure (50 + 50 PM) and *in-situ* green manuring (50 + 50 GM) of sunnhemp (*Crotalaria juncea* L.). Crop productivity, runoff coefficient, soil loss, and post harvest soil fertility parameters were assessed to estimate the effects of combined use of inorganic and organic sources of nutrients. The results indicated that 50 + 50 (FYM) could maintain significantly higher ($p < 0.05$) productivity of maize (18–74%) and wheat (10–77%) than 100-0 in different years. However, 50 + 50 (GM) resulted in higher reduction of runoff (16–40%) and soil loss (13–50%) than 100-0 in different years, leading to higher conservation of natural resources. Maize grain yield was significantly negatively correlated with run-off ($r^2 = 0.16$ with $p = 0.005$) and soil loss ($r^2 = 0.26$ with $p = 0.0001$). Our study concluded that combined use of chemical fertilizers and organic manures particularly FYM or GM may be considered as a feasible and environment-friendly option for soil conservation.

1. Introduction

Realizing the importance of soils, the United Nations declared the year 2015 the "International Year of Soils" and mentioned that our soils (a non-renewable resource over the lifespan of a human being) are in danger because of widespread soil degradation which threatens the capacity of the soil functions to meet the needs of future generations for ecosystem services (FAO, 2015). Moreover, Keesstra et al. (2016) highlighted that soils are relevant to achieve the Sustainable Development Goals (SDGs) as many of them are dependent on the soil functions. Therefore, it is essential to understand the role of soils in the earth system functioning as they determine the geochemical and biological cycles and influence the hydrological and erosional processes (Keesstra et al., 2012; Mol and Keesstra, 2012; Brevik et al., 2015). Soils around the world are affected by land degradation processes as a consequence of the abuse of grazing, fire, mining or agriculture (Concostrina-Zubiri et al., 2017; Martín-Moreno et al., 2016; Martínez-Murillo et al., 2016). The mountains of the world are an important source of water and food; however the mountain ecosystems are more vulnerable to soil erosion because of their sloping topography (Mandal and Sharda, 2013).

Himalayan mountain system covers partly or fully eight countries of south Asia viz., Afghanistan, Bangladesh, Bhutan, China, India, Myanmar, Nepal and Pakistan. The Himalayan ecosystem is fragile and diverse. It habitats around 51 million people who practice hill agriculture and remains vulnerable to various constraints. Recent estimates indicate that nearly 39% area of the Indian Himalayas has potential soil erosion rate of more than 40 t ha^{-1} yr^{-1}, much higher than the soil loss tolerance limit (Mandal and Sharda, 2013). Erosion due to runoff on sloping croplands causes loss of soil, water and nutrients, leading to low productivity and environmental degradation (Singh et al., 2016; Zhang

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et al., 2016). Recent estimates made by Sharda et al. (2010), documented a productivity loss of 13.4 million tonnes of food grain worth US$ 1.85 billion due to soil erosion by water in rainfed areas of India. The findings in the Himalayan context can be seen as a study case that represents other mountain regions of the world (Nadal-Romero et al., 2016; Egarter-Vigl et al., 2017; Romero-Díaz et al., 2017).

Reducing erosivity (capacity of agents causing erosion) and erodibility (susceptibility of soil to erosion) are the two ways of minimizing the effects of soil erosion (Hudson, 1971). Soil properties have considerable influence on soil erodibility. Soil with stable aggregates is resistant to detachment. Stability of aggregates can be increased by application of carbon inputs in soil through organic manures, crop residues, green manures, cover crops etc. Organic matter is one of the most important and best known stabilizing agents in soils (Wischmeier and Mannering, 1969). There has been considerable experimentation and discussion on the mechanisms of the effect that organic fractions have on soil. The infiltration capacity decreases after rainfall events because of surface sealing and crusting processes (Zhang et al., 2016), and infiltration may be reduced to 1 mm h^{-1}. This situation corresponds to most of the cultivated land which generally is medium textured. Silty and loamy soils (which are our study soils) are the most prone to sealing, and in addition are more easily transported by runoff. Soil surface protection and fulfilling nitrogen demand of maize crop after decomposition (*in-situ* green manuring) of annual legume cover crop like sunnhemp (*Crotalaria juncea* L.) has proven to be one of the best management practices for the maintenance of soil health and soil water regime and effectively reduced the runoff coefficient, splash erosion in both up and down directions, and sediment yield according to studies and practical applications (Singh et al., 2011, 2016). The reason is that pores in the soil surface are protected from clogging by small clumps of soil and organic particles detached from the soil matrix by raindrop impact. With farming activities starting in rainy season in India (June–July), the soil surface is completely disturbed by conventional tillage in April-May and is exposed to rainfall before the maize (*Zea mays* L.) canopy fully develops in August (Sharma et al., 2017). Serious soil erosion and sediment discharge additionally occur during rainstorms. Increasing crop cover on the soil surface to slowdown flow velocities, as well as adding organic matter to decrease soil erodibility, may be more appropriate regulatory measures for reducing non-point source pollution into aquatic environments (Singh et al., 2016; Zhang et al., 2016).

Hill and mountain agriculture in Indian Himalayan Region (IHR) has evolved over the centuries with the application of 10–20 t ha^{-1} farmyard manure (FYM) (Tiwari et al., 2005). Availability of this huge quantity of FYM is now questionable because of reducing cattle population in IHR due to migration of farming families in search of employment in plain areas of Northern India. Increasing demographic pressures for food and soil health have necessitated research in integrated use of both organic and inorganic components of plant nutrient management of which soil conservation is a vital component (Bhattacharya et al., 2008). Balanced nutrition increases canopy cover in active growth stages, thereby reducing runoff, soil loss and erodibility (Wischmeier and Mannering, 1969; Ghosh et al., 2014; Singh et al., 2016; Zhang et al., 2016).

The main crops grown in the IHR are maize in rainy season and wheat (*Triticum aestivum* L. emend Fiori & Paol.) in post rainy season. The maize-wheat crop rotation in the IHR covers a total of 2.14 million ha with an average productivity of 1430 kg ha^{-1} of maize and 1850 kg ha^{-1} of wheat under rainfed conditions, which is far less than the national average productivity of 2602 kg ha^{-1} of maize and 3059 kg ha^{-1} of wheat (Choudhary et al., 2013). Usually these crops are grown on outwardly terraced or sloping croplands, largely under rainfed conditions, and usually the crops experience deficit moisture stress at different critical growth stages of crop growth (Tuan et al., 2014). In this crop rotation, maize is sown at wider row spacing (60–90 cm) to maintain optimum plant population which provides sufficient space for soil erosion (erosion permitting nature). Farmers continue to do planting of maize because maize is staple food in IHR (Choudhary et al., 2013) and most of the farmers are resource poor and not capable to apply recommended doses of major nutrients due to lack of awareness, resulted in poor canopy covers of maize in the early growth stages (Sharma et al., 2017).

There is scanty information on performance of various organic manures particularly vermicompost, poultry manure and *in-situ* green manuring on maize-wheat system in the sub-tropical condition and we are unaware of information available about the run-off and soil loss activities of soils in IHR. This study investigated productivity, soil conservation and soil fertility improvement to know to the critical roles of different organic manures in finding out the sustainability of rainfed maize-wheat system. Information regarding the regression relationship between runoff, soil loss and productivity changes due to continuous application of both organic manures and chemical fertilizers is also limited under sloping croplands.

We hypothesized the novel idea (probably first of its kind), a sloping crop land that continuous long-term integrated application of carbon, N, P and K through different combinations of manure and fertilizers will have distinguish impact on maize canopy cover in the early growth stages resulting in more conservation of soil and water, improved soil fertility and enhanced crop productivity. This hypothesis led us the following objectives as (i) to determine the system productivity of maize-wheat rotation as affected by combined application of manure and inorganic fertilizers as a source of nutrients, and (ii) to quantify the combined effect of organic and inorganic nutrient sources on the run-off and soil loss reduction and soil fertility improvement.

2. Material and methods

2.1. Site

An experiment on the maize–wheat cropping system was conducted during 2009–2016 at the Research Farm, Selakui of the ICAR- Indian Institute of Soil and Water Conservation, Dehradun, Uttarakhand, India (30° 20′ 40” N latitude, 77°52′12” E longitude) at 516 m above mean sea level on 2% land slope. Bunds of the permanent plots (25 × 15 m^2 size of each) were strengthened and sodded with grass (*Cynodon dactylon*). A uniformity trial on wheat was undertaken during winter season of 2008–2009 to ensure uniform soil fertility in the entire field. Before 2008, the plot was under the maize–wheat cropping system (with recommended mineral fertilization for both crops) for past 20 years. The climate of the study areas is sub-tropical with hot summers and cold winters (Singh et al., 2016). Monthly mean values of the parameters during the experimentation period recorded at the ICAR-IISWC meteorological observatory adjoining to the experimental site are presented in Fig. 1.

The soils at the experimental site were fine mixed hyperthermic Typic Udorthents (Soil Survey Staff, 2014). Before imposing the treatments, initial soil samples from 0 to 15 cm depth (n = 6 for each plot) were collected from all the plots. The initial physico-chemical properties of the experimental plots are mentioned in Singh et al., 2016. The soil moisture content at maximum water-holding capacity, field capacity and permanent wilting point were 35.5, 24.8 and 11.2%, respectively.

2.2. Experimental details

The field experiment was conducted with seven treatments [control *i.e.* without any dose of fertilizer to both the crops (0); 100% recommended dose of N, P_2O_5, and K_2O to both the crops (100:60:40 according to Singh et al., 2016) through inorganic fertilizers (100-0); FYM @ 20 t ha^{-1} to both the crops (0–100); 50% N through inorganic fertilizer + 50% N through FYM to both the crops (50 + 50 FYM); 50% N through inorganic fertilizer + 50% N through vermi-compost to both the crops (50 + 50 VC); 50% N through inorganic fertilizer + 50% N