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Increasing farmer's income and reducing soil erosion using intercropping in rainfed maize-wheat rotation of Himalaya, India

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ABSTRACT

Humankind faces the need to achieve sustainable agriculture production, meanwhile increasing crop yields and reducing soil and water losses. Soil conservation through intercropping or crop canopy management is widely accepted as one of the ways of diversifying crop yields in rainfed agriculture in sloping landscapes. Field experiments were conducted between 2009 and 2014 to evaluate the effects of one or two rows of cowpea/okra intercropped with maize (planted either in 90 or 150 cm row spacing) on productivity, profitability, and resource conservation on 4% sloping crop land in the Himalayas. During five years of experimentation, a total of 110 runoff events were observed in the maize crop grown in rainy months of June to September. The results showed that by growing one row of cowpea in between two rows of maize (90 × 20 cm), no effect was observed on the productivity of rainfed maize. Productivity of the succeeding wheat crop was enhanced by 13% which resulted in a higher net return (117 US$ ha^{-1}) than in a maize-wheat system. This system also reduced runoff and soil loss by 26% and 43%, respectively, compared to only a maize cropping system. Regression analysis revealed as runoff in maize crop increases, grain yield of succeeding rainfed wheat crop decreases due to the less availability of soil moisture.

1. Introduction

Realizing the importance of soils, the United Nations declared 2015 the "International Year of Soils" and mentioned that the 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 (Food and Agricultural Organization, 2015). Soils around the world are affected by land degradation processes as a consequence of the abuse of grazing, fire, mining or agriculture (Pereira et al., 2017; Rodrigo Comino et al., 2016a, 2016b). The growing world population needs an increase in food production, and therefore it is needed to increase crop yields to avoid famines and malnutrition. Furthermore, the expansion of cropland can have negative consequences for the sustainable use of land. The shrinking area of forest soils and increased soil erosion on steep slopes that were previously not cultivated and protected from soil erosion by forest cover are of major concern (Mwango et al., 2016; Singh et al., 2016). This is especially relevant in developing countries where the population growth is often higher than the increase in food production due to agricultural innovation; which means a large risk for food insecurity (Nyssen et al., 2015; Muluneh 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 steep slopes. The Himalayan Mountains have fragile and diverse ecosystems which cover parts or fully eight countries of south Asia viz., Afghanistan, Bangladesh, Bhutan, China, India, Myanmar, Nepal and Pakistan. It is home to over 51 million people who practice hill-slope agriculture for their livelihood. The Indian Himalayan region (IHR) due to steep slopes, fragile geology and intense storms is intrinsically prone to soil erosion (Sharma et al., 2014). Recent estimates indicate that nearly 39% area of the Indian Himalayas has a potential soil erosion rate of more than 40 Mg ha^{-1} yr^{-1}, which is much higher than the specified soil loss tolerance limit of 10 Mg ha^{-1} y^{-1} (Mandal and Sharda, 2011). Erosion due to runoff on sloping land causes loss of soil, water and nutrients, leading to low agricultural productivity and threatens agricultural and environmental sustainability (Singh et al., 2016). 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-Diaz et al., 2017). Recent estimates made by Sharda et al. (2010)

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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 main crops grown in the IHR are maize (*Zea mays* L.) in rainy season and wheat (*Triticum aestivum* L. emend Fiori & Paol.) in post rainy season. Usually these crops are grown on outwardly terraced or sloping lands, largely under rainfed conditions, and usually the crops experience deficit moisture stress at different critical crop growth stages. Furthermore, nutrient deficiency, particularly of nitrogen (N), and unchecked weed growth inflict considerable reduction in grain yield. 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).

Intercropping is one of the most promising possibilities for enhancing productivity in sub-tropical Asia (Singh et al., 2015, 2016), and tropical Africa (Egarter-Vigl et al., 2017), where most agriculture is in the hands of smallholder farmers, who have limited land resources and generally low crop productivity. Intercropping systems involve growing two or more crops simultaneously with distinct row arrangement for complementary use of the natural resources that enhances the productivity (Willey, 1979). In this specific intercropping system maize is sown at wider row spacing (60–90 cm), which provides sufficient space for soil erosion (erosion permitting nature) and cultivation of short duration intercrops like cowpea (*Vigna unguiculata* L.) (Egarter-Vigl et al., 2017) and okra (*Abelmoschus esculentus*) (Fawusi, 1985) which are erosion resisting in nature. Intercropped legumes benefit the associated crop (maize in this case) by (i) transferring a part of fixed N_2, (ii) the sparing effect (Singh et al., 2015) because of their smaller N requirement and (iii) the mitigation of droughts as the legumes acts as a live mulch, which reduces the soil erosion and evaporation (Khola et al., 1999). In addition the system provides a good canopy cover in the early stages and therefore reduces soil erosion especially on light textured sandy loam soils. Lastly, this intercropping system also controls weeds, reducing the labour effort of the farmers (Khola et al., 1999).

But there is little information on the performance of cowpea or okra intercropping with maize and their effects on crop yield of succeeding rainfed wheat in a maize-wheat rotation in sub-tropical climate conditions. In addition, there is no information about the effects of this intercropping system on runoff and erosion in the sloping landscape of the IHR. This is a relevant issue as the sustainability of the crops are related to the soil erosion rate that can change the fate of the future crop production due to the continuous lost of nutrients, water, and sediments (Rodrigo Comino et al., 2016c; García-Díaz et al., 2017). Moreover, soil erosion has a strong economic impact as there is often a need to repair infrastructures such as roads, irrigation or drainage networks (Cerdà et al., 2009; Andriyani et al., 2016). Another reason to control onsite soil erosion is the damage that it causes in the down slope and downstream areas including reservoir siltation (Ben Slimane et al., 2016; Licciardello et al., 2016). Pollution of the surrounding areas due to the agrochemicals transported from the fields is also an important issue (Prosdocimi et al., 2016; Trujillo-González et al., 2016).

This study investigated productivity, profitability and soil erosion to assess the critical roles of cowpea/okra intercropping by determining the optimum combination in rainfed maize-wheat system. We hypothesized that continuous inclusion of cowpea/okra intercrops in rainfed maize-wheat cropping system has a distinct effect on the agricultural productivity and profitability. In addition it is hypothesized to reduce soil erosion which in turn will depict the sustainability of the system. Keeping in view the above hypothesis, the following goals were derived for this study: (i) to determine the changes in maize-wheat productivity between the year 2009 and 2014 as affected by continuous inclusion of cowpea/okra intercrops in the system; (ii) to estimate the change in runoff and soil loss due to the inclusion of intercrops; and, iii) to know the best planting pattern of maize and intercrops in terms of profitability and soil conservation.

2. Material and methods

2.1. Experimental site

An experiment was conducted on the rainfed maize–wheat crop rotation on a 4% sloping cropland during 2009–2014. Experiment site is situated at Research Farm, Selakui of the ICAR- Indian Institute of Soil and Water Conservation (Erstwhile Central Soil and Water Conservation Research and Training Institute), Dehradun, Uttarakhand, India (30° 20′ 40” N latitude, 77°52′12” E longitude) at 516 m above mean sea level (Supplementary Fig. 1). Test plots ($100 \times 20\ m^2$) used for study were 35 years old and have been continuously used for experimental purposes on rainfed maize-wheat rotation. The climate of the study area is sub-tropical with hot summers and cold winters. May and June are the hottest months with mean daily maximum temperature being ~ 36 °C, while January is the coldest month with mean daily minimum temperature of ~ 4 °C. The mean annual rainfall is 1615 mm, of which 80% is received during the south-west monsoon from July to September, and the rest through the ‘western disturbances’ from December to February. Skymet Weather defines Western Disturbance as “a low pressure area or a trough over surface or the upper-air in the westerly winds regime, north of 20°N, causing changes in pressure, wind pattern and temperature fields. Pan evaporation varied between 1.25 and 7.41 mm d^{-1}. Monthly mean values of the weather 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 are fine mixed hyperthermic Typic Udorthents (United States Department of Agriculture (Natural Resource Conservation Service), 2014). Bulk and core soil samples were collected from three randomly selected places in each plot. At each sampling point, 10–12 cores (5 cm diameter) were randomly taken within 1 m of each other to a depth of 15 cm. Then, all the samples of individual treatment plots were thoroughly mixed to prepare a composite sample. Each composite sample was air dried, powdered and passed through a 2 mm sieve for determination of soil pH in a 1:2.5 soil: water suspension (Jackson, 1973), oxidizable SOC by the method of Walkley and Black, (1934), available soil nitrogen by the alkaline- $KMnO_4$ method (Subbaiah and Asija, 1956), Olsen-P (Olsen et al., 1954) and NH_4OAc-K (Jackson, 1973). A 5 cm diameter sampler was used for soil bulk density determinations. Soil texture was determined using a Bouyoucos hydrometer (Bouyoucos, 1927). The initial physico-chemical properties of experimental plot are given in Table 1.

2.2. Experimental details

The field experiment was conducted with six treatment combinations of maize crop in rainy season (June-September) followed by succeeding crop of rainfed wheat crop in winter season (November-April). T_1 − Maize (90 cm row to row spacing and 20 cm plant to plant spacing or 90 × 20 cm) followed by wheat (Supplementary Fig. 2a), T_2 − maize (150 × 20 cm) followed by wheat (Supplementary Fig. 2b), T_3 − maize (90 × 20 cm) + okra (45 × 30 cm) followed by wheat (Supplementary Fig. 2c), T_4–maize (90 × 20 cm) + cowpea (45 × 30 cm) followed by wheat (Supplementary Fig. 2c), T_5 − maize (150 × 20 cm) + cowpea (two rows of cowpea at 60 × 30 cm spacing by leaving 45 cm spacing from adjacent maize rows) followed by wheat (Supplementary Fig. 2d), T_6–maize (150 × 20 cm) + okra (two rows of okra at 60 × 30 cm spacing by leaving 45 cm spacing from adjacent maize rows) followed by wheat (Supplementary Fig. 2d), with three replications in randomized block design (RBD) during 2009–10 to 2013–14. The recommended dose of N: P: K was 80:40:40 kg ha^{-1} for both the crops. Nitrogen, phosphate and potassium were applied through urea, di-ammonium phosphate and muriate of potash,