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Potato production through bio-resources: Long-term effects on tuber productivity, quality, carbon sequestration and soil health in temperate Himalayas

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A field study was conducted on potato crop during summer (April–July) seasons of 2007 to 2011 in temperate north–western Himalayas to evaluate the effects of three different organic manure sources [Farm yard manure (FYM)/chicken manure (CM)/vermicompost (VC)] alongwith microbial consortia (MC) as well as their combinations on tuber productivity, tuber quality and soil health. This five years' study clearly revealed that application of FYM @ 10 t ha^{-1} + chemical fertilizers to meet remaining recommended fertilizer dose (CF_{RDF}) + MC proved as a better combination with respect to growth, yield attributes, total tuber yield (23.4 t ha^{-1}), marketable tuber yield (22.2 t ha^{-1}), large grade tuber (>75 g) yield (44.2%), profitability (net returns, Indian Rs. 161599 ha^{-1}; benefit: cost ratio (3.72), tuber quality, NPK uptake, available NPK and soil microbiological properties; which was followed by the application of CM @ 7.5 t ha^{-1} + MC. However, soil organic matter (SOC) storage (24.7 Mg C ha^{-1}), SOC retention (15.8 Mg C ha^{-1}), soil microbial biomass carbon (SMBC) (376.4 μg g^{-1} soil), and CO_2 evolution (180 μg g^{-1} soil hr^{-1}) were significantly higher using FYM @ 25 t ha^{-1} + MC, followed by FYM @ 10 t ha^{-1} + CM @ 2.5 t ha^{-1} + VC @ 2.5 t ha^{-1} + MC over rest of the treatments. Interestingly, sole application of organics in this exhaustive crop is not enough in realizing sufficient marketable tuber yield even on long–term basis in temperate Himalayan soils where mineralization rate is quite slow and inappropriate to meet the nutrient needs of the crop. Thus, application of FYM @ 10 t ha^{-1} + chemical fertilizers to meet remaining RDF + microbial consortia is the better combination under such agro–ecologies for enhancing nutrient supplying capacity and soil health for sustaining long–term potato productivity and profitability with better tuber quality in diverse NW Himalayan potato production systems and similar socio–agro–economic conditions in temperate world.

1. Introduction

Wet–temperate to dry–temperate type climate in north–western (NW) Himalayas assumes greater importance for growing potato (*Solanum tuberosum*) which fetch high premium prices in the Indian vegetable markets and sustain rural livelihoods of Himalayan farmers (Choudhary et al., 2010, 2013). India is the second largest potato producer in the world after China, with annual production of 43.4 million tonnes from about 1.99

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million ha (Indian Horticulture Database, 2012–13). Potato has become a commercial crop in Indian Himalayas where hill farmers grow potato on gentle slopes (10–15°) of mid and high–hills between 1500 and 2200 m above mean sea level during summers, but poor edaphic factors coupled with poor crop management lead to low crop yields (17.4 t ha^{-1}) compared to national (22.8 t ha^{-1}) and world (18.9 t ha^{-1}) averages (Indian Horticulture Database, 2012–13). The current fertilization rates are also insufficient to sustain higher potato yields besides replenishing nutrient removals by the crop (Choudhary et al., 2013). Most of the arable land in NW Himalayan region is rainfed and dependent on rainfall. In addition, hilly and mountainous topography coupled with high rainfall is prone to soil erosion, nutrient run–off losses and soil organic matter (SOM) depletion which lead to low crop productivity and unhealthy soils (Choudhary et al., 2013; Yadav et al., 2015; Choudhary, 2016). Thus, sustaining the crop productivity and soil health in above context is a challenging task. Hill farmers of this region are resource–poor having small and marginal land holdings in remote hilly terrains lacking awareness about advanced farm technologies (Economic Survey, 2012–13; Choudhary et al., 2013; Kumar et al., 2016a,b).

Potato demands high level of plant nutrients due to its high yield potential in a shorter cycle but with relatively less developed and shallow root system (Choudhary et al., 2010). Thus, high production levels coupled with sub–optimal nutrient management result in exhaustive nutrient mining, nutrient imbalances in soil–plant system and deterioration in soil health and poor quality (Choudhary et al., 2013; Islam et al., 2013). The poor economic conditions of hill farmers, high price of chemical fertilizers and their inadequate supply also discourage to meet–out the nutritional requirements of this crop fully through chemical fertilizers resulting in poor potato productivity (Choudhary et al., 2010, 2013). Thus, integrated nutrient management can be a viable option to supply balanced nutrition to the crop (Choudhary et al., 2013). Crop production, livestock rearing and agro–forestry are integral component of Himalayan farming systems (Choudhary et al., 2012). Thus, farmyard manure (FYM), chicken manure, vermicompost, forest–litter and crop residues are amply available nutrient bioresources in the region which may add substantial amount of essential plant nutrients and SOM in the soil (JaiPaul et al., 2011; Yadav et al., 2013; Paul et al., 2014). The SOM acts as substrate for soil microbial diversity and their activities (Steenwerth et al., 2008). Soil is a dynamic living system containing many free enzymes as a result of soil biological activities (Suri and Choudhary, 2013; Kumar et al., 2014). These soil enzymes play a critical role in influencing many biochemical reactions like SOM decomposition and nutrient dynamics, thus serve as bio–fertility indicators of soil health (Paul et al., 2014). The soils of NW Himalayas are acidic to strongly acidic due to leaching of bases due to high rainfall leading to phosphorus (P) fixation with Al and Fe which results in low P availability to plants (JaiPaul et al., 2011; Kumar et al., 2014, 2016a,b). In order to enhance the plant nutrient availability especially P under such soils, the biofertilizers assume great importance (Suri et al., 2006; Bai et al., 2015, 2016). In this direction, microbial consortium is a new carrier based microbial product that contains efficient rhizospheric competent N fixing bacteria (*Azotobacter* spp.), P solubilizers (*Bacillus spp., Pseudomonas spp., Aspergillus* spp. and *Penicillium* spp.), Zn solubilizers (*Bacillus spp., Pseudomonas* spp. and *Aspergillus* spp.), plant growth promoting rhizobacteria (PGPRs') (*Bacillus* spp. and *Pseudomonas spp*.), and biocontrol agent *Trichoderma* spp. against fungal plant diseases which also act as organic matter decomposer in a single carrier. Therefore, harnessing the benefits of microbial consortia to enhance nutrient availability and promoting plant growth through PGPRs becomes more critical under such soils (Kumar et al., 2012), besides induction of biocontrol agents like *Trichoderma spp*. against plant diseases specifically when organic cultivation is in practice.

Thus, integration of locally available bioresources in combination with microbial consortia and chemical fertilizers could be a viable low–cost option to sustain potato productivity (JaiPaul et al., 2011) as well as soil–health on long–term basis (Islam et al., 2011). In general, meagre information is available on effect of integrated use of locally available bio–resources, chemical fertilizers and microbial consortia on potato productivity and quality, profitability, carbon sequestration and soil physico–chemical and biological properties under rainfed conditions of NW Himalayas. Thus, present experimentation was aimed at enhancing the potato productivity and quality besides sustaining soil–health utilizing local bioresources for overall sustainability of diverse potato production systems in NW Himalayas and similar socio–agro–economic conditions in temperate world.

2. Materials and methods

2.1. Experimental details and crop management

The experiment was conducted for five years during summer (April–July) seasons of 2007–2011 in potato var. *Kufri Jyoti* at Organic Research Farm, College of Horticulture, GBP University of Agriculture & Technology, Bharsar, India [30°03′35″ N latitude; 78°59′42″ E longitude; 2200 m altitude] falling under wet–temperate region of North–Western Himalayas, India. The soil of experimental site was silty–loam in texture, acidic in reaction (pH 5.4) with bulk density 1.35 Mg m^{-3}, electrical conductivity 0.20 dSm^{-1}, and soil organic carbon 7.5 g kg^{-1} soil besides available nitrogen (N), phosphorus (P_2O_5) and potassium (K_2O) to the tune of 235.8, 12.2 and 360.2 kg ha^{-1}, respectively. The experiment was laid–out in randomized block design (RBD) replicated five times comprising six treatments [T_1 = control ($N_0P_0K_0$); T_2 = farmyard manure (FYM) @ 25 t ha^{-1} + microbial consortia; T_3 = chicken manure @ 7.5 t ha^{-1} + microbial consortia; T_4 = vermicompost @ 10 t ha^{-1} + microbial consortia; T_5 = FYM @ 10 t ha^{-1} + chicken manure @ 2.5 t ha^{-1} + vermicompost @ 2.5 t ha^{-1} + microbial consortia; and T_6 = FYM @ 10 t ha^{-1} + chemical fertilizers to meet remaining 100% recommended fertilizer dose of $N_{150}P_{75}K_{75}$ (CF_{RDF}) + microbial consortia]. In all the five treatments except control (Table 1), it was attempted to keep the NPK additions through organic manures (T_2–T_5), and organic manure + chemical fertilizers (T_6) equivalent to 100% RDF ($N_{150}P_{75}K_{75}$) as followed in NW Himalayan states of India *viz*. Himachal Pradesh, Jammu & Kashmir and Uttarakhand. In general, the recommended fertilizer dose (RDF) for potato crop for this region is $N_{150}P_{75}K_{75}$; while recommended organic manure dose is 10 t FYM ha^{-1}, if available. The FYM was a mixture of cow and buffalo dung plus bedding material (oak leaves, pine needles and *Fingermillet* straw. The vermicompost was prepared from FYM, organic waste of experimental field and forest litter (2:1:1) at the experimental site. It was prepared in cemented tanks (size: 3 m × 2 m × 1.5 m). The earthworm sp. *Eisenia fetida* @ 1 kg t^{-1} raw material was applied to prepare the vermicompost.

The commercial formulation of microbial consortia consisted of *Azotobacter*, *Pseudomonas, Bacillus, Aspergillus, Penicillium* and *Trichoderma* microorganisms prepared by the researchers of GBP University of Agriculture & Technology, Pantnagar, India. This microbial consortia formulation was used as seed dip treatment (500 g per 15 l water + 150 g jaggery) before tuber planting in all above treatments except control. In T_6 treatment, the amount of NPK supplied through FYM was calculated thoroughly and the remaining shortfall in NPK to 100% of recommended NPK dose [150 kg N, 75 kg P_2O_5 and 75 kg K_2O ha^{-1} + 10 t FYM ha^{-1}] was supplied through urea (46% N), single super phosphate (16% P_2O_5) and muriate of potash (60% K_2O). The 100% of recommended NPK dose [150 kg N, 75 kg P_2O_5 and 75 kg K_2O ha^{-1} + 10 t FYM ha^{-1}] In gen-