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Improving yield and mineral nutrient concentration of potato tubers through cover cropping

Emad Jahanzad[a,*], Allen V. Barker[a], Masoud Hashemi[a], Amir Sadeghpour[c], Touria Eaton[a], Yeonhwa Park[b]

[a] Stockbridge School of Agriculture, University of Massachusetts, Amherst, MA, 01003, United States
[b] Department of Food Science, University of Massachusetts, Amherst, MA, 01003, United States
[c] Department of Animal Science, Cornell Univ., Ithaca, NY 14853, United States

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ABSTRACT

Over-fertilization of food crops has resulted in increased environmental concerns over the past decades. On the other hand, literature indicates a decline in concentration of mineral nutrients in vegetables in the past 50 years. Thus, a need occurs to employ cropping systems that are less dependent on fertilization while maintaining yield and nutritive value of food crops. This study evaluated tuber yield and nutrient concentration of potatoes (*Solanum tuberosum* L.) following rye (*Secale cereale* L.), forage radish (*Raphanus sativus* L.), winter pea (*Pisum sativum* L.) and no cover crops (NCC). Four nitrogen (N) fertilizer rates (0, 75, 150, and 225 kg N ha^{-1}) were applied to a red-skinned potato cultivar (Dark Red Norland) and a buff-skinned one (Superior).

Overall, potatoes grown after cover crops produced 13–25% more tubers compared to NCC. Potatoes following NCC needed to be fertilized at 225 kg N ha^{-1} to produce the highest yield of 26.5 Mg ha^{-1}, whereas potatoes after winter pea or forage radish produced the same or higher yields (10–25%) at 75 or 150 kg N ha^{-1}, respectively. Rye provided less N to a succeeding potato crop than forage radish or winter pea; however, potatoes following rye produced a greater yield than those planted after NCC. Potatoe tubers in cover crop plots accumulated more mineral nutrients compared to NCC; however, the differences among cover crops were not always significant. Overall, forage radish and winter pea were better alternatives to rye as indicated by less N fertilizer application, sustained tuber yield, and tuber mineral nutrient concentration.

1. Introduction

In recent decades, soil fertility issues associated with nutrient depletion by crop production has resulted in decreased arable lands and malnutrition in human diets (Barker et al., 2016). In addition, increasing world population indicates the necessity of growing high-yielding crops to cope with emerging hunger and malnutrition (Welch and Graham, 1999; Tan et al., 2005). Malnutrition is a primary factor affecting human health in modern times, and deficiencies of certain elements ((Calcium (Ca), Magnesium (Mg), Potassium (K), Phosphorus (P), Zinc (Zn), and Copper (Cu)) known as mineral nutrients, in diets of human are a substantial nutritional problem throughout the world (Darnton-Hill et al., 2008). Davis (2009) reports 5–40% decline in mineral content of vegetables and fruits in the past 50–70 years in the United States. Potato is one of the most important staple foods in industrialized and developing countries, and according to the International Potato Center, the worldwide demand for potatoes will exceed that of wheat (*Triticum aestivum* L.) or rice (*Oryza sativa* L.) by 2020 in terms of human consumption and production volume (IPC, 2009). However, increasing demand for potatoes along with economic pressures have forced potato growers to move toward more intense production systems with extensive use of fertilizers and increased frequency of potato in crop rotations, actions that raise environmental concerns and costs of production (Munoz et al., 2005). Therefore, alternative fertility management practices to reduce synthetic fertilizer use seem crucial. Management practices such as tailoring N fertilizer rates and use of appropriate species of cover crops in rotation with potato cultivation can reduce nutrient losses and enhance farmers' profitability by lowering fertilizer costs (Delgado et al., 2004). Cover crops play crucial roles in serving ecosystems through nutrient cycling (Coombs et al., 2017), restricting soil erosion (Liu et al., 2002), increasing soil organic matter (Fageria et al., 2005), alleviating soil compaction (Weil and Kremen, 2007), and suppressing weeds and other pests (Fisk et al., 2001). Several studies have indicated that continuous

* Corresponding author.
E-mail address: ejahanzad@gmail.com (E. Jahanzad).

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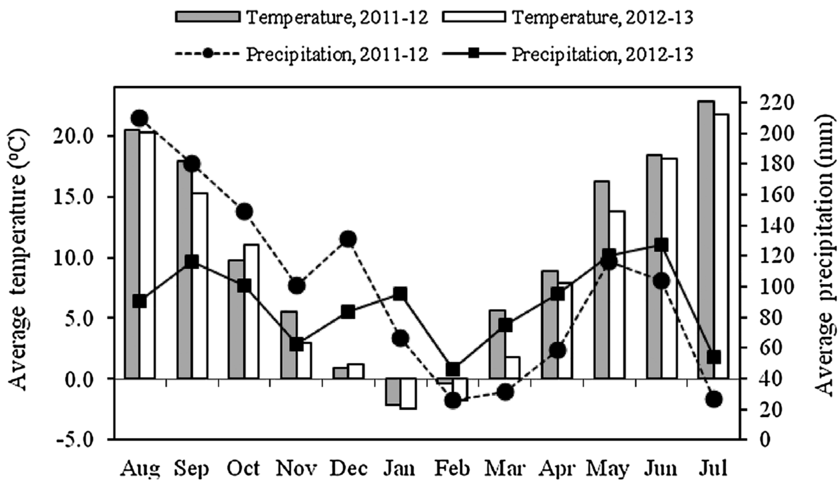

Fig. 1. Precipitation and average temperature.
Monthly precipitation and average temperature during the first (August 2011–July 2012) and the second year (August 2012–July 2013) of the experiment at the Crops and Animal Research and Education Farm of the University of Massachusetts.

potato production without crop rotation or use of cover crops leads to higher fertilization for producing high-yielding potatoes (Rosen and Bierman, 2008; Essah et al., 2012). On the other hand, Essah and Delgado (2009) reported that over application of N fertilizer in a potato rotation system limited tuber yield and quality. Grass and legume winter cover crops are important components of sustainable cropping systems, facilitating nutrient cycling and providing soil and water conservation (Ranells and Wagger, 1996). Small grain cover crops, such as winter rye, can remove a significant amount of residual soil N in the fall during the period of its rapid establishment (Herbert et al., 1995; Sadeghpour et al., 2014a). On the other hand, Neeteson (1989) reported significant improvement in potato yields if potatoes followed leguminous crops, such as red clover (*Trifolium pretense* L.) and alfalfa (*Medicago sativa* L.) with low N fertilization rates. Besides legumes and grasses, *brassicaceae* cover crops could serve as nutrient scavenger crops to recover residual soil nitrate and subsequently to release N to a succeeding crop (Vyn et al., 2000). In addition to N, cover crops with long tap roots can scavenge and recycle mobile nutrients from deep soil layers and make them more available for the succeeding crops in the shallower level after plant tissues break down. White and Weil (2010) reported that shoots of forage radish or rye cover crops have the potential to take up substantial quantities of P when they are managed for maximum dry matter production. They found that after three years of cultivating forage radish in a no-till system, P concentration in top soil moderately increased since forage radish cycled large quantities of P from the subsoil. They concluded that in the vicinity of holes made by forage radish roots, P concentration increased dramatically even when the total P cycled by the forage radish cover crops was small. Eckert (1991) reported that rye cover crop increased the concentration of exchangeable K near the soil surface by removing K from lower levels in the soil profile. Recycling of other mineral nutrients such as Ca, S, and B have been reported by *brassicaceae* cover crops (Wang et al., 2008).

Rye is the most widely grown cover crop in the Northeast U.S.A. due to its N-scavenging capacity and adaptability to the soils and climate of the region (Staver and Brinsfield, 1998; Hashemi et al., 2013; Sadeghpour et al., 2014b). Therefore, rye can be a logical benchmark to which other crop performance as cover crops could be compared within the northeastern region and areas with similar climatic conditions. However, rye residue might not be an adequate source of N for potatoes due to its relatively high C:N which may tie up N in the soil. Moreover, most of rye growth takes place in early spring and may interfere with soil preparation and early planting of potatoes.

Forage radish has recently gained a good reputation as cover crop in the region mainly due to its strong nutrient-recycling capacity. However, its impact on potato production has not been investigated. There remains a need for further studies on integrating cover crops to sustainable potato production. This study investigates whether adopting winter pea and forage radish, as winter-killed cover crops, can serve better in a potato cultivation system than rye. Another goal of the current study was also to evaluate potato tuber yield and mineral nutrient concentration as affected by cover crop species and different N application rates.

2. Materials and methods

2.1. Research location

A 2-yr field study was conducted at the Crops and Animal Research and Education Farm of the University of Massachusetts in South Deerfield, MA (42°28′37″ N, 72°36′2″ W, elevation 60 m) in 2011–2012 and 2012–2013. The soil was Hadley fine sandy loam (coarse-silty, mixed, superactive, nonacid, mesic Typic Udifluvent), and selected physical and chemical characteristics of the top 15 cm soil was as follow: 55% sand, 13% silt, 32% clay; pH of 5.7, organic matter content of 13 g kg^{-1}, Morgan's solution extractable N, P, K, and Ca content of 3.5, 12, 80, and 763 mg kg^{-1}, respectively. The research field was fallow for a year before planting cover crops and the same field was used during the experiment. The mean annual temperature and precipitation during the experiment are presented in Fig. 1.

2.2. Experimental design and cultural practices

The experiment was laid out as a randomized complete block design with spit-split plot arrangements and replicated four times. The main plots consisted of three species of cover crops, rye, forage radish, and winter pea along with no cover crop plots. Two early-maturing potato cultivars, 'Dark Red Norland' (DRN) and 'Superior' (SUP) and four N fertilizer rates, 0, 75, 150, and 225 kg N ha^{-1} supplied as urea (46-0-0), were assigned to sub and sub–sub plots, respectively. Prior to planting, plots were plowed, disked, and leveled. Rye, forage radish, and winter pea were planted using a small grain drill (Kincaid Manufacturing, Haven, KS, USA) at the seeding densities of 100, 9, and 120 kg ha^{-1}, respectively. Seeding occurred on September 2, 2011, and August 25, 2012. Winter pea was inoculated with *Rhizobium leguminosarum* (N-DURE peat-based, OMRI, Eugene, OR, U.S.A) prior to planting. Seeds were inoculated 30 min before planting using 75 mL of inoculant per 27.2 kg seed, according to the rate suggested by the inoculant label. Besides inoculation, no fertilizer was applied prior to cover crop planting.

The aboveground forage radish and winter pea biomass were collected and weighed by cutting at ground level in each plot prior to winter frost on 1 Dec. 2011 and 28 Nov. 2012. A hedge clipper (Makita, La Mirada, CA) was used for harvesting cover crops from 1 m^2 quadrats (two per plot). Rye biomass was also harvested in April before plowing