Mycorrhiza Influence Potato Crop Productivity in the Altiplano of Peru©

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Mycorrhizal fungi serve as biofertilizers, reduce plant stress, and can increase plant productivity. It is highly desirable to utilize native mycorrhiza in sustainable agriculture systems. Since the potato originated from the altiplano of Peru and Bolivia — a goal of this research was to utilize indigenous Peruvian mycorrhizal populations to enhance crop productivity in a subsistence production site. The field study was also conducted to test the effectiveness of the flavonoid, formononetin, to stimulate native mycorrhizal activity and subsequent yield of six Andean potato (*Solanum tuberosum* L.) selections. The site was located at an altitude of 3900 meters (12,800 ft) in San Jose de Aymara (Department of Huancavelica), in the central Altiplano of Peru. This is approaching the highest altitude in the world that potatoes are grown. The site had a sandy-loam soil with pH 3.6, with low phosphorus (P) availability and high aluminum (Al). Prior to planting, the site had been fallow for 15 years. Tubers were planted in November 1999, just before the rainy season. Minimal organic fertilizer was applied and the potato crop received no supplementary irrigation. Formononetin was applied as a soil drench when shoots began to emerge. At the end of the 6-month study, four of the six cultivars had either increased potato tuber dry mass and/or greater no. 1 and 2 grade tubers. Formononetin increased soil sporulation of indigenous mycorrhizae. There were differences in mycorrhizal colonization among the six cultivars.

INTRODUCTION

Potatoes are grown worldwide under a wider range of altitude, latitude, and climatic conditions than any other major food crop—from sea level to over 4000 m elevation. No other crop can match the potato in its production of food energy and food value per unit area. It is also high in Vitamin C, niacin, and vitamin B6. Yet, the potato plant has one of the heaviest production demands for fertilizer inputs of all vegetable crops, i.e., its nitrogen (N), phosphorus (P), and potassium (K) requirements are respectively 100%, 100%, and 33% greater than that required for tomato or pepper plant production. Normal applications are 1000 $kg \cdot ha^{-1}$ of the fertilizer 10N-30P-10K20 applied in bands around the seed tuber. Subsistence growers may

not have access or be able to afford suitable organic or inorganic fertilizers. Modern sustainable agriculture systems are increasingly utilizing reduced fertility inputs. Hence, there are excellent opportunities to incorporate mycorrhizal fungi as biofertilizers to enhance crop productivity and reduce fertilizer inputs.

These symbiotic fungi increase nutrient and water uptake, alleviate cultural and environmental stresses, and enhance disease resistance and plant health. Mycorrhizal fungi can enhance productivity of potatoes. In part this may be due to enhanced nutrient uptake of potato plants, particularly phosphorus as well as enhanced disease resistance. In Columbia, experiments show that a considerable amount of P fertilizer can be saved when potatoes are inoculated with effective arbuscular mycorrhizal fungi (AMF). In a greenhouse study conducted in Peru, a mycorrhizal isolate from Europe enhanced potato productivity and nutrient uptake. However native AMF isolates from Peru have yet to be characterized and tested in Peruvian potato production systems.

The Altiplano of Peru and Bolivia is the center of origin and diversity of the cultivated potato. Potato is the main staple crop in the Altiplano and accounts for 63% gross value of all crop production. Average potato yields are very low (between 5 to 8 tons/ha) and limited by low fertility. While small producers apply organic N as animal or green manure, P is applied via chemical fertilizers which are costly and not always available. For subsistence and modern sustainable potato production in Peru it is important that native mycorrhizal isolates be selected. A limitation of mycorrhiza application is its commercial availability and the added production cost.

The flavonoid, formononetin, has been reported to enhance mycorrhizal effectivity of mycorrhizal plants, i.e., this could allow for lower, more cost-effective levels of mycorrhiza inoculum to be incorporated or to stimulate indigenous mycorrhiza. It is highly desirable to utilize native AMF in sustainable agriculture systems. Since the potato originated from the Altiplano of Peru and Bolivia — a goal of this research was to utilize indigenous Peruvian AMF populations to enhance crop productivity in a subsistence production site. The field study was conducted to test the effectiveness of the flavonoid, formononetin, to stimulate native mycorrhizal activity and subsequent yield of six Andean potato (*Solanum tuberosum* L.) selections.

RESULTS

The soil texture was a sandy-loam and is classified as an Entisol. The cation exchange capacity (CEC) was low. The soil pH was very acid, 3.6, and organic matter was relatively high (5.8%). Soil phosphorus (P) was 18.2 ppm, however P availability to plants was low since the soil had a very low pH (3.6), limiting P availability; also, the Olson Method extracts P at pH 8.5, which would give a higher soil P value than is available to the plant.

Calcium (Ca) levels were low and aluminum (Al) was high. Hence, low soil pH contributed to low P availability and high extractable Al. Ideally, the soil should be amended with Ca to increase Ca levels, raise the pH, decrease extractable Al levels, and increase soil P availability.

At the end of the 6-month study, four of the six Andean selections treated with Formononetin had either increased potato tuber dry mass and/or greater No. 1 and 2 grade tubers. Formononetin had the greatest effect on selection #1 (CIP700724), increasing its tuber diameter, No. 1 and 2 tubers and mycorrhizal/formononetin effect (MIE) [+115%] compared to controls. Formononetin also enhanced the MIE

of selections #2 (CIP703531) and #6 (CIP705131) by +28% and +23%, respectively. Formononetin did not enhance selection #4 (CIP704483) which had among the greatest tuber mass, nor selection #3 (CIP704058) which had lowest tuber yield, MIE, and fewest #1 & #2 tubers.

Formononetin increased soil sporulation of indigenous AMF. With controls there were 6.3 ±1.2 spores g^{-1} soil and formononetin treatments had 19.4 ±1.1 spores g^{-1} soil ($P \leq .0001$). There were differences in mycorrhizal colonization among the six Andean selections, which ranged from 14% to 41%. Formononetin did not have a significant effect on total mycorrhizal colonization. The predominant mycorrhizal genera were *Gigaspora* and *Glomus* spp. (Fig. 1). Spore size ranged from: 45 to 180 um. In the Formononetin treatment, *Scutellosporas* was also observed. Formononetin had the greatest effect on spore production of *Gigaspora*. *Glomus* spp. was more abundant in the nonformononetin treatment.

DISCUSSION

To our knowledge this is one of the first reports of mycorrhizal activity and crop enhancement in a potato field at such a high altitude — 3900 m (12,795 ft). Arbuscular mycorrhizal fungi are known to tolerate a wide variety of soil pH conditions and mineral ion conditions. Formononentin caused a stimulation of native mycorrhiza (3-fold greater sporulation) and subsequent increase in tuber development in four of the six Andean potato selections.

In subsistence agricultural systems, it is important to use indigenous AMF that are ecotypically adapted to a site. With the soil problems encountered at the site, it would have been cost-prohibitive to add sufficient calcium as limestone or gypsum ($CaSO_4$) to sufficiently raise the soil pH, increase P availability, and reduce Al levels. Likewise, introducing non-indigenous AMF would have likely been unsuccessful due to the extreme soil conditions.

One of the strengths of this research is that it shows potential benefits of applying Formononetin to stimulate the effectivity of native, ecotypically adapted mycorrhiza at lower inoculum levels under field production conditions. Formononetin used in combination, could also allow for lower, more cost-effective levels of mycorrhiza inoculum to be utilized. The isoflavanoid, Formononetin, has been reported to enhance effectivity of mycorrhizal plants. Hence, there are excellent opportunities to utilize and manipulated mycorrhizal fungi to enhance crop productivity and reduce agricultural chemical inputs.

Beneficial mycorrhizal fungi are one of the important cornerstones of sustainable agricultural systems. They can make plants more efficient in utilizing available soil water and fertility, i.e., they serve as biofertilizers and increase drought resistance and plant productivity. A long-term goal of our research is to utilize native mycorrhizal populations to enhance potato crop productivity in a cost-effective manner.