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*Corresponding author

J Franco, Private Consultant and Technical Manager of Agro Innovation Co. in Lima, Peru

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Research Article

Improving Productivity of Small Farmers by Bio-Rational Soil Management: II. The Case of Horticultural Crops

J Franco[1,2*], O Navia[2], G Main[2] and J Herbas[2]

[1]Private Consultant and Technical Manager of Agro Innovation Co. in Lima, Peru

[2]Integrated Crop Management, Foundation for Promotion and Research of Andean Products (PROINPA), Cochabamba, Bolivia

Abstract

Production of horticultural crops in the Andean region of Bolivia is low as a result of various abiotic and biotic soil constraints, and the recourse to pesticides and fertilizers is frequently too expensive. Agricultural soils in this region of Bolivia are generally characterized by a low fertility with low content of organic matter and yields of most crops are limited. Therefore, it was proposed a recycling of organic waste into compost and the use of natural microbial soil inhabitants, - AMF and PGPR - to reduce chemical–dependence of small-scale agriculturists Several field trials located in Cochabamba department (Bolivia) with different horticultural crops were conducted. After four years. farmers are able to prepare with post-harvest organic residues and animal manures their own compost for its field incorporation at planting time (7-10 t/ha). Several native isolates of PGPR and AMF were identified (*B. amyloliquefaciens & G. intraradices*, respectively). However with a commercial B. subtilis product (BZF 24WP), which later on was locally multiplied and formulated, and a Bolivian commercial mycorrhiza of *G. fasciculatum* (DESAmic), a biofertilizer was formulated and evaluated in several trials with different horticultural and orchard crops in farmer fields showed both plant growth promoting effect (horticultural and orchard crops:42.0 to 98.0 %). It was also observed a suppressive/inhibitory soil borne diseases effect. Therefore, it was also showed that micro-scale composting production based on organic waste from rural post-harvest residues in combination with animal manures, represent an alternative to chemical fertilizers

Introduction

Agricultural soils in the Andean region of Bolivia are generally characterized by a low fertility with low content of organic matter (0.5 to 2%), and yields of most crops are especially limited by low soil levels of N and P. Small farmers in Bolivia use fertilizers but in low quantity , 2.8 and 22.6 units of NPK per ha, as compared to other countries of the region such as Venezuela and Colombia with values of 122 and 139 units of NPK per ha, respectively [1].

By 2015, more than half of the world's population will live in urban areas, increasing the threat to food security, the urban environment and quality of life. In response to growing urbanization, increased attention is to be focused on rural and peri urban farmers, both on their own needs and on ways in which they can be more productive. Therefore, there is a need to seek technologies that are appropriate to their realities.

Recycling of organic waste – utilizing the power of microorganisms - to a safe and useful end product (compost) is a realistic option aimed at improving crop production [2]. Besides, the management of natural microbial soil inhabitants, which positively impact the development, nutrition and health of plants - (AMF) Arbuscular Mycorrhizal Fungi and (PGPR) Plant Growth Promoting Bacteria - has been acclaimed as a major agricultural practice to reduce chemical inputs i.e. pesticides and fertilizer, and to improve the ecological potential and sustainability of soils in Andean cropping systems. Their major benefits for plants concern improved nutrient uptake and increase tolerance/resistance to abiotic and biotic stresses. These environmental-friendly, natural bio-fertilizers and bio-protectors of plants represent a major opportunity to reduce chemical inputs, i.e. pesticides and fertilizers, saving costs that are frequently too high for small-scale agricultural systems [3-5].

Production in the Andean region is low as a result of various abiotic and biotic soil constraints, and the recourse to pesticides and fertilizers is frequently too expensive. Therefore, a project financed by EC for recycling of organic waste into compost and management of natural microbial soil inhabitants, - AMF and PGPR - was carried out as major agricultural practices to reduce chemical–dependence of small-scale agriculturists and to improve the ecological potential and sustainability of soils in rural and peri-urban systems by stimulating local collective capacities to develop micro-scale composting systems and management of microbial inoculants [6,7]. Several participatory farmer field trials located in different provinces of Cochabamba department (Bolivia) with different crops were conducted. Results of participatory farmer field trials on potato showed that micro-scale composting production based on organic waste from rural post-harvest residues in combination with animal manures, represent an alternative to chemical fertilizers [8,9].

Materials and Methods

Once farmers adopted micro-scale composting production based on available organic rural post-harvest residues (potato, peas, barley straw, wheat, etc.) and animal manures from farmers (chicken,cow,sheep), several field trials with different crops (i.e. potatoes, onions, tomato, peaches, etc.) were established in different agroecological zones such as Lope Mendoza (3440 masl, Carrasco Province), Tiraque highlands (3453 masl, Tiraque province), La Villa (2650 masl, Cochabamba province) and Colomi (3200 masl, Chapare Province) in deparment of Cochabamba ,Bolivia, with a very active participation of local farmers, in order to evaluate strategies of integrated soil management (ISM) for the incorporation of commercial and / or native local formulated bio-fertilizers. Field trials were established with a standard rate of formulated composts as single treatments (8-9 t/ha) or in combination with commercially available AMF *(Glomus fasciculatum)* and PGPR *(Bacillus subtilis)* as shown in Table1.

Trials in farmer fields were also conducted to evaluate the effect of native Bolivian isolate of *B. amyloliquefaciens* as single or mixed treatments with *G. fasciculatum* (Table 2) and always associated to the incorporation of compost in several crops/ fruit trees (lettuce, onion, maize, peaches, etc.) in rural and peri-urban areas of Cochabamba, and similar evaluation approaches were taken as those used before with commercial formulation of *B. subtilis.*

Field trials with grains, vegetables, and tubers were established under a statistical design of Completed Randomized Blocks with four replicates and follow farmer agricultural practices during the growing season.

Table 1: Treatment of several crops with *B. subtilis* (Bs) and *G.fasciculatum* (Gf).

Crop	Treatment
Grains: Corn	Spraying on seed and compost placed in bottom of furrow (250 g Bs + 15 kg Gf / 200 liters of water / ha) or cover seeds in prepared paste (20 g Bs + 1.0 kg Gf / 5 liters of water / 50 kg of seeds)
Vegetables: Onion, Letucce, Tomato, Sugarbeet	Spraying at plant base stem after transplanting (250 g Bs + 15 kg Gf /100-200 l water / ha) or seedling dipping before transplanting (20 g Bs + 1.0 kg Gf / 2 liters of water / 2000 seedlings)
Fruits: Grapes, Peaches, Watermelon	Spraying at bottom of open ridge on incorporated compost at initial sprout formation (250 g Bs + 15 kg Gf / 100-200 liters of water / ha)
Tubers: Oca	Spraying on seed and compost placed in bottom of furrow (250 g Bs + 15 kg Gf /200 liters of water / ha)

Table 2: Treatment of several crops with B. subtilis (Bs), *B. amyloliqufaciens* (Ba) and *G.fasciculatum* (Gf).

Crop	Treatment
Tubers: Potato	Spraying on seed and compost placed in bottom of furrow (250 g Bs or Ba+ 15 kg Gf /200 liters of water / ha)
Vegetables: Onion	Spraying at plant base stem after transplanting (250 g Bs or Ba+ 15 kg Gf / 100-200 l water / ha) or seedling dipping before transplanting (20 g Bs or Ba + 1.0 kg Gf / 2 liters of water / 2000 seedlings)
Fruits: Strawberry, Peaches	Spraying at bottom of open ridge on incorporated compost at initial sprout formation (250 g Bs or Ba + 15 kg Gf / 100-200 liters of water / ha)

Results and Discussion

Results showed that B. subtilis and AMF treatments had significantly higher yields than farmer control plots but significantly lower yields as compared to the combination of B. subtilis and AMF. The combination of *B.subtilis* and AMF suggests a strong synergy effect between the two microbial inoculants.. Results of field trials confirmed the positive effects of both micro inoculants and the compost incorporation on their tuber yield. When crop development and yields were evaluated for the presence of some fungal diseases, the incidence was lower in treatments with both micro inoculants either as single or combined application These results confirmed the suppressive effect of PGPR such as B. subtilis and the AMF *G. fasciculatum*, already observed on the incidence of other soil-borne diseases in different crops.

On the other hand, other farmer field trials with several horticultural and orchard crops were established where these crops play a very important economic rol. Those crops are the main source of cash money for the local farmers who represent the peri-urban producers and therefore they provide to local markets in the city of Cochabamba with fresh vegetables and fruits. Results on plant development, earliness, yield and plant health of different crops just confirmed early results obtained with potato crop. The most important positive effects were observed when both micro inoculants (*B. subtilis* + *G. fasciculatum*) were applied in combination with the compost (7-10 t/ha) at planting or transplanting time (Table 3). Yields were increased from 20.4 % (*G. fasciculatum* on peaches) up to 99.8 % (*B. subtilis* + *G. fasciculatum* on maize forage yield). As with the potato crop, a suppressive effect of micro inoculants was observed on the incidence and severity of soil-born diseases such as damping-off, Phytium, Fusarium, etc. in onion, lettuce, tomato, and other horticultural crops. This effect was observed in both conditions, nursery plots as well as definitive transplanting fields.

Table 3: Yield of horticultural and orchard crops (t/ha) under different agroecological conditions and the application of two commercial biological products, FZB 24WG (B. subtilis) and DESAmic *(G. fasciculatum)* in Cochabamba, Bolivia.

Treatments	Oxalis "oca"	Water melon	Sugarbeet	Tomato	Lettuce	Peaches	Onion		Maize	
							Granex	Red	Forage	Grain
FZB 24WG *(B. subtilis)*	32.5 (30.0%)	270.0 (40.9%)	30.0 (28.8%)	33.0 (33.1%)	21.5 (47.3%)	34.4 (23.3%)	34.9 (67.8%)	33.0 (33.1%)	52.1 (25.2%)	19.0 (37.7%)
DESAmic *(G. fasciculatum)*	NE*	NE*	28.5 (22.3%)	32.5 (31.1%)	20.3 (39.0%)	33.6 (20.4%)	33.6 (61.5%)	32.5 (31.0%)	64.1 (54.1%)	20.9 (51.4%)
FZB+DESAmic	35,5 (42.0%)	280 (70.4%)	33.8 (45.1%)	35 (41.1%)	23.6 (61.6%)	38.3 (37.3%)	37.3 (79.3%)	35.0 (41.1%)	83.1 (99.8%)	25.4 (84.1%)
Control (100 %)	25.0	230.0	23.3	24.8	14.6	27.9	20.8	24.8	41.6	13.8

NE*: No Evaluated

Results in some situations showed better effect of the native micro inoculants than B. subtilis on plant growth, and yield (Table 4). As response to the favourable results obtained with several different horticultural and orchard crops with the native isolate of *B. amyloliquefaciens* as single treatment or mixed with *G. fasciculatum* and vermicompost, a bio fertilizer was formulated and it is being used by farmers dedicated to organic production. Once an efficient and effective native isolate of AMF can be produced locally, it will be used as ingredient for replacing the commercial DESAmic product of *G. fasciculatum*. The local formulation of those bio-fertilizers and the recommended incorporation of compost locally prepared by farmers is playing a very important role in improving or maintaining soil fertility in both conventional and organic agriculture as well as the livelihood of poor small Bolivian producer and urban consumers.

Table 4: Yield of horticultural and orchard crops (t/ha and foliage development) under different agroecological conditions and the application of three biological products, B. subtilis (FZB 24WG), Fertisol (native isolate of *B. amyloliquefaciens*) and DESAmic (commercial *G. fasciculatum*) in Cochabamba, Bolivia.

Treatments	Peaches	Strawberry**	Onion	Onion	Potato	Potato	Potato
Native *B. amyloliquefaciens*	36.6 (59.1 %)	92.0 (31.4%)	45.0 (76.5%)	105.0 (84.2%)	30.0 (36.4%)	14.0 (36.4%)	24.9 (38.3)
DESAmic *(G. fasciculatum)*	NE*	NE*	NE	87.0 (52.6%)	NE*	14.2 (94.0%)	NE*
B. amyloliquefaciens + DESAmic	NE*	NE*	47.0 (84.3%)	75.0 (31.6%)	NE*	14.2 (94.0%)	28.2 (56.7)
FZB 24WG *(B. subtilis)*	34.8 (51.3 %)	90.0 (28.6%)	42.0 (64.7%)	70.0 (22.8%)	29.0 (31.8)	11.6 (57.7%)	25.5 (41.7)
B.subtilis + DESAmic	NE*	NE*	46	70	NE*	16.3	29.3
B. s. + B. a. + DESAmic	NE*	NE*	45.0 (76.5%)	NE*	NE*	14.6 (99.8%)	NE*
Control (100 %)	23.0	70.0	25.5	57.0	22.0	7.3	18.0

NE*: No Evaluated; **: Foliage development

In order to promote the adoption of this innovation by small rural and peri-urban farmers on composting and use of microbial inoculants products, numerous contacts with various stakeholders (farmers associations, and individual farmer), and diffusion through documents and publications project activities have been locally diffused. The training program and diffusion related to composting process, bio-fertilizers use (Figure 1), soil management, and complementary activities related to community organization, and organic agriculture was carried out by field days (Figure 2) in collaboration with local actors including municipalities, national foundations in Bolivia.

Figure 1: FertiTrap (left upper corner) and BioFertil (right upper corner), biofertilizers formulated with B. subtilis and *B. amyloliquefaciens*, respectively, mycorhiza *(G. fasciculatum)* as micro-inoculants and vermicompost as inert material; Fertitrap treatment of onion seedlings before transplanting (center upper row); untreated plants (left lower corner and left side of center lower row); treated plants: right lower corner and right side of center lower row).

Figure 2: Visiting a onion farmer field trial in La Villa and a potato field trial showing collaborating farmer family in Chullchunqani, Cochabamba, Bolivia.

Successful Story

After four years almost fully, achievements of our proposed objectives were reached, and this is really a "success story" with small Andean farmers of rural and peri-urban. areas of Cochabamba in Bolivia. Farmers are able to prepare with post-harvest organic residues and animal manures their own compost for its field incorporation at planting time (7-10 t/ha). Several native isolates of PGPR and AMF were identified (*B. amyloliquefaciens* and *G. intraradices*, respectively). However, with a commercial B. subtilis product (BZF 24WP), which later on was locally multiplied and formulated, and a Bolivian commercial mycorrhiza of *G. fasciculatum* (DESAmic), a biofertilizer named FertiTrap was formulated and evaluated in several trials in farmer fields. Results with different horticultural and orchard crops showed both plant growth promoting effect and suppressive/inhibitory soil borne diseases effect. When native *B. amyloliquefaciens* was available this was also locally multiplied and formulated and another bio fertilizer was formulated with the name of BioFert in a similar way as FertiTrap, Obtained results with new bio fertilizers on several crops required less number of pesticide applications and no chemical fertilizers As bio fertilizers are quite demanded by organic and conventional producers, a small pilot plant has been set up and small volumes of similar quality of commercial ones are being formulated and commercialized.

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