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Sustainable management strategies focused on native bio-inputs in *Amaranthus cruentus* L. in agro-ecological farms in transition

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A B S T R A C T

In the province of Córdoba, Argentina, most crops are produced with a large volume of agrochemicals. Awareness of pollution and its implications has led to a social demand for the protection of the environment and for the provision of products free of contaminants. Small farmers are incorporating sustainable and ecological perspective into of production and management techniques and are currently in an agro-ecological transition process. The increased use of native bio-inputs and the incorporation of crops with high nutritional quality strengthen the expansion of agro-ecological farming in the sites in transition. The aims of this study in a transition agro-ecological area were to propose sustainable management strategies focused on the use of native bioinputs, comparatively evaluate the biological response of *Amaranthus cruentus* L. "amaranth" to the application of biodigester effluent, *Trichoderma atroviride* P. Karst. Alfacp8, vermicompost from horse and rabbit manure and control, and to evaluate the economic output of *Amaranthus* sp. by treatments. At a significance level of 0.05, no differences were detected between the average growth of effluent-treated plants and those treated with *Trichoderma* sp., and these averages were significantly higher than those obtained with vermicompost and control treatments. For the variables dry weight of leaves, stems and roots, inflorescences and seeds, no significant differences were detected between the treatments at a significance level of 0.05. The average yield with *Trichoderma* sp. was 700 kg ha^{-1} higher than the control; the average with vermicompost was 630 kg ha^{-1} higher and the digester effluent average was 490 kg ha^{-1} higher than control. These differences are economically important for farmers. Also, the estimated economic output was greater for plants treated with biodigester effluent and *Trichoderma* sp. than with vermicompost. Thus, native bio-inputs and ancestral culture can provide affordable and sustainable management strategies for farmers in agro-ecological transition.

1. Introduction

In conventional agriculture, production systems rely heavily on harmful practices for the conservation of resources and the quality of the products obtained. In Argentina, monoculture, the continuous application of fertilizers and pesticides, increasing doses and frequencies of applications, the deterioration of the fertility, structure and biotic balance of soils, surface water and ground water pollution, are characteristics of a farming model which is hazardous and harmful to ecosystems and human health.

Nitrogen fertilizers are regularly applied to extensive crops such as wheat *Triticum aestivum* L., corn *Zea mays* L., sunflower *Helianthus annuus* L. and sorghum *Sorghum vulgare* L. However, the greatest area is devoted to the cultivation of soybean, which does not require nitrogen fertilizers (urea), since biologically it fixes nitrogen from the air in symbiosis with *Rhizobium* sp., provides a smaller volume of stubble than other crops, giving rise to a decrease of carbon in the soil and less coverage (Magnasco et al., 2013).

According to the Argentine national Inventory of Greenhouse Gas for 2012, direct and indirect emissions from the use of synthetic fertilizers were 4712 Gg CO_2 eq (Secretaría de Ambiente y Desarrollo Sustentable de la Nación, 2015a). This inventory

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applies the methodology recommended by the Intergovernmental Panel on Climate Change (IPCC, 2006). Direct CO_2 emissions from fertilization with urea and urea-ammonium nitrate (UAN) were 781 Gg CO_2 eq. for 2012. In one decade, the amount of nitrogen incorporated into fertilizers practically quintupled. 23% of the emissions correspond to N_2O from agricultural soils with 2–3 kg of N_2O/ha emitted every year (Secretaría de Ambiente y Desarrollo Sustentable de la Nación, 2015b), which is higher than the average for Latin America (Jantalia et al., 2008; Perdomo et al., 2009).

In the province of Córdoba, Argentina, most crops are produced with a large volume of agrochemicals, leading to problems of pollution at all levels (Lantieri et al., 2011). The awareness of pollution and its implications has led to increasing social demand for protection of the environment and for products free of contaminants. Agro-ecology recommend methods for primary food production to be carried out in an environmental, economic and socially sustainable framework that protects natural resources in order to meet the needs of future generations. Altieri and Nicholls (2007) recommend a transition from chemical-intensive agriculture to a more sustainable and low-external input agriculture.

Small rural and periurban farmers, in particular, have recently incorporated agro-ecological perspective into production and management techniques and are currently in a process of transition (Altieri and Nicholls, 2013) . These practices aiming at sustainability are usually in small family farms (up to 2 ha). The new national Law on family farming Nº 27.118 (Senado y Cámara de Diputados de la Nación Argentina, 2014) recognizes the contribution of family production to safety and food sovereignty. Although the small agroecological farmers in Córdoba, located in the green belt of the city, produce vegetables and aromatic species (basil, rosemary, mint, oregano, sage) as the most common crops and use agroecological-inputs, it is necessary to enhance diversification and the use of native inputs (Cabanillas et al., 2015).

The expansion of agro-ecological farming in pilot sites in transition can be strengthened through the increased use of bioinputs and the incorporation of high nutritional quality crops. Bioinputs can be used both for nutrient management and against pests and diseases. For example, *Trichoderma* species used as biological control agents have been shown to stimulate the growth of plants and protect them from diseases (Druzhinina et al., 2008). In greenhouse tomato cultivation, the application of *Trichoderma* sp. had a positive effect on yield and fruit quality and also increased the amount of dry matter of roots and aerial parts of the plants (Herrera, 2005). *Trichoderma* sp. increased the absorption and concentration of some nutrients (Cu, P, Fe, Mn, and Na) in roots (Li et al., 2015) and modified the levels of growth regulators such as auxin in the rhizosphere (Contreras et al., 2009). *Trichoderma* has also been used in bioremediation, freeing the soil of heavy metals such as cadmium and nickel, or environmental contaminants such as hydrocarbon phenanthrene (Cao et al., 2008).

Trichoderma harzianum is widely used for disease management because of its efficient control of a wide range of pathogenic fungi in plants, including *Botrytis* sp., *Colletotrichum* sp., *Alternaria solani*, *Pythium* sp., *Phythopthora capsici*, *Rhizoctonia* sp. *and Fusarium* sp. (Verma et al., 2007; Michel Aceves et al., 2005). Native *Trichoderma* species have been isolated from soil in Córdoba and have demonstrated superior performance than exotics, because they better adapt to the environment (Pérez et al., 2013).

Other sources of bioinputs are solid organic refuse, such as vegetables and fruit from the markets, and manure, which is often discarded, causing environmental pollution. In the province of Córdoba, the fruit and vegetable markets are in the cities of Córdoba, Río IV, Villa María and Malagueño. Annually 216,000 tons of products are sold and the amount thrown away daily for their quality is 21%, which means 46,000 tons of organic wastes per year. In general, these wastes end up in open air dumps (Pettigiani et al., 2013). In other contexts, this refuse can be an important input. For example, solid organic refuse can be processed by anaerobic biodigestion for biogas production (Sitorus et al., 2013; Lin et al., 2011; Bouallagui et al., 2005). Indeed, the San Miguel fruit and vegetable market, Malagueño, which sells 7000 tons of products per year, has a treatment area on its premises in which refuse is reused through biodigestion. Biodigestion effluents are rich in nutrients and their use as amendment has positive effects on agricultural productivity (Martí-Herrero et al., 2014), as was reported in *Coffea arabica* L. and *Zea mays* L. (Oliveira et al., 2011) and in biomass production of *Sida hermaphrodita*, *Zea mays* L. and *Medicago sativa* L. (Bueno Piaz Barbosa et al., 2014).

Manure from livestock can be reused through the preparation of compost and vermicompost and its application has had favourable responses in aromatic and vegetable crops (Cabanillas et al., 2013a, 2013b; Ravindran and Sequaran, 2010) and in *Amaranthus hipocondriacus* (Vázquez-Benítez et al., 2011). Both biodigestion and vermicomposting are feasible strategies for family farms and small-scale production units, encouraging the use of their own resources to obtain energy and amendment of high biological value.

Another component in the transition to agro-ecological production is crop diversification, one of the basic pillars for system equilibrium and pest management. In this context, native species have an important role. In our area, the genus *Amaranthus* comprises some eighty native species from tropical to temperate warm regions. In the Pampa, more than half a dozen species can be found (Montoya et al., 2015). Despite being a self-pollinated crop, varying amounts of outcrossing and interspecific and intervarietal hybridization have brought wide variation in amaranth genotypes (Tui and Satyesh, 2009). Various properties have been found for *Amaranth* grains: the amount of protein (16%) is higher than in other grains, the quality is the best of the vegetable kingdom in the high proportions of essential amino acids such as lysine (16.6%) and the calorie, carbohydrate, fibre and mineral contents in grains promote the reduction of serum cholesterol (Rojas et al., 2010). Additionally, *Amaranthus* sp. supplies an alternative food resource in view of increase in cereal food allergies because it does not contain gluten and can be consumed by people with celiac disease (Berghofer and Schoenlechner, 2002; Gimplinger et al., 2007). Commercially, it has broad applications in the food and beverage industry and in the chemical and pharmaceutical industries.

Amaranthus sp. is a rustic crop that adapts to different environments. It is a promising C4-crop that may gain importance particularly with increasing temperatures and drought conditions (Roitner-Schobesberger and Kaul, 2013). Recommendations for optimal crop density differ substantially (Aufhammer, 2000; Henderson et al., 2000; Martin de Troiani et al., 2004; Gimplinger et al., 2008; García-Pereyra et al., 2011). Seed numbers per square metre depend on genotypes, environment, soil fertility and crop patterns (Pourfarid et al., 2014). Plant height varies depending on soil fertility, moisture, plant density and variety (Martin de Troiani et al., 2004; Yarnia, 2010). *Amaranthus cruentus* L. had greater plant height and inflorescence length (Pospišil et al., 2006). The yield of grains differs according to the authors (Martin de Troiani et al., 2004; García-Pereyra et al., 2009; Reinaudi et al., 2011; Bisikwa et al., 2014). These studies were made in amaranth under the conventional system.

Agro-ecological fertilization studies in amaranth are scarce. In Puebla (México), applying three organic fertilizers (bat manure, bionitrogen and chicken manure) the yield was 2.05, 2.17 and 2.17 ton ha^{-1}, respectively (Vázquez-Benítez et al., 2011). Research is needed on the cultivation of *A. cruentus* L. under agro-ecological systems in transition, without the addition of pesticides.