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Research article

Recycling organic residues in soils as amendments: Effect on the mobility of two herbicides under different management practices

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ABSTRACT

The addition of organic residues to soil to increase its organic matter content is considered as a viable option for sustainable food production in soils sensitive to degradation and erosion. However, the recycling of these organic residues in agricultural soils needs to be previously appraised because they can modify the behaviour of pesticides when they are simultaneously applied in agricultural practices. This study evaluated the changes in the mobility and persistence of two herbicides, triasulfuron and prosulfocarb, after two repeated applications in field experimental plots in an unamended soil and one amended with green compost (GC) for seven months. Different factors were studied: i) soil without amendment (S), ii) soil amended with two doses of GC ($\sim$12 t C ha^{-1}, S + GC1 and 40 t C ha^{-1}, S + GC2), and iii) soils unamended and amended with different irrigation conditions: non-irrigated and with additional irrigation (2.8 mm per week). After the first application of herbicides, the results initially indicated no significant effects of soil treatments or irrigation conditions for triasulfuron mobility in agreement with the residual concentrations in the soil profile. The effect of irrigation was noted after one month of herbicide application and the effect of the soil treatment was significant after two months because the persistence of triasulfuron in S + GC2 was maintained until 50% of the applied amount. For prosulfocarb, the influence of soil amendment was significant for the initial persistence of the herbicide in S + GC2, higher than in S or S + GC1, in agreement with its adsorption constants for this soil. However, dissipation or leaching of the herbicide over time was not inhibited in this soil. After the repeated application of herbicides, the influence of the treatment of soils and/or irrigation was significant for the leaching and dissipation of both herbicides. The initial dissipation/degradation or leaching of herbicides was higher than after the first application, although persistence was maintained after five months of application in amended soils for triasulfuron and in unamended and amended soils for prosulfocarb. The results confirm that high doses of GC increased the persistence of both herbicides. This practice may offer the possibility of applying a tailored dose of GC to soil for striking a balance between residual concentrations and the soil agronomic effect.

1. Introduction

Management strategies are now being implemented for sustainable food production in soils susceptible to degradation and erosion. These strategies involve an increase in soil organic matter (OM) (Martins Gomes et al., 2018) because OM has a direct influence on the physical, chemical and microbiological properties of soils, and hence on soil fertility and plant development (Bastida et al., 2007; Tejada et al., 2009; Yazdanpanah et al., 2016). A possible option is the addition to the soil of amendments or organic wastes from different origins (urban, agricultural or industrial), which are currently generated in large quantities. The improvement in soil properties due to the OM content in these residues has been well documented, so its application as an organic amendment in agriculture is a common practice (Aranda et al., 2015; Bastida et al., 2015; Ferreras et al., 2006; Tejada and Gonzalez, 2008). In addition, the application of organic wastes represents an opportunity to increase the soil capacity for carbon sequestration, especially lignocellulosic organic wastes (Castellano et al., 2015; Hernandez et al., 2017). These residues have a more recalcitrant or less biodegradable nature than other residues, albeit with greater affinity to bind to the soil's mineral particles, increasing the stable soil carbon pool when protected against decomposition (Nicolás et al., 2017).

After being composted, the plant residues generated in the pruning carried out in parks and gardens have an OM content > 15% on dry weight and could be considered a more stable source of soil OM than that provided by other more biodegradable residues such as biosolids or

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sewage sludge. However, the recycling of these organic residues in agricultural soils has to be previously evaluated because they can modify the behaviour of pesticides when they are simultaneously applied in agricultural practices (Herrero-Hernández et al., 2011). Organic residues can be effective tools for controlling soil and water pollution by pesticides, but the agronomic efficiency of these compounds could be decreased by changing their adsorption, mobility, persistence or bioavailability. In this sense, investigations are necessary before the implementation of these products in agricultural soils to optimize their use in pursuit of pollution control and/or the agronomic effect of pesticides. Some studies related to this subject are reported in the literature for different types of pesticides (Jiang et al., 2016; Marín-Benito et al., 2009a, 2009b; Tejada and Benítez, 2017). In general, these studies are carried out under laboratory conditions, being rarely conducted under field conditions for a more realistic approach to this issue (Herrero-Hernández et al., 2015; Stipičević et al., 2015).

The evaluation of the effect of organic amendments in soils with cereal crops and its possible incidence on the behaviour of simultaneously applied herbicides is of special interest. Cereals are among the most important crops in world agriculture, with Spain devoting over five million ha to this crop. It is one of the crops with the largest amount of active ingredients available to be used as herbicide, and the competition between weeds and the crop will depend on, among other factors, the conditions of the environment and the soil. Compounds of the chemical groups sulfonamide and thiocarbamate, such as triasulfuron and prosulfocarb, are usually recommended for individual or joint use for the control of weeds in rainfed and irrigated cereal crops since provide a good control of weeds (Bajya et al., 2015; Cirujeda and Taberner, 2010; Knežević et al., 2010; Mehmeti et al., 2018).

Triasulfuron (2- (2-chloroethoxy) -N - [[(4-methoxy-6-methyl-1,3,5-triazin-2-yl) amino] carbonyl] benzene sulfonamide) is a sulfonylurea with selective herbicide activity in the pre- and post-emergence control of broadleaf species in barley, oats and wheat. Triasulfuron has a high mobility in the soil due to its high solubility in water and low hydrophobicity (EC, 2000). Prosulfocarb (S-(phenylmethyl) dipropylcarbamothioate) is a systemic thiocarbamate with selective herbicide activity, being applied in early pre- and post-emergence against grasses and broadleaf weeds in crops such as long-cycle barley and wheat. It is a hydrophobic herbicide and has high adsorption, low mobility, and moderate persistence in soil (EFSA, 2007a).

In a previous work, we evaluated the behaviour of these herbicides, triasulfuron and prosulfocarb, in a short field experiment in an unamended soil and one amended with a low dose of green compost (GC) (Marín-Benito et al., 2018). The dissipation and mobility of herbicides were determined from concentrations obtained at various times in the soil surface and at different depths up to 50 cm. Variable effects of organic carbon (OC), dissolved organic carbon (DOC) from GC, soil water infiltration or formulation type (Logran®, Auros® and Auros Plus®) on the adsorption/persistence and leaching of herbicides in the soil profile were observed. The interest of these results is sustained considering that the leaching of herbicides from the soil surface shortens the duration of residual weed control and may contaminate groundwater. Furthermore, the amounts retained in the soil profile could exceed the recorded threshold for the sensitivities of susceptible species. The results of previous experiments were obtained after a single application of these herbicides and a single dose of GC. However, in practice, herbicides could be applied repeatedly to the soil-crop system for weed control with different soil amendment doses, and these practices can alter their degradation rate and persistence in soil, making it difficult to forecast their environmental impact.

Considering there are no studies on prosulfocarb mobility in soils in the literature, while the mobility of triasulfuron has been evaluated at field and laboratory scale (Stork, 1995; Weber et al., 1999), although in no case have they been carried out on soils amended with organic wastes, it is deemed of interest to expand the study of the behaviour of both herbicides under broader conditions. Both herbicides are usually applied as individual formulations or as a joint one when it comes to tackling a weed mixture. A good weed control of winter wheat (> 96.7%) has been reported with the herbicide combinations of prosulfocarb plus triasulfuron (Knežević et al., 2010).

Accordingly, the objective of this paper was to expand the study of the mobility of triasulfuron and prosulfocarb using a joint formulation (Aurus Plus®) in an agricultural field devoted to cereal cultivation under different conditions: i) soil without amendment, ii) soil amended with two doses of green compost, and iii) soils unamended and amended with different irrigation conditions (non-irrigated and with additional irrigation). These factors were studied in field experimental plots in two time periods (2 + 5 months) during which repeated doses of herbicides were applied, and the results involved the physical, chemical and physicochemical properties of soils.

2. Materials and methods

2.1. Herbicides

The commercial formulation of triasulfuron + prosulfocarb (Auros Plus®) (Syngenta Agro S.A., Madrid, Spain) was used in the study. Analytical standards of both compounds were purchased from PESTANAL® (purity > 98.9%) (Sigma Aldrich Química S.A., Madrid, Spain). Water solubility is 815 and 13.0 mg L^{-1} and log Kow is −0.59 and 4.48 for triasulfuron and prosulfocarb, respectively (PPDB, 2018). The chemical structure and general characteristics are included in Table S1 in Supplementary material.

2.2. Green compost residues

Two composted organic residues of vegetal origin (< 5 mm) generated from the pruning of plants and trees in parks in the city of Salamanca (NW-Spain) were used. They were supplied by the City Council (GC1) and by the nursery "El Arca" in Salamanca (Spain) (GC2). Their main physicochemical characteristics on a dry weight basis were determined as indicated in Marín-Benito et al. (2018), and they are pH 7.33 and 7.58, OC% 9.8 and 24.1 and N% 1.04 and 1.10, respectively, for GC1 and GC2.

2.3. Experimental set-up

The field assay was conducted in plots located in the Muñovela experimental farm belonging to the Institute of Natural Resources and Agrobiology of Salamanca, Spain (latitude 40º54′15″ N, longitude 5º46′31.51″ W). These plots were located in the same experimental field (sandy clay loam soil, Typic Haploxerept) (Soil Survey Staff, 2010) where we carried out a previous experiment in 2015 (Marín-Benito et al., 2018). In February 2016, the experimental layout of randomized complete blocks (18 plots of 3 m × 3 m) was designed as follows: unamended soil (S, 6 plots), soil amended with GC1 at the rate of 120 t ha^{-1} on a dry weight basis (~12 t C ha^{-1}) (S + GC1, 6 plots) and soil amended with GC2 at the rate of 180 t ha^{-1} on a dry weight basis (~40 t C ha^{-1}) (S + GC2, 6 plots) (Fig. 1). GC1 and GC2 amendments were used by availability effect to get different OC content in plots. They were incorporated into the 20-cm topsoil layer by using a rototiller. Three plot replicates per treatment received only natural rainfall (NI), and a further three replicates per treatment received additional sprayer irrigation (I, 2.8 mm per week).

Eighteen unamended and amended plots were treated with the combined commercial formulation of both herbicides (Auros Plus®). Water herbicide solutions were applied manually using a backpack sprayer (volume of 5 L) shortly after the soil was amended. The doses jointly applied to the plots were 11.25 kg a.i. ha^{-1} of prosulfocarb as Auros® 80% and 250 g a.i. ha^{-1} of triasulfuron as Logran® 20%, corresponding to 2.5 times the maximum agronomic dose for both herbicides recommended for heavy soils with a greater adsorption capacity.