Effects of foliar fertilization of a biostimulant obtained from chicken feathers on maize yield

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Abstract

Due to the important contribution that it makes to human nutrition, maize is one of the most widely-consumed cereals in the world. There is, therefore, high demand for fertilizers that will maintain maize production at both high yield and quality levels. The objective of this work was to study the effect of foliar fertilization using a biostimulant, obtained by enzymatic hydrolysis from chicken feathers, on the productivity and quality of maize crops (*Zea mays*, L. cv PR32W86 Pioneer), located in Trujillanos (Extremadura, Spain), over two consecutive seasons. Foliar biostimulant/biofertilizer was applied three times each season and at two rates (3.6 and 7.2 l ha^{-1}). At the higher rate and for both seasons, foliar fertilization significantly increased the leaf concentrations of macro- and micronutrients, while grain protein content and yield increased by 26% and 14%. These results suggest that the foliar use of this biostimulant could be of great interest to the farmer for improving both maize crop yield and quality.

Keywords: biostimulant; chicken feathers; foliar fertilization; maize crop

1. Introduction

Foliar fertilization is currently a highly efficient agronomic crop fertilization technique since it favours the assimilation of the nutrients in the plant and consequently, the utilisation of the nutrients applied with the fertilizer, thus increasing crop yields and quality (Tejada and González, 2004; Abbas and Ali, 2011; Osman et al., 2013). Since it significantly reduces the effects of groundwater contamination caused by applying inorganic fertilizers to the soil it is, moreover, a technique that contributes to sustainable, environmentally friendly agriculture (Tejada and González, 2003a; Fernández and Eichert, 2009).

In recent years, foliar fertilization has been used to apply macronutrients, micronutrients and humic substances. This results in a great number of positive effects in the plant, principally at physiological level (respiration and photosynthesis), at morphological level, (root length and leaf area index), and the yield of various crops such as rice, tomato, pepper and maize (Tejada and Gonzalez, 2003a, 2004; Karakurt et al., 2009; Tejada et al., 2016).

The use of biostimulants (BS) obtained from various organic residues (carob germ, sewage sludge) by enzymatic hydrolysis processes via foliar fertilization is increasing. This is because these organic compounds are easily assimilated by crops and therefore improve crop nutrition, increasing both the productivity and the quality of the grain or fruit harvested (Parrado et al., 2008; Tejada et al., 2016).

Several authors have tested the effectiveness of a BS obtained from chicken feathers by enzymatic hydrolysis processes in the bioremediation of polluted soils with organic xenobiotics (Gómez et al., 2014; Rodríguez-Morgado et al., 2015a, b). However, there are no studies concerning the use of this type of organic compound via foliar fertilisation in order to increase both crop yield and quality.

Maize (Zea mays L.) is one of the world's major cereal crops, ranking third in importance after wheat and rice (Lashkari et al., 2011). Most of the maize produced worldwide is used for animal feed, although it is also part of the basic diet in human nutrition, as it is a good source of starch, proteins, lipids, polyphenols, carotenoids, vitamins and dietary fibre (Nuss and Tanumihardjo, 2010; Blandino et al., 2017). Consequently, studying the response of this crop to foliar fertilization of a new BS could be of great interest to the farmer.

The main objective of this paper is to study the effect of a BS obtained from chicken feathers by enzymatic hydrolysis processes when it is applied via foliar in a corn crop, observing both maize yield and grain quality.

2. Material and methods

2.1. Site and properties of the biostimulant

The study was carried out during two consecutive experimental seasons (from April to October in 2014 and 2015) at Trujillanos, (Extremadura, Spain). The climatic characteristics of the study area are detailed in the supplemental material (Table S1) (AEMET 2017). Total annual rainfall was 342.3 mm in 2015 and 458.4 mm in 2016. Average air temperature averaged 17.8 °C in 2015 and 17.5 °C in 2016.

The soil used was the same as that described in Tejada et al. (2016). The main soil characteristics (0-25 cm) are described in Table 1. The methodology used for determining each parameter is described in Tejada et al. (2016).

The BS used was obtained from chicken feathers by the enzymatic hydrolysis. The obtaining process is described in Rodríguez-Morgado et al. (2014). This process was carried out in a bioreactor under the following conditions: (a) substrate concentration: 10%; (b) solvent: water; (c) catalytic agent: subtilisin, 0.15% (v / v) (d) Enzymatic concentration: 1 ml l^{-1} substrate; (e) temperature: 55 ° C; (f) pH: 9, controlled by the addition of 10 M NaOH; (g) time: 180 min. Finally, the hydrolysed product was centrifuged obtaining the biostimulant. The organic compound's chemical composition is described in Table 2. The methodology used for determining each parameter is described in Rodríguez-Morgado et al. (2015b).

Amino acid composition was determined by reversed-phase HPLC analysis of 6-aminoquinolyl-*N*-hydroxysuccinimidyl carbamate (AQC) derivatives, with γ-aminobutyric acid as internal standard (Table 3). The methodology used for determining each parameter of these amino acids is described in Parrado et al. (2008).

2.2. Experimental layout and treatments

For each experimental season, the experimental layout was a randomized complete block with three treatments and three replicates per treatment. Each plot size was 9 m × 7 m. The treatments were the following:

(1) A0 treatment, plots fertilized with 300 kg N ha^{-1} (as urea), 80 kg P ha^{-1} + 41.7 kg N ha^{-1} [as $(NH_4)H_2PO_4$] and 120 kg K ha^{-1} (as K_2SO_4), which is common practice in the area

(2) A1 treatment, plots fertilized with the A0 treatment mineral fertilizers and foliar fertilized with BS at a dose of 3.6 l ha^{-1}

(3) A2 treatment plots fertilized with the A0 treatment mineral fertilizers and foliar fertilized with BS at a dose of 7.2 l ha^{-1}

The doses used in the BS are those described by Tejada et al. (2016) when they applied a BS obtained from sludge and hydrolytic processes. The inorganic fertilizers were incorporated on April 13th 2015 and 18th April 2016, respectively, to a depth of 20-25 cm.

Similar to Tejada et al. (2016), BS was applied three times during the maize vegetative cycle and for each experimental season. In this regard, the BS was applied on July 13th, July 27th and August 17th during the 2015 season, and July 11th, July 25thand August 22ndduring the 2016 season. Therefore, the total doses used in the experiment were 10.8 l ha^{-1} or A1 and 21.6 l ha^{-1} for A2 in each experimental season.

Maize (Zea mays cv PR32W86 Pioneer) was sown at a rate of 100000 seeds ha^{-1} with 75-cm inter-row spacing. The planting dates were April 14th 2015 and April 19th 2016, respectively. Once the harvest was collected during the first experimental season, all of the residues generated were also collected. This was done to prevent these organic residues interfering with plant nutrition.

The irrigation system, irrigation time and amount of water applied to the crop were similar to that described by Tejada et al. (2016). Table 4 shows the chemical composition of the irrigation water used. Values were obtained from the arithmetic mean of 6 samples per year during each vegetative cycle of the plant.

2.3. Plant sampling and analytical determinations

In each fertilizer treatment and for each experimental season, the leaves of 10 plants located in the central area of each plot were selected. Leaf samples were collected in two stages of growth: (1) at tasselling [R1 physiological state according to Hanway scale (Ritchie et al., 1986)], occurring on August 8th 2015 and August 5th 2016; and (2) at harvest [R6 physiological state according to Hanway scale (Ritchie et al., 1986)], which took place on October 16th 2015 and October 20th 2016, by selecting the spike leaves (Tejada and González, 2003a; Tejada et al., 2016).

Before their analysis, the leaves were subjected to a washing and drying process, described in Tejada et al. (2016). Furthermore, the macro- and micronutrients in the leaves were determined according to the methods described in Tejada et al. (2016).

For each season and fertilizer treatment, all the corncobs located in each experimental plot were collected. Number of grains per corncob and crop yield (kg ha^{-1}) was determined in samples collected from each plot on October 14th 2015 and October 20th 2016, respectively.

On the other hand, protein concentration, macro- and micronutrients in the grain were determined according to the methodology described in MAPA (1986) and Tejada et al. (2016).

2.4 Statistical analysis

With the data obtained, an analysis of variance (ANOVA) was performed considering the treatment as independent variable followed by Tukey's significant difference as a post hoc test, considering a significance level of $p < 0.05$ throughout the study and using Statgraphics Plus 2.1 software package.

3. Results

Table 5 shows the macro- and micronutrient leaf contents during the maize cycle for each experimental season expressed on a dry matter basis.

Regarding N, at harvest and for both experimental season, the A2 treatment showed the highest levels of N in leaf. Compared with the A0 treatment, foliar N concentration was 14.4% and 39.1% higher in the A1 and A2 treatments for the 2015 season, whereas it was 15% and 33.3% higher in A1 and A2 treatments for the 2016 season.

In the same way, and at harvest, the A2 treatment showed the highest values of P, highlighting the effect of BS on the contents of this macronutrient in leaf. Compared with A0 treatment, leaf P concentration was 32.8% and 52.2% higher in A1 and A2 treatments for the 2015 season, whereas it was 43.5% and 51.1% higher in the A1 and A2 treatments for the 2016 season (K, Ca and Mg in leaf) are also higher in the foliar fertilized plots with A2, followed by A1, demonstrating the effect of the BS dosage on the concentration of the macronutrients analysed in maize leaf.

The micronutrients analysed in leaf show a similar evolution to the macronutrients. At harvest and for both experimental seasons, the highest values were obtained in the A2 treatment, followed by the A1 treatment. The statistical analysis showed significant differences with A2 treatment only, again highlighting the importance of the BS rate used in the experiment.

The chemical composition of the grains presented a very similar behaviour to the nutrient content in the leaves (Table 6). For both experimental seasons, there was a significant increase in macro- and micronutrients analyzed, principally when the higher BS rate was used.

Compared with the A0 treatment, grain protein concentration significantly increased by 26.5% in the A2 treatment in the first season and by 25.3% in the second (Table 7). Moreover, the number of grains per corncob significantly increased by 15% in the A2 treatment in the 2015 season and by 15.8% in the 2016 season. Finally, the higher application rate significantly increased yield by 13.4% and by 14.6% in the first and the second seasons.

4. Discussion

Our results suggest that there is a positive effect on the mineral nutrition of corn when a BS obtained from chicken feathers was appliedvia foliar application. These results are in agreement with those obtained by Tejada and González (2003a) and Tejada et al. (2016), who observed an increase in the plants' mineral nutrition after the application of a BS obtained from sewage sludge or from a by-product of the two-step olive oil milling process via foliar to a corn crop.

In the same way, other authors have obtained similar results after the foliar application of different organic substances and amino acids on rice, corn, tomato, pepper, cucumber, wheat, asparagus and green beans (Tejada and González, 2003b, 2004; Yildirim, 2007; Karakurt et al., 2009; Katkat et al., 2009; Abdel-Mawgoud et al., 2011; El-Nemr et al., 2012).

This improvement in the plant mineral nutrition after the foliar fertilization of humic substances and amino acids is mainly due to an improvement in the plants' uptake of nutrients (Tejada et al., 2003b, 2016). Several studies have shown that the foliar application of humic substances increases leafcuticlepermeability, favouring the entry of ions attached to these molecules within the plant cell (Fageria et al., 2009; Çelik et al., 2010).

Numerous studies have shown the importance of amino acids in the plant's physiological activities, mainly at the cellular level. Since they are highlywater-soluble, the positive effects of applying amino acids might be due to their internal function within the cell as an osmo-regulator.

This increases the concentration of cellular osmotic components (Abdel-Mawgoud et al., 2011), stimulating cell growth and consequently increasing the plants' chemical composition, as well as the growth, yield and quality of the harvest (Awad et al., 2007; Abdel Aziz, 2009; Thomas et al., 2009; Abd El-Aal et al., 2010). Also and due to the chelating effect of amino acids on micronutrients, when applied together with micronutrients they facilitate the absorption and transport of these micronutrients inside the plant, since they also positively affect cell membrane permeability (Ibrahimn et al., 2010).

Some authors propose different formulations of humic acids, amino acids, hydrolysed proteins, etc. as growth promoters, thus improving plant nutrition (Thomas et al., 2009). Our results confirm these judgments, since the BS, with the mixture of substances used in this experiment, favours the mineral nutrition of corn.

The increase in grain macro- and micronutrient concentrations is possibly due to the improvement in the plant's mineral nutrition. These results are in agreement with those obtained by Tejada et al. (2016), who found a significant increase in the concentration of macro- and micronutrients in corn grain when they applied the same doses of a BS obtained from sewage sludge, also composed of a mixture of humic substances, low molecular weight peptides, amino acids and macro- and micronutrients. In the same way, these data are in agreement with those obtained by other authors, who found a significant increase in macronutrients in rice and maize grains after the foliar application of different humic substances (Tejada et al., 2006; Osman et al., 2013).

The increase in micronutrients in grain is a consequence of the micronutrient-rich BS foliar fertilization. These results are in agreement with those obtained by other authors when applying different micronutrients via foliar to crops such as wheat, cowpea and rice (Simoglou and Dordas, 2006; Dordas, 2009; Zeidan et al., 2010; Mabesa et al., 2013; Manzeke et al., 2017). For many authors, foliar fertilization can be used to satisfy the essential micronutrient requirements in crop grains, increasing yields and the quality of production (Fang et al., 2008).

The significant increase in the concentration of micronutrients in the grain after the foliar application of the experimental biostimulant is very important. This is because, in general terms, cereal crops usually present a low concentration of such micronutrients in their grain (Cakmak, 2010).

Finally, the increase in plants' nutrient uptake may be responsible for the increase in the maize yield, highlighting again the influence of the dose of the biostimulant applied to the plant.

Many authors consider N as the essential element that directly influences the number of grains per corncob, weight of grains and, consequently, in crop yield (Osborne et al., 2002; Ma et al., 2006; Jin et al., 2012). In our experiment, the high concentration of N that was applied to the plant from the BS in the form of N or as amino acids could be responsible for this increase in the crop yields, number corncob and grains per corncob.

5. Conclusions

Foliar fertilization with biostimulants obtained from chicken feathers (rich in organic matter, low molecular weight peptides and amino acids) significantly increased the maize nutrition and, consequently, maize yield and grain quality. This increase was higher whenthe said product was applied three times during the maize vegetative cycle at a dose of 7.2 l ha^{-1}. It is, however, necessary to continue studying the behaviour of this biostimulant on crops in order to optimise both the application rates and the number of applications needed with the aim of obtainingthe maximum responses from the crops when using this compound. In the same way, it is also necessary to study the behaviour of this new organic compound on different soils, since the different physical-chemical properties of the soils can also influence the response of the crop when applying these biostimulants.

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