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RESEARCH ARTICLE

On-farm soybean response to a field foliar applied humic biostimulant at differing cropping environments of Uruguay

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ABSTRACT

Soybean (*Glycine max* (L.) Merr.) is an important crop in Uruguay with increasing production destined to exports that has been negatively affected by drought in the last years. Assessing the consistency of a biostimulant efficacy in field conditions involves multiyear replication across locations. The main objective of this study was to evaluate the effects of a single treatment with a humic biostimulant (HB) field foliar-applied at R3-R4 at dose of 4 L ha^{-1} on soybean crops grown during 8 yr (2014 to 2021) at 156 farm sites with different soil and water conditions on the main country cropping areas. The CONEAT index that measures soil quality and production capacity, and effective rainfall (eR) were assessed for each soybean farm site. The average grain yield varied from 8.83 (2018) to 19.93 g (2017) per untreated plants, and from 10.20 (2018) and 24.01 g (2017) per biostimulant-treated plants. The means for grain yield (g plant^{-1}) by site were poorly related to the CONEAT and the eR indices. Similarly, the yield response to HB treatment (Δ%) was not related to the environmental indices which indicates a relatively constant and positive effect of the biostimulant independent of the environment, considering soil productivity and rainfall. Yield component analysis at the farm trials attributed the yield boosts by the humic largely to increased pod retention without affecting the grain weight. Overall, data analyses from all the farm trials across the years showed that the treatment significantly increased soybean yield by an average of 16.3% relative to the untreated plants. These results confirm that HB can be incorporated into the normal management plan for soybean production in Uruguay.

Key words: Biostimulants, field foliar application, *Glycine max*, humic substances, on-farm trials, soybean.

INTRODUCTION

New sustainable farming practices have become a major goal in agriculture to boost crop productivity and safeguard the environment. In recent years, biostimulants have gained interest as innovative “green” products that could foster plant growth and yield in both optimal and sub-optimal growing conditions. Soybean (*Glycine max* (L.) Merr.), the sixth world most important crop (in terms of tonnage) is of considerable importance in Uruguay. While the harvested area has remained ranging in the last 5 yr from 0.86 to 1.33 Mha, total production has undergone significant interannual variations from 3.16 to 0.28 Mt due to prolonged droughts, but positioning still as the fourth world soybean exporter to China, the main consumer country in the world (FAO, 2020). Legume crop yields tend to vary more than cereal crops largely due to environmental constraints such as drought, which limits symbiotic N fixation (Foyer et al., 2016). Changes in temperature and rainfall can influence soybean yield and most research have focused on planting date, supplementary irrigation and varieties as primary factors to increase grain yield (Araji et al., 2018). Up to 43% decrease in yield has been reported for soybean due to drought stress (Kobraei et al., 2011) and water deficiencies occurring between advanced fruiting and grain filling that happen in Uruguay during February and March. This causes significant reduction up to 50% on the yield (Gimenez, 2014), being the maximum achievable yield for soybeans around 5-6 t ha^{-1} (Rizzo, 2018) with an estimated crop yield gap of 1.2-1.8 t ha^{-1} (Rizzo et al., 2021). The country soybean cultivation in 2020-2021 covered 0.908 Mha planted obtaining a production of 1.7 Mt with an estimated average yield of 1.8 t ha^{-1}, one of the lowest in the last 10 yr due to pronounced drought. Rainfed soybean cultivation shows variations in yield between years and the main Uruguayan production ecoregions: South, northeast and east coasts and the occurrence of water deficit, resulting in interannual variability in the soybean yields (Sawchik and Ceretta, 2005). The yields at the coastal zone were 2.1, 1.9 and 1.9 t ha^{-1} in Colonia, Río Negro, and Soriano, respectively, on the 2020-2021 crop season (Oficina de Estadísticas Agropecuarias, 2021).

Biostimulants are known as, “any substance or microorganism that, when applied to seeds, plants, or the rhizosphere, stimulates natural processes to enhance or benefit nutrient uptake, nutrient efficiency, tolerance to abiotic stress, or crop quality and yield” (Sible et al., 2021). Humic biostimulants (HB) have been used for decades in applications to the seeds, soil or leaves on horticultural crops, but less to field crops to stimulate growth, nutrient absorption, product quality, yield and tolerance to abiotic stress. The positive effects of humic substances have motivated the preparation of commercial products based on isolated natural or artificially synthesized humic substances. The effects, measured by bioassays, immunological tools and molecular genomics under controlled conditions are being explained by signaling of endogenous genes responsible for biosynthesis of protective compounds, attenuating oxidation processes caused by water stress and high temperature (Yakhin et al., 2017, Fleming et al., 2019). Application of vermicompost extracts has resulted in the activation of the antioxidant enzymatic function and increase of ROS-scavenging enzymes to block toxic oxygen radicals produced in plants under stress (García et al., 2012; Du Jardin, 2015; Zandonadi et al., 2016). Dry weights of roots of different plant species increased 22% in response to exogenous application of HB (Rose et al., 2014). Although foliar applications of HB are sometimes adverse (de Santiago et al., 2010; Hartz and Bottoms, 2010), they have been successful to induce higher yields in garlic, tomato and asparagus (Jindo et al., 2020), and legume crops such as dry beans (Kaya et al., 2005), mung-bean (Waqas et al., 2014), soybean (Prado et al., 2016) and cowpeas (El-Hefny, 2010). Extracting humic substances from agro-industrial vermicomposted residues is environmentally promising because it recycles precious C which would be otherwise burnt or landfilled (Savy et al., 2020). However, in the literature there is a paucity of field results on the efficacy of humic biostimulants for multiple locations and over several years (Olk et al., 2022) and the use of HB is not part yet of the agronomic management and still not considered as an effective way to reduce the soybean crop yield gap and/or integrated to other practices as double-cropping and irrigation. Humic biostimulant foliar-field applied in conjunction (tank mix) with herbicides, fungicides and insecticides continue to be studied given a growing market and expectations in practical methods that would allow their incorporation after extensive testing in the soybean sustainable management. This can be pursued as an extensive and low-cost practice to be adopted by soybean farmers only after proper and long-term validation at farm level and technology transfer to soybean farmers. Therefore, the objective of this study was to assess the effect of a foliar-applied HB on the grain yield and yield components of soybean crops grown under differing soil and water conditions over a period of 8 yr.

MATERIALS AND METHODS

On-farm trials

From 2014 to 2021, 156 soybean (*Glycine max* (L.) Merr.) crops at commercial farms were field-foliar sprayed with a humic biostimulant (HB) at 4 L ha^{-1} in the phenological reproductive stage R3-R4. As described by Fehr et al. (1971): R3-R4 stages is the time spam on the soybean reproductive development between plants having pods 0.5 cm long at one of the four uppermost nodes and showing pods 2 cm long at one of the four uppermost nodes with a completely unrolled leaf. Previous work (Izquierdo and García-Pintos, 2021) have shown that the effect of the HB is increased when applied at this stage. In each trial, a strip of 18 m wide across the crop was left unapplied (untreated control). At harvest, five sections of 3 m each were randomly selected from treated and untreated rows, from which 15 up to 81 plants were also randomly selected from each treatment. Individual data per plant as yield (g plant^{-1}) and yield components (pods plant^{-1}, grains pod^{-1}, grains plant^{-1} and 1000 seed weight) were also recorded. During the covered study period, the 156 on-farm trials were distributed on 53 localities of 16 Departments of Uruguay. One hundred four trials were located in the Departments of Río Negro (16), Soriano (44), San José (3), Paysandú (3) and Colonia (37) representing the western coastal zone ("litoral"), the main producer of summer and winter crops at national level. The remnants were distributed in the Departments of Artigas (2), Salto (4), Lavalleja (17), Tacuarembó (9), Florida (8), Treinta y Tres (5), Rivera (3), Cerro largo (2) and Canelones, Flores and Durazno with one each. A map showing the on-farm trials installed at the differing soybean production zones of Uruguay is given at Figure 1. In some trials, the timing of the application was advanced by the farmer due to crop management problems or availability of machinery for timely spraying to an unrecommended vegetative stage (V5) when the biostimulant application is ineffective as shown in previous work (Izquierdo and García-Pintos, 2021).

Figure 1. Map of the biostimulant on-farm trials installed at the differing soybean production zones of Uruguay from 2014 to 2021. Production zone departments: Paysandú, Río Negro, Soriano, Colonia and San José (Western, "Litoral"); Artigas, Salto, Rivera and Tacuarembó (North); Durazno, Flores and Florida (Central); Cerro Largo, Treinta y Tres and Lavalleja (East).

Source and application of the humic biostimulant

The foliar-applied HB was obtained locally from wheat and maize crop residues mixed with horse and cow manure and vermicomposted 6 mo by the earthworm *Einsenia foetida*. The extraction, pH stabilization and dilution of the HB was carried out following agro-industrial methods under Uruguayan license and production registry. The final product, Promobacter Soja (Biocis, Mercedes, Uruguay) was sprayed at 4 L ha^{-1} with automotive sprayers using a volume of water between 60 and 85 L ha^{-1} according to previous work (Izquierdo and García-Pintos, 2021). The HB had the following composition: Total humic extracts 5.72% w/v, humic acids 4.05% w/v, fulvic acids 1.22% w/v, density ± 0.003 g mL^{-1}, pH 6.8.

Environmental indices

The environmental conditions of each on-farm trial across years were assessed by the National Commission for Agroeconomic Study (CONEAT) of Uruguay for soil productivity index, and effective rainfall for INIA Uruguay.

The soil productivity index established the CONEAT index (Lanfranco and Fraga, 2011), at national level, each farm property is assigned a CONEAT productivity index based on predominant soils and considering the slope, geological material and soils use based on aerial photo-cartographic maps (scale 1:20.000). This index integrates homogeneous areas defined by their productive capacity based on the soil fertility in each property and it has a value ranging from 0 to 300 (being 0 and 300, very low and very high productivities, respectively). Although the CONEAT index has a livestock bias since it was calculated based on the productivity of meat and wool on a particular field, it represents a well-accepted estimator of the productive capacity of a determined agricultural field, and it allows to establish the economic and productive value of that field (environment). The average index of productive capacity of the country equals to 100. In this study, each on-farm trial was associated with the corresponding CONEAT index obtained from https://www.gub.uy/ministerio-ganaderia-agricultura-pesca/tramites-y-servicios/servicios/consulta-coneat as a measure of environmental soil variation and production capacity.

The effective rainfall (eR, mm) data of each trial site was provided from GRAS Unit of INIA (Uruguay's National Institute of Agricultural Research) from data of two large networks comprising a meteorological network of 23 stations and a conventional pluviometric network with about 300 stations distributed throughout the country. Being the soybean critical period between the phenological stages R4 and R6 in terms of water requirements, in this study eR covers February and March from 2014 to 2021, respectively.

Agronomic management

In Uruguay, soybean farmers get seed supplies from companies that offer numerous cultivars grouped according to their maturity in terms of short, medium and long cycles. In 2017, an INIA-National Institute of Seeds (INASE) collaboration agreement was signed, in which more than 50 cultivars were evaluated for yield, pod shattering and prevalent diseases, mainly soybean rust (*Phakopsora pachyrhizi*) and root and stem base rot (*Phytophthora sojae*), without concluding specific recommendations on disease tolerance and/or performance (Castro and Baycé, 2018). The foregoing, together with problems of seed availability, make farmers to change the varieties year after year, not being feasible in this work to collect this information and to analyze the response by groups of genotypes at the numerous trial sites. However, the same cultivar was used in each farm trial which makes the comparison between treated and untreated plants valid at each site. At country level farmers use an average 72 kg ha^{-1} seed, obtaining an implantation density of 360.000 plants ha^{-1}, which is affected in some years by the heavy incidence of birds (Fassio et al., 2016). The density of plants in the sites where the samplings of this work were carried out ranged from 190.000 to 230.000 with the density of plants being the same between treated and untreated areas on each on-farm trial site. The agronomic management practices were decided by the field managers, including the cultivar used, N fixation inoculant, planting date, fertilizer rates, pest management, and harvesting practices. Specific agronomic management of soybean in Uruguay is outlined in Sawchik and Ceretta (2005).

Statistical analysis

Data of yield and yield components were analyzed by site for each year and combined over all sites for each year and across years. A linear mixed model was performed to study the effect of biostimulant and year on yield components of soybean. For the mixed model, biostimulant treatment and experimental year were considered as fixed effect, and the location sites was treated as random effects. Significant differences between means of yield components were determined using a paired t-test. The Pearson correlation procedure was used to analyze the relationships between the different yield components for treated and untreated data. Significant differences were determined at $p < 0.05$. The percentage of change ($\Delta\%$) for yield and yield components parameters due to the application of the biostimulant was calculated as follows:

$$\Delta\% = [(\text{Treated} - \text{Untreated})/\text{Untreated}] \times 100$$

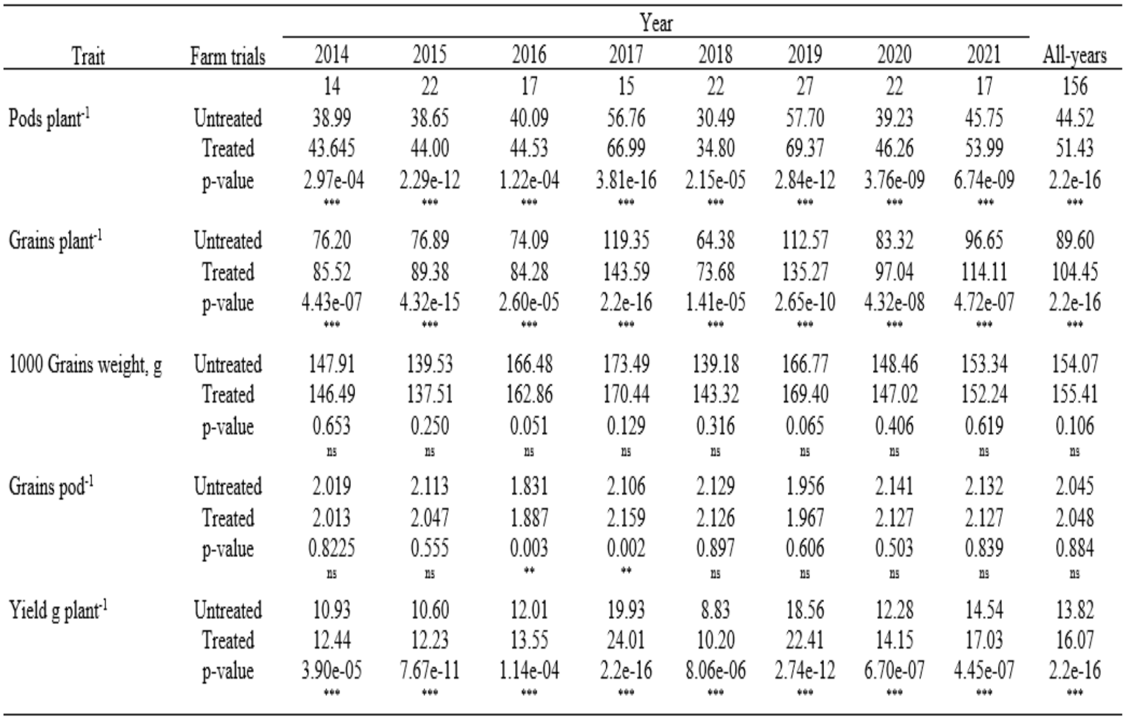
Quadratic and linear regression models were performed to examine the relationship between the environmental indices, means, and percentage of change (Δ%), respectively, for yield and yield components by each site. All statistical analyses were performed in RStudio software (Posit PBC, Boston, Massachusetts, USA) and the following packages were used: “lme4” “car” and “ggplot2”. The interaction effect Location×Year×Treatment was not evaluated since the varieties were not the same and the sites were different each year.

RESULTS AND DISCUSSION

Climatic variables substantially affect crop growth and soil nutrient availability at each site studied causing that the year factor was significant for pods plant^{-1}, grains plant^{-1} and yield g plant^{-1} ($p > 0.05$). In multi-year and treatment combined statistical analyses for the on-farm data, yield components showed significant differences between means for pods plant^{-1}, grains plant^{-1} and yield g plant^{-1} (Table 1). The HB treatment increased pods plant^{-1} and grains plant^{-1} determining 2.32 g plant^{-1} additional, representing +17.27% yield change over the untreated control (Table 1). Analysis of data from all the trials across 8 yr showed that use of HB significantly ($p < 0.001$) increased soybean yield by 2.25 g plant^{-1} or 16.28% compared with the untreated plants (Table 1). The weight of 1000 grains and grain number per pod were not significantly affected.

High and significant correlations between yield per plant and pods plant^{-1} and grains plant^{-1} were found for untreated and treated plants (Table 2). The r coefficients for yield *vs*. 1000 seed weight were low and do not change with the HB treatment application, showing the fact that HB increased yield across the years based on greater pod retention without effects on seed weight.

Table 1. Mean effect of a field-foliar applied humic bioestimulant on yield components and yield per plant of soybean crops over 8 yr and multiple sites per year. ***Significant at $p < 0.001$; ^{ns}: nonsignificant.



Trait	Farm trials	Year								
		2014	2015	2016	2017	2018	2019	2020	2021	All-years
		14	22	17	15	22	27	22	17	156
Pods plant^{-1}	Untreated	38.99	38.65	40.09	56.76	30.49	57.70	39.23	45.75	44.52
	Treated	43.645	44.00	44.53	66.99	34.80	69.37	46.26	53.99	51.43
	p-value	2.97e-04 ***	2.29e-12 ***	1.22e-04 ***	3.81e-16 ***	2.15e-05 ***	2.84e-12 ***	3.76e-09 ***	6.74e-09 ***	2.2e-16 ***
Grains plant^{-1}	Untreated	76.20	76.89	74.09	119.35	64.38	112.57	83.32	96.65	89.60
	Treated	85.52	89.38	84.28	143.59	73.68	135.27	97.04	114.11	104.45
	p-value	4.43e-07 ***	4.32e-15 ***	2.60e-05 ***	2.2e-16 ***	1.41e-05 ***	2.65e-10 ***	4.32e-08 ***	4.72e-07 ***	2.2e-16 ***
1000 Grains weight, g	Untreated	147.91	139.53	166.48	173.49	139.18	166.77	148.46	153.34	154.07
	Treated	146.49	137.51	162.86	170.44	143.32	169.40	147.02	152.24	155.41
	p-value	0.653 ns	0.250 ns	0.051 ns	0.129 ns	0.316 ns	0.065 ns	0.406 ns	0.619 ns	0.106 ns
Grains pod^{-1}	Untreated	2.019	2.113	1.831	2.106	2.129	1.956	2.141	2.132	2.045
	Treated	2.013	2.047	1.887	2.159	2.126	1.967	2.127	2.127	2.048
	p-value	0.8225 ns	0.555 ns	0.003 **	0.002 **	0.897 ns	0.606 ns	0.503 ns	0.839 ns	0.884 ns
Yield g plant^{-1}	Untreated	10.93	10.60	12.01	19.93	8.83	18.56	12.28	14.54	13.82
	Treated	12.44	12.23	13.55	24.01	10.20	22.41	14.15	17.03	16.07
	p-value	3.90e-05 ***	7.67e-11 ***	1.14e-04 ***	2.2e-16 ***	8.06e-06 ***	2.74e-12 ***	6.70e-07 ***	4.45e-07 ***	2.2e-16 ***

Table 2. Correlation coefficients among mean yield and yield components for untreated and foliar-field treated soybean crops with a humic bioestimulant from 156 sites during 8 yr. **, ***Significant at $p < 0.01$ and $p < 0.001$, respectively.

	Grains pod^{-1}	Grains plant^{-1}	1000 Grains weight (g)	Yield g plant^{-1}
Untreated				
Pods plant^{-1}	-0.06***	0.93***	0.08***	0.88***
Grains pod^{-1}	-	0.05***	-0.07***	0.03
Grains plant^{-1}		-	0.01	0.92***
1000 Seeds weight, g			-	0.31***
Treated				
Pods plant^{-1}	-0.13***	0.93***	0.07***	0.88***
Grains pod^{-1}	-	0.20***	-0.20***	0.13***
Grains plant^{-1}		-	0.02	0.92**
1000 Seeds weight, g			-	0.32***

The average percentage of change (Δ%) for yield and yield components varied from 0.14% to 17.20% for 1000 grains weight and grains plant^{-1}, respectively. Only 11 out of 156 sites resulted with negative response (-Δ%) to the HB treatment (Figure 2). Few cases of adverse results have been associated to HB applications (de Santiago et al., 2010; Hartz and Bottoms, 2010) possible due to unrecommended timing of application (Fleming et al., 2019). Due to the great variability of soil fertility conditions and rainfalls, the overall site effect was significant as it was expected. In most of the sites, grouped by production zone, the HB treatment increased yield by an average of +17.01%, although the response at the west coastal zone was more variable relative to the other regions studied. However, the effect of the biostimulant on the three main yield components (pods plant^{-1}, 1000-seeds weight and yield g plant^{-1}) was constant in the four different zones of Uruguay evaluated (Figure 3).

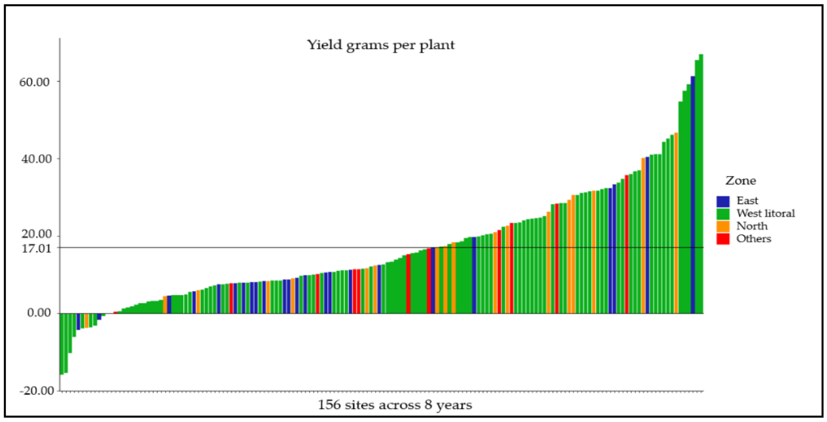


Figure 2. Histogram of the response to treatment with a humic bioestimulant (Δ%) in 156 sites in Uruguay during 8 yr.

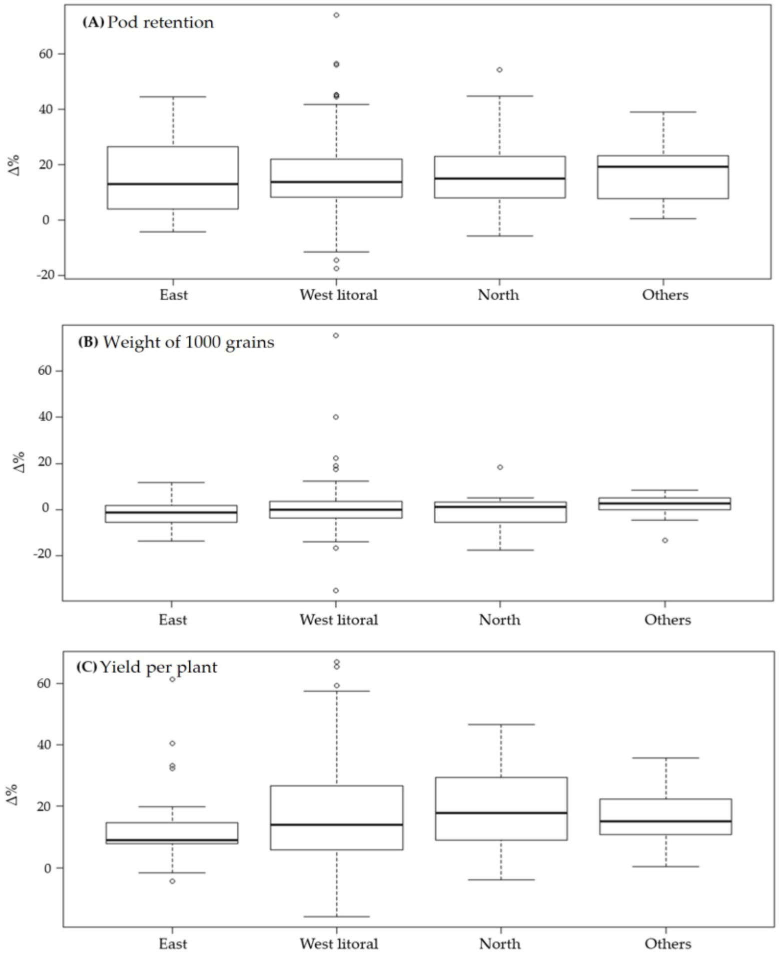


Figure 3. Soybean response to treatment with a humic biostimulant in pod retention (A), weight of 1000 seeds (B) and yield per plant (C) in four production zones over 8 yr in Uruguay (2014-2021). The word "Litoral" is a local expression for the West coastal area.

The best-fit regression model between the means for grain yield (g plant^{-1}) by site and the environmental indices was described by quadratic regression models. The means for grain yield (g plant^{-1}) by site were poorly related to the CONEAT (R^2: 0.028) and eR (R^2: 0.157) environmental index (Figure 4), although the models were significant ($p < 0.01$). In addition, this result indicates that the best grain yields from 2014 to 2021 were obtained when the CONEAT index varies from 200 to 300, and rainfall ranges between 200 and 250 mm in February and March. While the best-fit relationship between the grain yield response to treatment (Δ%) and the environmental indices was described by linear regression models. In the same way, the yield response was not related to the CONEAT (R^2: -0.002) and eR (R^2: -0.003) environmental indices, although a positive and negative trend can be observed for CONEAT and eR indices, respectively (Figure 5). However, the models were nonsignificant for both indices ($p > 0.05$).

The specific modes of action of biostimulants are currently being investigated and there are still restrictions on the reliability of the results, so it is important in the case of HB to determine a repeatable pattern of response for providing economically viable and increased grain yields. This study continues and confirm previous work (Izquierdo and García-Pintos, 2021) with a broader scope in years and number of farm trials in Uruguay. First, our results show that the recommended dose of the HB is effective in driving significant changes in soybean yield components over an extensive range of years and sites, where crops have endured a range of different types of climates and cope with distinct water and high temperature stresses, and/or excessive rainfall and years with very favorable conditions. Reducing the abscission of reproductive organs during the flowering and pod filling period in grain legumes, which are often higher than 50% in common bean, has a direct and positive consequence on legume crops yields (Izquierdo and Hosfield, 1981). Determinate soybeans cultivars from different maturity groups have high levels of reproductive abscission ranging from 41 to 90 harvested pods per plant, and it averaged 57 pods per plant (Wiebold et al., 1981). Field foliar applied HA increased the number of pods and yield (Abd El-Aal and Eid, 2017), consistently in all the years evaluated in this work, confirming previous research results.

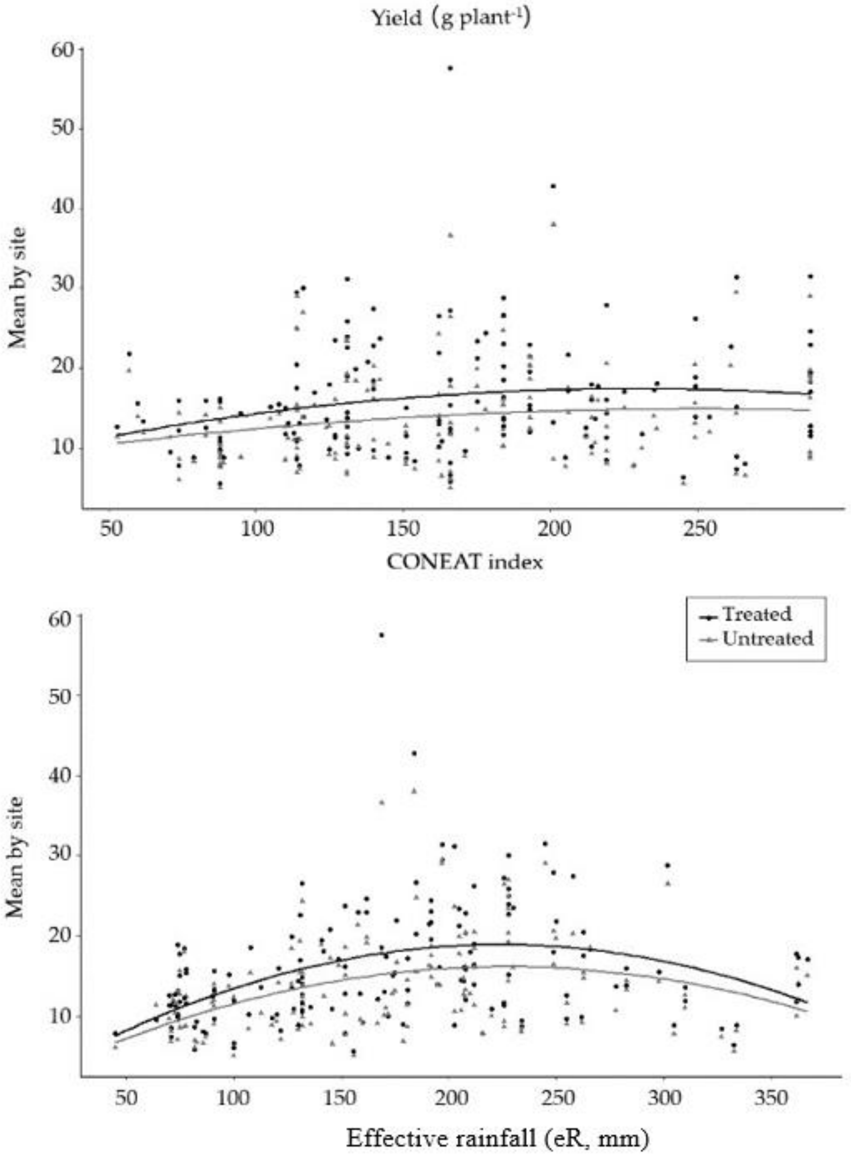


Figure 4. Means for yield in each site related to environmental indices CONEAT and effective rainfall.

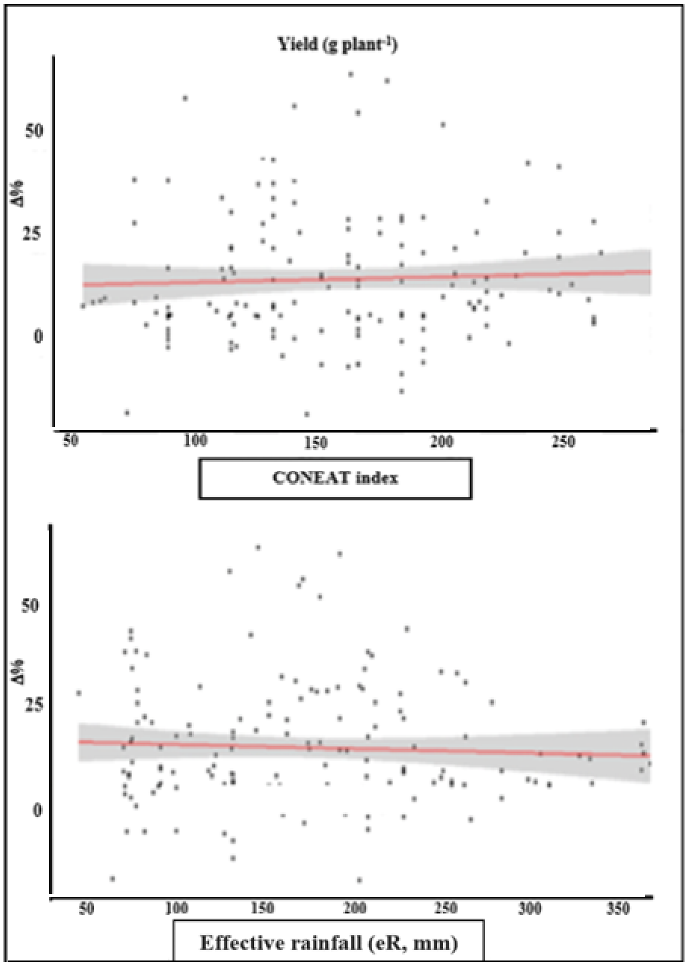


Figure 5. Yield per plant response (Δ%) to treatment with a humic biostimulant as related to environmental indices CONEAT and effective rainfall.

Beneficial effects of HB have been documented since the 1980s, including to be supportive of local circular economy when obtained from vermicompost and extraction, such as from animal manure and crop residues in this work. However, very few studies have been published with results of HBs field-foliar sprayed on rice, soybeans, wheat and barley. This work focused to study in Uruguay the use of HB products in soybean cultivation which is still rare in terms of standard management technologies due to insufficient knowledge on their functions. The usage of HB is still associated to concerns by farmers of lack of consistency on yield improvement. We are aware of the need to have soil and climate data at the local level, which in this case were supplied with indices that, although valid as an estimate of both soil productivity and water availability, did not reflect specifically the productive condition of each tested site. Given the number of years and sites and the limited available resources, it was very difficult to analyze soil water capacity due to the shortage of meteorological instruments at each one of the test sites studied.

The necessary increase in yields required for the growing demand for food and feed is threatened by evolving abiotic and biotic stresses associated with climate change. In this context, the application of tested HB with the capacity to alleviate this type of stress acquires great importance. Current soybean nationwide average yield is still far from its maximum potential and the most restrictive factor is water deficit. Although an increase in rainfall is projected in Uruguay towards 2060, higher temperatures are likely to maintain unchanged the water deficit conditions (Borges, 2019). Irrigation provides costly but higher soybean grain yields relative to the current scenario in Uruguay, in which soybean is mostly produced under rainfed conditions. In addition, the incorporation of new irrigation regions would allow more flexibility in the sowing dates of soybean (Montoya and Otero, 2019).

As reviewed in Uruguay (Fassio et al., 2016), the average yield between the years 2014 and 2018 was 1.882 kg ha^{-1} at Treinta y Tres (east) and 2.357 kg ha^{-1} at Soriano (west coast) while Soriano, Colonia and San José in the west coast zone are the ones with the highest soybean yield nationwide; however, this zone was the most variable in terms of yields per year (Couto, 2019). This agrees with our results given that the west coast zone showed the greatest variation in the yield response to the HB treatment ranging from 60 to -15 (Δ%) in Río Negro and Colonia. In contrast, Treinta y Tres was the one with the lowest yield, but it was more stable over the years.

Considering that the HB treatment increased yield by an average of 17.01%, which is equivalent to 2.32 g plant^{-1}, if we conservatively assume a plant population of 180 000 ha^{-1}, the equivalent yield increase on the basis of the observed data can be estimated at 417 kg ha^{-1} (24% to 36% of the reported yield gap), which would be very important for improving the profitability of the Uruguayan soybean farmers in the different departments and zones, including those with lower yields. The results represent a large geographic coverage on field efficacy of a humic product and demonstrate the capability of a humic to improve soybean growth in high variable yielding conditions. As the base of scientific data on biostimulants being peer-reviewed and published in scientific journals is growing, there is a need to show their efficacy at field conditions in ways that truly matter to soybean farmers. Further agricultural research to increase our basic knowledge on physiology and biostimulant gene signaling for reducing legume crops reproductive abscission will undoubtedly benefit agriculture, as well as conducting extensive field trials, such as in this work.

CONCLUSIONS

An increasing number of commercial plants biostimulants are appearing in the market, but there is still an element of unpredictability with regard to the effect they might have on a row crop considering soil, environmental factors, application rate and time, species, and even the cultivar used. Most of the time they are applied without a long-term local field experimentation on crop response. According to our results, having found a significant, positive, constant response during 8 yr experimentation, this study opens up the possibilities of incorporating the application of the humic bioestimulant (HB) in the ongoing farming practices for soybean cultivation, by integrating it with the applications of other agrochemical products in the phenological stages R3-R4. This simple technology can help to increase yield and reduce the yield gap. We propose the foliar application of the HB on soybeans as an adoptable practice. Given promising farmer prices in the last soybean harvests, the prospects for cultivation and the introduction of new technologies can be auspicious to increase crop profitability. Finally, a unique foliar spray of an HB tested on soybean crops at numerous sites and years with soil and water differing conditions resulted in increased yield due to less shedding of reproductive organs, and HB application is appropriate as an agronomic tool to respond to mild drought conditions and sustain and/or reduce soybean yield losses. Based on the present data it should be considered as a viable and relieving alternative for increasing yields under stressful conditions for Uruguayan soybean farmers and other producing countries. More research on the response of different genotypes to the application of HB is necessary as well as studying, under field conditions, physiological responses such as the evolution of leaf chlorophyll and N content in the reproductive phase, which will allow us to advance in the understanding of the causes of the response to HB on soybean.

Author contributions

Conceptualization: J.I., G.G.P. Field sampling: G.G.P. Statistic analysis: O.A. Writing-original draft preparation: J.I. Writing-review and editing: J.I., A.S., O.A. All authors have read and agreed to the published version of the manuscript.

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