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MAIZE RESPONSE TO SOIL-APPLIED HUMIC SUBSTANCES AND FOLIAR FERTILIZATION WITH POTASSIUM

M. Szczepanek* and E. Wilczewski

Department of Agrotechnology, Faculty of Agriculture and Biotechnology, UTP University of Science and Technology in Bydgoszcz, Poland
*Corresponding author email: Malgorzata.Szczepanek@utp.edu.pl

ABSTRACT

Application of some compounds stimulating growth and physiological processes may have favourable effect on maize productivity. The study aimed to assess the response of maize germination and initial growth to soil-applied humic substances, and the effect of these substances and foliar potassium fertilizer on the maize grain yield. The study was based on a single-factorial field experiment conducted over 2006-2008 in Poland, (17º35′ E; 53º09′ N), on soil classified as mesic Typic Hapludalf, in a randomized block design, in four replications. The effect of the following was evaluated: humus preparation Humistar (12% humic acids and 3% fulvic acids), applied pre-sowing into soil, at a rate of 40 dm^3 ha^{-1} (T1), foliar fertilizer Drakar (25.7% K and 3% N), applied at BBCH 16 and 17, at a rate of 2 dm^3 ha^{-1} (T2), combined application of Humistar and Drakar (T3), and the control (T4). Humistar application resulted in an increase in germination energy, but it did not affect germination capacity or seedlings weight of maize. Humistar or Drakar caused an increase in cob weight, grain proportion in the cob weight and grain yield, as compared with the control. The increase in grain yield in individual years of the study after Humistar application ranged from 1.21 to 8.41% (140-620 kg ha^{-1}), whereas after Drakar from 0.35 to 5.8% (40-430 kg ha^{-1}). Combined application of these preparations caused an increase in grain yield on average from the years in relation to control (by 2.1%), but there was no difference in yield as compared with the application of Humistar or Drakar only. Further studies are necessary to evaluate the effect of these preparations in weak soils with low content of organic matter and nutrients.

Key words: maize, grain, germination, humic substances, leaf greenness index, potassium.

INTRODUCTION

Maize (*Zea mays* L.) is one of three most important cereal crops (besides rice and wheat) in the world in respect of harvested area and grain production. In 2013 grain production was the highest in North America (368 Mt), then in Asia (305 Mt), in South America (127 Mt) and in Europe (119 Mt). The largest producer in the UE is France (15 Mt), whereas Poland takes the 7th position (4 Mt) (FAOSTAT, 2015). Maize grain is commonly used in the food industry and brewery, as an energy plant and a fodder. High demand for maize grain gives an impulse to look for methods to increase the production, mostly by growing yield levels. An increase in yield, particularly under pressure of stress environmental factors, can be obtained by stimulating natural physiological processes affecting the yield-forming properties of plants. One of methods might be the application of preparations containing humic substances. These substances are produced from organic wastes (Ortega and Fernandez 2007; Eyheraguibel *et al.*, 2008; Ertani *et al.*, 2011) or obtained from natural ores, e.g. from leonardite (Verlinden *et al.*, 2009; Shahryari *et al.*, 2011). The studies by Quaggiotti *et al.* (2004) showed that humic acids affect plants in different ways, depending on the molecular size and concentration. The effect of application of humic substances is particularly strong during germination and initial growth of plants (Szczepanek and Wilczewski 2011; Traversa *et al.*, 2014). Studies of maize seedlings show the favourable effect of humic substances on development of roots (Canellas *et al.*, 2008), activity of plasma membrane H^+ATPase, carbohydrates and N metabolism and photosynthesis (Canellas *et al.*, 2013). Studies over the effect of humic substances application in field crops and vegetables confirmed stimulation of the root system development (Ortega and Fernandez 2007) and yield (Verlinden *et al.*, 2009). In maize cultivation, a positive effect of humic substances on the whole plant growth was proved, including roots, stems and leaves (Eyheraguibel *et al.*, 2008).

Also potassium is a factor stimulating physiological processes affecting the quantity and quality of maize grain yield. It regulates water relations in the plant, photosynthesis and enzymatic activity. Potassium deficit may cause a reduction in the number of leaves and their size, and consequently, a decrease in production of assimilates. In conditions of potassium deficit also the transport of assimilates is limited, which reduces the quantity and quality of yield (Pettigrew, 2008). In conditions of good potassium supply for plants, the shoots are strong and more resistant to lodging. Potassium and nitrogen act synergistically in taking up, translocation and use of nutrients that affect the yield and its components. Potassium deficit is usually hardly noticeable, but it strongly reduces maize yield (Bukhsh *et al.*, 2012). Potassium concentration in grain is relatively low, but considerable amounts of this element are found in straw. To produce one thousand kilograms of grain, maize takes up 15.3-15.9 kg ha^{-1} K in aboveground parts (Xu *et al.*, 2013). Effects of potassium fertilization are usually less spectacular than those of nitrogen application, particularly in soils abundant in potassium (Yu *et al.*, 2009). Response of maize to potassium fertilization also depends on genotype, due to the root to shoot ratio as well as the growth rate and potassium uptake during the growth period (Saleh *et al.*, 2010; Bukhsh *et al.*, 2012). The aim of this study was to assess the response of germination and initial growth of maize seedlings to introduction of humic substances into soil, as well as the effect of these substances and foliar fertilization with potassium on the maize grain yield.

MATERIALS AND METHODS

The study was based on field experiment conducted over 2006-2008, in Poland, in the Kuyavian-Pomeranian region (17°35' E; 53°09' N). The soil of the experimental site is classified as mesic Typic Hapludalfs (USDA), and it is characterized by a very high content of available P (173 mg kg^{-1}), a high content of K (185 mg kg^{-1}), both determined with Egner-Riehm′s method and a very high content of Mg (93.3 mg kg^{-1}) determined with Schachtschabel′s method, and neutral reaction (pH in KCl 6.71). The single-factorial field experiment aimed at comparing the effect of humic preparation Humistar (T1), foliar fertilizer Drakar (T2) and the combined application of these preparations (T3) with the control, without treatments (T4) in cultivation of stay-green type maize, cv. LG 2244, for grain. The plots were distributed in the randomized block design in four replications. Humistar is an extract with leonardite – highly oxidized form of brown coal from Canada (Verlinden *et al.*, 2009). It contains 12% of humic acids and 3% of fulvic acids and it has an acidic pH. Humistar was used directly before seed sowing into soil, as the water solution at a rate of 40 dm^3 ha^{-1} dissolved in 250 dm^3 of water. Drakar is a liquid fertilizer containing 31% K_2O and 3% N. It was used at the beginning of June (BBCH 16) and after 7 days from the first treatment (BBCH 17). Each time 2 dm^3 ha^{-1} of fertilizer dissolved in 200 dm^3 of water was applied. In the treatment of combined application of the preparations they were used in the same way as in treatments with a single application. The plot area for harvest was 33 m^2. Maize was sown on the 25th of April in 2006 and 2007 and 26th of April in 2008, at a density of 85 000 grains ha^{-1}. The crop was kept free of weeds by using 900 g ha^{-1} of linuron and 1 g ha^{-1} of iodosulfuron-methyl-sodium. The following rates of autumn fertilization were used: 50 kg ha^{-1} P_2O_5, and 80 kg ha^{-1} K_2O. In spring 72 kg ha^{-1} P_2O_5, 60 kg ha^{-1} K_2O, and 140 kg ha^{-1} N were applied. The leaf greenness index (SPAD) was evaluated using the Chlorophyll Meter SPAD-502. It measures the difference in light absorption with the wavelength of 650 nm, the maximal light absorption by chlorophyll a and b, and 940 nm, light kept by the leaf tissues. The quotient of those differences is displayed as SPAD (*Soil-Plant Analyses Development*) units and is called the leaf greenness index. Measurements were made on 26-28 May (BBCH 14), and 27-29 June (BBCH 51), on 30 fully formed youngest leaves on each plot. The cob weight, the proportion of grain in the cob weight (after separation of grain from maize cobs), grain moisture (with drying method), and grain yield from each plot were determined during maize harvest on the 10th of October 2006, 04th of October 2007 and 08th of October 2008.

Laboratory examinations evaluated the effect of the humic preparation Humistar on maize germination. In each year of the study, on the day of field sowing, seed grain was sown in laboratory, in two rectangular plastic boxes (70x60x10 cm), separately in soil collected from the plots with Humistar, directly after its application and plots without treatment. Soil was collected in equal blocks (35x30x10 cm), in 4 replications of a given treatment, in the total amount corresponding to the volume of boxes. In each container 200 grains were sown, 50 grains in each in four replications. Containers were placed in a room with a temperature of 20 ±1°C, and constant humidity was kept by adding distilled water. The germinating seedlings were counted after 4 and 7 days, to assess of germination energy and capacity, respectively (ISTA, 2006). The weight of shoots and roots was assessed at the end of the experiment, 14 days after sowing based on 20 randomly selected seedlings in four replications for each treatment.

The obtained results were subjected to the statistical analysis. The analysis of variance of single experiments in the years and the synthesis from the years in the mixed model were made using the statistical program Analysis of variance for orthogonal experiments by the University of Technology and Life Sciences in Bydgoszcz. Significance of differences for the results were assessed with Tukey's test, assuming the significance level $P \leq 0.05$.

Distribution of air temperatures and precipitation in the period from April to September was much varied in individual years of the field study (Table 1). The least favourable year for maize was 2006, where in June and July the total precipitation constituted only 1/3 of the average long-term precipitation for that period. In contrast, 2007 was very good for plant growth. The mean monthly air temperature in April, May and June was higher than in the long-term period, and rainfalls in May, June and July were very heavy. Also 2008 was very favourable, where rainfalls, although not very heavy, in conditions of moderate temperatures turned out to be sufficient (no signs of water deficit during the growth or no reduction in maize grain yield were noted).

RESULTS AND DISSCUSSION

Laboratory tests of germination indicated a positive effect of soil application of the preparation Humistar on germination energy (Table 2). However, the maize germination capacity was not dependent on this factor. No effect of introducing the preparation Humistar into soil on the root and shoot dry weight of maize seedlings was shown either. Small effect of humic substances on germination resulted probably from the method of their application into soil. Similarly, Eyheraguibel *et al.* (2008) did not prove the effect of humic substances used for soaking filter paper on which grain was placed on the maize germination capacity. In contrast, in the study by Matysiak *et al.* (2011) maize grains soaked in a solution of humic substances had a higher germination capacity in comparison with the control. However, the same method of application did not affect the root and shoot weight of maize seedlings, but two-time foliar application (at BBCH 12-13 and 14-16) resulted in its increase (Matysiak *et al.*, 2011). In another study, after foliar application stimulation of development of maize lateral roots at the initial growth stage was indicated (Canellas *et al.*, 2013). From the study by Traversa *et al.* (2014) it follows that the response of root and shoot growth to the application of humic substance depends on the source of their origin, concentration and genotype sensitivity.

In the present study, the leaf greenness index, being an indirect measure of chlorophyll content, was not dependent on the application of the preparations (Table 3). In contrast, Matysiak *et al.* (2011) showed a positive effect of humic acids on chlorophyll content in maize leaves. However, in studies by these authors the number and form of application was different (two-time, foliar, at BBCH 12-13 and 14-16). The literature data show that the effect of humic substances on chlorophyll content depends on the applied dose (Ertani *et al.*, 2011), as well as on the source of their origin and is varied in individual genotypes of maize (Shahryari *et al.*, 2011).

In the present study, no significant effect of the applied preparations on the number of plants and cobs per plot or the shoot height was indicated (not presented data). However, the application of Humistar or Drakar caused, on average in the long-term period, an increase in the cob weight and grain proportion in the cob weight in comparison with the control (Table 4). Moreover, on average in the long-term period, grain yields obtained after the application of Humistar or Drakar and combined application of both preparations were similar and significantly higher than in the control (Table 5). However, no significant effect of the studied preparations on grain humidity at harvest was indicated.

Favourable effect of application of humic substances on maize yield indicated in the present study is also reported by other authors (Canellas *et al.* 2013; Daur and Bakhashwain, 2013). In the present study, however the increase in grain yield after application of Humistar was relatively small (4%). Considerably higher growth in grain production, amounting to as much as 17%, was reported in the study by Canellas *et al.* (2013). In studies by these authors, however, humic preparations were applied foliar. The maize response in our study could also be limited due to favourable soil conditions and a relatively small dose of the preparation. Also Verlinden *et al.* (2009) regards the application of humic preparations in good soil conditions as the cause of poor response of maize. Daur and Bakhashwain (2013), in turn, indicated that only after the application of high doses of humic substances maize had more leaves and gave higher yield of green and dry mass. According to Ortega and Fernandez (2007), recommended doses of humic preparations should be verified, since considerable agronomic effects were obtained only at 15-26 times higher doses than those indicated by the producers.

In the present study, maize showed a positive response (increasing the cob weight, proportion of grain in the cob weight and grain yield) to foliar application of the potassium fertilizer Drakar (Table 4 and 5). Also the literature data indicate an increase in the maize aboveground weight and grain yield as a result of potassium fertilization (Yu *et al.*, 2009; Ahmad *et al.* 2011; Liu *et al.*, 2011; Maleki *et al.*, 2014; Zhang *et al.*, 2014). Moreover, some researchers claim that fertilization of maize with potassium can minimize the effects of draught, since potassium has a favourable effect on osmotic regulation, transpiration rate, and water uptake by roots (Bukhsh *et al.*, 2012; Aslam *et al.* 2014; Zhang *et al.*, 2014). In the present study, the unfavourable rainfall distribution, particularly the water deficit in June in 2006 (Table 1), caused the reduction in grain yield by 28,8-32,4% as compared with the other years of the study (Table 5). Unfortunately, two-time foliar application of the potassium fertilizer Drakar at the beginning and in the middle of June did not alleviate the effects of rainfall deficit, probably because the humidity stress was too strong. It was deepened by limited precipitation at high air temperatures in July.

In the present study, as a result of the foliar application of Drakar, grain yield was increased on average in the long-term period by 260 kg ha^{-1} (Table 5). This relatively weak response of the maize grain yield to foliar potassium application could result from high soil abundance in potassium and a rather high rate of soil fertilization with this element. According to Clover and Mallarino (2013), as well as Bruns and Ebelhar (2006), potassium fertilization increased the maize grain yield only at a small content of this element in soil. The reason for the poor effectiveness of foliar potassium fertilization may also be too small leaf area capable of absorption of components during the application (Ling and Silberbush 2002).

Based on the results obtained from three-year field study, it can be stated that the soil application of the humus preparation Humistar and/or the liquid potassium fertilizer Drakar even in favourable soil conditions brought an increase in cob weight, grain proportion in the cob weight and grain yield, as compared with the control. The highest increase in yield occurred after the application of Humistar, ranging from 140 to 620 kg ha^{-1}, depending on the study year. Further studies are necessary to evaluate the effect of these preparations in soils with low content of nutrients and humus substances.

Table 1. Meteorological conditions

Month	2006	2007	2008	Mean from 1980-2008
		Mean air temperature [°C]		
April	7.8	9.9	8.0	8.3
May	12.8	14.3	13.7	14.0
June	17.2	18.2	17.3	16.8
July	22.6	18.0	18.9	19.1
August	17.4	18.1	17.7	18.6
September	15.9	12.7	12.7	13.2
Mean	15.6	15.2	14.7	15.0
		Total precipitation [mm]		
April	60.4	16.6	40.0	29.6
May –	67.4	83.5	13.8	47.4
June	14.6	111.7	19.6	67.6
July	28.5	88.9	65.0	70.7
August	164.0	29.4	101.0	59.8
September	55.6	39.5	27.3	45.2
Total	390.5	369.6	266.7	320.3

Table 2. Germination and seedling weight, mean for 2006-2008

Characteristics	Treatments		LSD (P≤0.05)
	Humistar	Control	
Germination [%]			
after 4 days (energy)	99.58	96.75	2.0
after 7 days (capacity)	99.58	99.67	ns‡
Dry matter of seedlings† [g]			
Shoots	2.225	2.247	ns
roots	0.552	0.542	ns

‡ns – non significant; †20 seedlings, 14 days after sowing

Table 3. Leaf greenness index [SPAD], in 2006-2008.

Year	Treatments				LSD (P≤0.05)
	Humistar	Humistar+Drakar	Drakar	Control	
2006	22.6	23.5	23.1	22.2	ns‡
2007	37.2	36.8	35.9	36.2	ns
2008	32.0	35.6	33.9	34.3	ns
Mean	30.6	32.0	30.9	30.9	ns
2006	48.4	48.7	49.9	48.8	ns
2007	39.3	39.6	40.0	40.1	ns
2008	49.6	49.2	47.5	49.1	ns
Mean	45.8	45.8	45.8	46.0	ns

‡ns - non significant

Table 4. Cob weight and proportion of grain in the cob weight in 2006-2008.

Year	Treatments				LSD (P≤0.05)
	Humistar	Humistar + Drakar	Drakar	Control	
2006	13140	12430	13040	12420	ns[‡]
2007	19200	19000	18650	18620	ns
2008	18020	17790	18230	17630	ns
Mean	16790	16410	16640	16220	322
2006	77.15	76.25	75.80	75.25	ns
2007	78.58	77.88	78.40	78.28	ns
2008	85.51	85.66	85.80	85.95	ns
Mean	80.41	79.93	80.00	79.83	0.153

[‡]ns - non significant

Table 5. Grain yield and grain moisture in 2006-2008

Year	Treatments				LSD (P≤0.05)
	Humistar	Humistar + Drakar	Drakar	Control	
2006	7990	7820	7800	7370	ns[‡]
2007	11610	11340	11190	11150	316
2008	11670	11530	11850	11530	ns
Mean	10420	10230	10280	10020	202
2006	33.05	32.72	32.95	33.07	ns
2007	32.77	32.72	33.22	33.07	ns
2008	30.50	30.37	30.37	30.00	ns
Mean	32.11	31.94	32.18	32.05	ns

[‡]ns - non significant

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