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The efficacy of micronano particles across NPK doses and densities on maize growth and yield in Vietnam

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Abstract:

Increasing the efficiency of maize production in Vietnam is a prerequisite for increasing the quantity of maize for animal feed. With a view to reducing nitrogen-phosphorus-potassium (NPK) doses for maize production, a two-factor experiment using complex micronano particles across three NPK fertiliser doses and three densities on maize hybrid PAC999 was conducted following a randomized complete block design with plot size of 21.84 m^2, in Binh Dinh province of Vietnam from May to September 2017. Three NPK fertiliser doses (kg/ha) constitute the first factor, as P1: 156 N - 86 P_2O_5 - 84 K_2O (100% normal dose); P2: 140 N - 77 P_2O_5 - 76 K_2O (90%); and P3: 125 N - 69 P_2O_5 - 67 K_2O (80%). Three densities constitute the second factor, as M1: 71,429 plants/ha (100% normal density); M2: 64,935 plants/ha (90%), and M3: 57,143 plants/ha (80%). Nine combinations of M and P were developed into nine treatments; the control involved spraying with water rather than nano foliar fertiliser. Nano particles were applied as a foliar fertiliser solution at 20 days after sowing with 300 litres/ha, 30 days after sowing with 500 litres/ha, and 40 days after sowing with 700 litres/ha. The results show that 80% and 90% of normal NPK doses combined with 90% and 80% normal density produced a grain yield of 6.52 and 6.63 tons per ha, respectively, which is 14-16% higher than that of the control (5.71 tons/ha). The results of the experiment were demonstrated on large plots of 500 m^2 each in summer/autumn 2018 in Binh Dinh and Hau Giang provinces, spring/summer 2018 in Long An, and winter/spring 2017-2018 in Dong Nai province. Over an area of 500 m^2, 75% of farmers' NPK doses and the micronano solution were applied; the control involved applying 100% NPK doses. The results of the demonstration showed that the grain yield of maize (tons/ha) with the nano fertiliser solution (9.44 in Binh Dinh, 9.2 in Dong Nai, 9.52 in Long An, and 8.7 in Hau Giang) was 0.95, 0.28, 0.68, and 0.3 tons higher than that of the control (8.49, 8.92, 8.84, and 8.4 tons/ha, respectively).

Keywords: **demonstration, factors, fertiliser, foliar, micronano.**

Classification number: **3.1**

Introduction

Maize production in Vietnam is not only facing biotic and abiotic stresses, but also high costs of production due to minimal application of advanced technological fertilisers, low levels of mechanization, and post-harvest losses. Survey data from FAO Statistical Data [1] shows that the cost of production for one ton of maize grain was US$138 in Brazil, US$142 in the USA, US$225 in Thailand, US$275 in the Philippines, US$282 in Indonesia, but US$329 in Vietnam. Regarding the components involved in maize production in Vietnam [2], the average cost of fertilisers constitutes 30-35.5% of total costs; labour costs constitute 38.2%; mechanisation (machine hire) is between 5.0 to 8.7%; and pesticides vary from 4.9 to 12.2%.

Due to limited land area for maize production in Vietnam, one of the options that has emerged to increase the yield to meet demand is to study the efficacy of micronano particles (40-80 nm) manufactured by the Institute of Environmental Technology in the form of a foliar fertiliser for spraying maize plants in Binh Dinh province. The experimental results were demonstrated in Binh Dinh, Hau Giang, Long An, and Dong Nai provinces of Vietnam.

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Materials and methods

Materials

Seeds of maize hybrid PAC999 were provided by Advanta Seed Company. The micronano particles were manufactured by the Institute of Environmental Technology of the National Academy of Science and Technology of Vietnam. Nano size is 40-80 nm and the nutrient solution was applied in the form of foliar a fertiliser spray. The components of nano particles are listed in Table 1.

Methods

Experimental design: the plants in the experiment were planted as three replications on plots of 21.84 m^2 (5.2 m x 4.2 m), laid out in a randomized complete block design. Each plot was planted with six rows, each of which were 5 m long, with 0.7 m between the rows and 0.2 m between each plant in a row. The experiment consisted of 10 treatments of two factors. The first factor comprised three fertiliser doses: P1: 156 N - 86 P_2O_5 - 84 K_2O (100% normal dose); P2: 140 N - 77 P_2O_5 - 76 K_2O (90%); and P3: 125 N - 69 P_2O_5 - 67 K_2O (80%). The second factor comprised three densities: M1: 71,429 plants/ha (100% normal density); M2: 64,935 plants/ha (90%), and M3: 57,143 plants/ha (80%). Nine combinations of M and P were developed into nine treatments; the control involved spraying water instead of nano nutrients on P1M1. The three sprays of foliar nano nutrients are also presented in Table 1.

Duration of experiment: 24 April to December 2018. Location of experiment: Nhon Hau commune, An Nhon town, Binh Dinh province, Vietnam.

Temperature and rainfall at the sites of the experiment in Binh Dinh and demonstrations in Dong Nai, Long An and Hau Giang provinces: according to weather and climate data from Climate-Data.Org (2019) [3], in Binh Dinh province in the southern central region, the average annual temperature is 26.8^{0}C. About 1,630 mm of precipitation falls annually. The warmest month of the year is August, with an average temperature of 30.0^{0}C. In January, the average temperature is 23.0^{0}C. Such data for the provinces in which the results of the experiment demonstrated is presented in Fig. 1.

In Dong Nai province, in the southeastern region, the average annual temperature is between 23.9 and 29.0^{0}C, somewhat lower than the standard level of the tropical regions (26-30^{0}C). Rainy days in a year number between 120 and 170, with total rainfall of some 1,500-2,750 mm (Fig. 1). The average humidity is around 80-82%; in the dry season it is 10-12%, lower than in the rainy season; humidity varies considerably between the areas. In Hau Giang province, in the Mekong delta region of Vietnam, the summers are much rainier than the winters. The temperature here averages 27.1^{0}C. The average annual rainfall is 1,589 mm (Fig. 1). In Long An province, the summers are much rainier than the winters. The average annual temperature is 27.5^{0}C. About 1,809 mm of precipitation falls annually (Fig. 1).

Table 1. Constituents of foliar micronano stock solution sprayed on maize plants.

Nutrient	1st spray	2nd spray	3rd spray
N	200,000	150,000	150,000
P	200,000	50,000	50,000
K	200,000	450,000	450,000
Mg	15,700	11,800	11,800
S	20,000	14,000	14,000
$Si(OH)_4$	50,000	50,000	50,000
Fe	3,600	7,100	7,100
Cu	400	4,700	4,700
Zn	102,260	111,800	11,800
Mn	1,800	11,200	11,200
B	1,100	5,700	90,700
Mo	60	110	110
Se	20	20	20
Cytokinin	25.2	25.2	25.2
Gibberellin A3	14	14	14
IAA	14	14	14
IBA	14	14	14
Amino Acid	12,000	12,000	12,000
Chitosan	2,500	2,500	2,500

Note: 1st spray1: 1 litre of stock solution/ha, at six-leaf stage (22-25 days after sowing, DAS), diluted in 300 litres of water; 2nd spray: 2 litres of stock solution/ha, at 12-leaf stage (35-37 DAS), diluted in 500 litres of water; 3rd spray: 2 litres of stock solution/ha, at VT stage - a vegetative growth stage description that all branches of tassel visible (47-50 DAS), diluted in 700 litres of water.

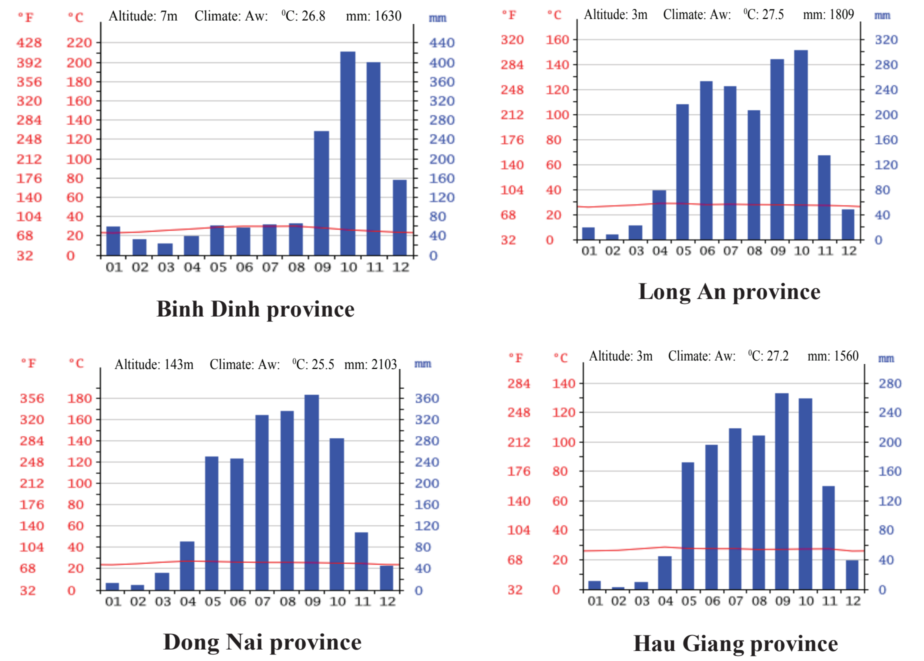

Fig. 1. Temperature and rainfall at the sites of the experiment in Binh Dinh and demonstrations in Dong Nai, Long An and Hau Giang provinces, 2017-2018.

Demonstration fields for applying nano foliar fertiliser: the plot size of the demonstration field was 500 m^2 for PAC999, with 75% NPK doses (126 kg N - 75 kg P_2O_5 - 75 kg K_2O/ha) and nano solution applied; in the control plot, 100% NPK doses (180 kg N - 100 kg P_2O_5 - 100 kg K_2O/ha) without nano solution were applied. Both testing and control fields were planted with 57,143 plants/ha (80%).

The method for spraying the nano foliar fertiliser was similar to that applied in the experiment. The locations of the demonstrations were Binh Dinh, Hau Giang, Long An, and Dong Nai provinces in Vietnam, in summer/autumn 2018 and winter/spring 2018-2019.

Data collection and analysis: for the experiment, data was collected from the two middle rows. Guidelines from CIMMYT were applied to the collection of agronomy and yield characteristic data [4]. For the demonstration plot, five grain samples were taken from the field and the data collected was based on five samples across the field of the experimental and control plots. The area of each sample was 11.0 m^2 (three rows x 5.25 m long x 0.7 m between rows).

MS Excel and IRRISTAT 5.0 were used for ANOVA analysis and the Duncan multiple test was used for comparing the means.

Time and place of the study

The experiment was conducted in summer/autumn season in Binh Dinh province. Large-scale demonstrations were implemented in summer/autumn 2018 in Binh Dinh and Hau Giang provinces, as well as in spring/summer 2018 in Long An province and winter/spring 2017-2018 in Dong Nai province.

Results

Results of soil analysis in Binh Dinh for experiment and in Dong Nai, Long An and Hau Giang provinces for demonstrations

According to the soil micronutrient classification for meeting demand for crop production in Vietnam by Pham Dinh Thai (2017) [5], the micronutrient content of soil in Binh Dinh is low in Mn, Zn, B, and high in Cu. The soil in Hau Giang province is acidic, poor in K, very poor in P, average in total N, with available Mn, Cu, and Zn, and rich in B. The soil in Long An province is acidic, very poor in total N, poor in K and B, average in Zn, and rich in P. The soil in Dong Nai province is slightly acidic, poor in total N total, with available Cu, average in Zn and B, and rich in available K (Table 2).

Table 2. Result of soil analysis in four provinces in Vietnam.

Criteria	Unit	Binh Dinh	Hau Giang	Long An	Dong Nai	Testing methods
pH (KCl)		4.91	3.45	4.31	5.19	TCVN 5979-2007
N (total)	%	0.108	0.177	0.091	13.3	TCVN 6498-1999
P (available)	mg/kg	44.8	14.2	157	454	TCVN 8942-2011
K (available)	mg/kg	48	63	53	226	TCVN 8662-2011
B (available)	mg/kg	0.775	0.405	0.38	0.56	Australian Manual for Soil and Water Analysis, 2011 (12C1)
Cu (available)	mg/kg	1.88	1.85	5.3	8	TCVN 7727-2007
Zn (available)	mg/kg	2.81	4.46	9.0	33.7	TCVN 7727-2007
Fe (available)	mg/kg	*	*	1.68	1.8	
Mn (available)	mg/kg	21.8	11.6	0.301	*	TCVN 7727-2007

Source: soil analysis laboratory of the Institute of Agricultural Sciences for Southern Vietnam. Note: *: not available.

Results of the experiment

Efficacy of micronano nutrients across densities and NPK fertiliser applications on the growth and development of maize hybrid PAC999 in Binh Dinh province: there was no significant difference between treatments for the number of days (Table 3) from sowing to emergence (6 days) and from sowing to pollen-shedding (50-51 days), meaning that no effects of nano across plant densities and NPK doses on growth of maize were found. There was no clear effect of the micronano nutrients across fertiliser applications and densities on plant height of the PAC999 maize hybrid. At 15 DAS, the shortest plant height was that of treatment M1P1 sprayed with micronano solution (35 cm), 89% compared to the control (M1P1 sprayed with water only); at 45 DAS, the shortest treatments were M1P1, M2P2, and M3P3 (141-142 cm); and at maturity the shortest treatment was M2P3 (192 cm). These may be the result of soil variation being higher than that of the fertiliser, density, and nano effects (Table 3).

Table 3. Effects of micronano nutrients across densities and fertiliser applications on the growth and development of maize hybrid PAC999 in Binh Dinh province, 2017.

Treatments	Days to emergence (days)	Days to pollen shedding (days)	Plant height					
			15 DAS		*45 DAS*		*At maturity*	
			cm	*% check*	*cm*	*% check*	*cm*	*% check*
M1P1	6	50	35c	89	141bcde	92	190ab	100
M1P2	6	50	39ab	98	156a	101	191a	101
M1P3	6	51	38abc	95	147abc	96	192a	102
M2P1	6	50	35bc	89	133e	87	189ab	100
M2P2	6	50	39ab	98	142bcde	92	191a	101
M2P3	6	50	37abc	93	147abcd	95	184b	97
M3P1	6	50	38abc	95	147abcd	95	192a	101
M3P2	6	50	36abc	90	138de	90	189ab	100
M3P3	6	50	36abc	90	141cde	92	192a	102
Control	6	50	40a	100	154ab	100	189	100
CV (%)			6.24		4.51		1.97	
$LSD_{0,05}$			3.99		11.74		6.46	

Note: Duncun's multiple range test: similar character in the column (a, or b, c, d or e) means no significant difference among the average data.

Effects of micronano nutrients across plant densities and fertiliser application doses on abiotic and biotic stress tolerance: for the summer/autumn maize crop in Binh Dinh (2017), there were no storms or typhoons and therefore the maize plants were not broken, resulted in good plant aspects (score of 1). A similar trend can be seen for insects and diseases of maize crops in this season in Binh Dinh province (Table 4).

Table 4. Effects of micronano nutrients across densities and fertiliser applications on plant aspect and infection by insects and diseases of maize hybrid PAC999 in Binh Dinh province, 2017.

Treatments	Plant aspect (1-5)	Stalk lodg (%)	Root lodg (%)	Stem borer (%)	BLSB (%)	*H. turci* (%)	Rust (%)
M1P1	1	0	1	1	0	0	0
M1P2	1	0	1	1	0	0	0
M1P3	1	0	1	1	0	0	0
M2P1	1	0	1	1	0	0	0
M2P2	1	0	1	1	0	0	0
M2P3	1	0	1	1	0	0	0
M3P1	1	0	1	1	0	0	0
M3P2	1	0	1	1	0	0	0
M3P3	1	0	1	1	0	0	0
Control	1	0	1	1	0	0	0

Note: Lodg: lodging; *H. turci*: *helminthosporium turcicum*; BLSP: banded leaf spot blight.

Effects of micronano nutrients across densities and fertiliser applications on yield components of maize hybrid PAC999 in Binh Dinh province: the ratio of ears per plant varied from 0.97 to 1.02, leading one to infer that there was no effect of the nano solution across treatments of densities and fertiliser applications (Table 5). The shelling percentage of treatment M3P1 (57,143 plants/ha and 156 kg N - 86 kg P_2O_5 - 84 kg K_2O/ha (100% normal dose) was highest, at 84%, 5% superior to the control, to which 156 N - 86 P_2O_5 - 84 K_2O was applied without nano fertiliser at a density of 71,429 plants/ha (100% normal density). This can be explained by the fact that at low density and the normal NPK dose, with the support of nano fertiliser, a maize plant could absorb enough nutrients so that the shelling percentage was the highest. For the treatment of M3P2: 57,143 plants/ha (80%) and 140 kg N - 77 kg P_2O_5 - 76 kg K_2O (90%) with the support of the nano fertiliser, the number of kernels/row, kernel rows/ear, and 1,000 kernel weight were 105%, 104%, and 106%, respectively, higher than that of the control treatment. All these factors resulted in the grain yield of treatment M3P2 (6.63 MT/ha) being significantly higher than that of the control treatment (5.71 MT/ha) ($p<0.05$), or 116% higher than the control. This result was wholly derived from the effect of micronano nutrients across three levels of NPK doses and three levels of plant density because there were no significant interaction effects of NPK doses ($p=0.92>0.05$) and density ($p=0.249>0.05$) (Table 6).

Table 5. Effects of micronano nutrients across densities and fertiliser applications on yield components of maize hybrid PAC999 in Binh Dinh province, 2017.

Treatment	Ears/ plant	Kernel/rows		Rows/ear		1,000 kernel weight		Shelling percentage		Grain yield	
		Kernel	*% check*	*Row*	*% check*	*g*	*% check*	*(%)*	*% check*	*MT/ha*	*% check*
M1P1	1.00	36	102	12.1ab	100	343ab	104	81	102	6.06bc	106
M1P2	0.98	35	100	12.1ab	100	344ab	104	78	99	5.76c	101
M1P3	0.98	37	105	11.9b	98	342ab	103	79	100	6.25abc	109
M2P1	1.02	35	101	12.0ab	99	334ab	101	79	100	5.75c	101
M2P2	1.02	36	102	11.9b	98	347ab	105	79	100	5.78c	101
M2P3	1.01	36	102	12.1ab	100	350a	106	80	101	6.52ab	114
M3P1	0.98	35	101	12.4ab	102	348a	106	84	105	6.25abc	110
M3P2	1.02	37	105	12.5a	104	351a	106	79	100	6.63a	116
M3P3	0.97	36	103	12.1ab	100	350a	106	79	100	6.04bc	106
Control	0.99	35	100	12.1ab	100	331b	100	79	100	5.71c	100
CV (%)		2.67		3.63		2.75				5.17	
$LSD_{0.05}$										0.26	

Note: Duncun's multiple range test: similar character in the column (a, or b, c) means no significant difference among the average data.

Table 6. Analysis of variance in grain yield of micronano foliar solution experiment across NPK applications and densities of PAC999 in Binh Dinh province.

Source of variation	DF	Sum of squares	Mean	F ratio	PROB	ER
Replication	2	2.27767	1.13884	18.63	0.000	6
Plant Density	2	.391385	.195692	2.01	0.249	3
Replication-Plant density	4	.390355	.975886E-01	1.60	0.238	6
NPK doses	2	.996476E-02	.498238E-02	0.08	0.922	6
Plant Density-NPK doses	4	1.62549	.406371	6.65	0.005	6
Residual	12	.733629	.611357E-01			
Total (corrected)	26	5.42849	.208788			

Results of the demonstration field applied with micronano foliar fertiliser

Results of the demonstration field application of nano foliar fertiliser to PAC999 maize hybrid in Binh Dinh province: the average plant height of PAC999 (Table 7) was similar in the pilot field with and without nano fertiliser application (209.5-208.1 cm). However, the average grain moisture in the pilot field (30.9%) was much lower than that of the field without nano fertiliser (33.0%). Due to high drying rate of kernels, the average grain weight of 1,000 kernels in the pilot field with nano fertiliser (337 g) was significantly higher than that of the field without the nano application (312.8 g). The grain yield in the pilot field (9.44 MT/ha) was significantly higher than that of the field without nano fertiliser (8.49 MT/ha).

Table 7. Results of the demonstration field applied with micronano foliar fertiliser to PAC999 maize hybrid in Binh Dinh province, 2018.

Plot	Samples	Plant height (cm)	Grain moisture at harvest (%)	1,000 kernel weight (g)	Grain yield (MT/ha)
75% NPK doses with nano application	1	219.8	31.6	335.0	9.23
	2	221.8	28.5	371.6	9.45
	3	224.0	31.2	304.0	9.59
	4	218.3	31.6	329.0	9.68
	5	163.8	31.6	345.7	9.19
	Mean	209.5	30.9	337	9.44
100% NPK does without nano application	1	219.3	33.4	296.6	8.48
	2	219.0	34.6	312.1	8.17
	3	223.8	30.9	301.8	8.10
	4	217.3	35.9	324.6	8.61
	5	161.5	30.6	328.4	9.09
	Mean	208.1	33.0	312.8	8.49

Grain yield of PAC999 maize hybrid in the demonstration fields in Hau Giang, Long An, and Dong Nai provinces: the data in Table 8 shows that the grain yield of PAC999 maize hybrid with the application of 75% NPK dose (126 kg N - 75 kg P_2O_5 - 75 kg K_2O/ha) with nano fertiliser in Hau Giang, Long An, and Dong Nai provinces (9.2, 9.52, and 8.7 tons/ha, respectively) was 0.28, 0.68, and 0.3 tons higher than the control with 100% of NPK doses (180 kg N - 100 kg P_2O_5 - 100 kg K_2O/ha) (8.92, 8.84, and 8.4 tons/ha, respectively).

Table 8. Grain yield of PAC999 in demonstration plots in Hau Giang, Long An, and Dong Nai provinces, 2017-2018 (MT/ha).

Demo plot	Samples	Hau Giang summer/ autumn 2018	Long An winter/spring 2017-2018	Dong Nai winter/spring 2017-2018
Farmer practice without nano	1	8.59	8.59	8.93
	2	9.26	9.28	8.52
	3	8.85	9.26	8.03
	4	8.84	8.85	8.32
	5	9.05	8.84	8.23
	Mean	8.92	8.96	8.40
75% NPK plots with nano	1	8.61	10.0	8.96
	2	9.22	9.28	8.53
	3	9.34	8.81	8.73
	4	9.05	9.77	9.07
	5	9.8	9.73	8.15
	Mean	9.2	9.52	8.7

Table 9. Efficacy of nano foliar fertiliser on maize production in some provinces of Vietnam, 2017-2018.

Criteria	Binh Dinh	Dong Nai	Long An	Hau Giang
1. Total cost (1,000s VND/ha)				
With nano (75% NPK)	30,675	25,686	27,065	25,836
Without nano (100% NPK)	29,075	25,695	25,355	25,355
Difference	+1,600	-9	+1,710	+481
2. Grain yield (tons/ha)				
With nano (75% NPK)	9.44	8.70	9.52	9.20
Without nano (100% NPK)	8.49	8.40	8.96	8.92
Difference	0.95	0.30	0.56	0.28
3. Income (1,000s VND/ha)				
With nano (75% NPK)	51,920	46,110	50,350	48,760
Without nano (100% NPK)	46,695	44,520	47,435	47,276
Difference	5,220	1,590	2,915	1,484
4. Net benefit (1,000s VND/ha)				
With nano (75% NPK)	21,245	20,424	23,465	22,923
Without nano (100% NPK)	17,620	18,825	22,080	21,921
Difference	3,625	1,599	1,385	1,002
5. Cost of production (VND/kg)				
With nano (75% NPK)	3,249	2,973	2,843	2,806
Without nano (100% NPK)	3,424	3,058	2,727	2,842
Difference	-175	-65	+116	-36

The data in Table 9 shows that treatments with micronano spraying and 75% NPK had the cost of production almost similar to that compared to the treatments without micronano spraying and 100% NPK in Binh Dinh, Dong Nai, Long An, and Hau Giang provinces with the difference only 175, 65, 116 and 36 VND/kg, respectively. However, thanks to the effect of the micronano solution, the grain yields were 0.95, 0.30, 0.56, and 0.28 tons/ha higher than that of treatments without nano fertiliser and 100% NPK in Binh Dinh, Dong Nai, Long An, and Hau Giang provinces, respectively. This effect generated higher income for producers - 5,220,000, 1,590,000, 2,915,000 and 1,484,000 VND/ha - and higher net benefits - 3,625,000, 1,599,000, 1,385,000, and 1,002,000 VND/ha in Binh Dinh, Dong Nai, Long An, and Hau Giang provinces, respectively.

Discussion

In our study, there was no significant difference between treatments for number of days from sowing to emergence and from sowing to pollen-shedding and no clear effect of the micronano solution across NPK doses and densities on plant height. In a study conducted with maize seeds treated with Fe nano fertiliser, some aflatoxin substrates at harvest could be inhibited and Fe nano fertiliser inhibited disease microorganisms of maize [6, 7]. Nanoparticles were also found to improve the balance between oxidants and antioxidants status of treated plants. Solanki, et al. (2015) and Suriyaprabha, et al. (2012) [8, 9] reported that, for maize seeds treated with SiO nanoparticles, the maize plants had significantly enhanced plant dry weight and enhanced levels of organic compounds such as proteins, chlorophyll, and phenols. The results of our study may be due to soil variation, which was higher than effects of the fertiliser, density, and the nano solution.

Churilov (2010) [10] has found that nano particles stimulate enzyme systems that result in more efficient biological and physiological cycles and stronger antibiotic systems for better seed germination and plant growth. The results of an experiment in Russia [10] have shown the efficacy of micronano fertiliser on maize growth and yields, and the conclusions were that the Katrina CB maize hybrid, which is a succeptible to drought, was micronano more tolerant to drought conditions and produced twice as large a yield when treated with micronano fertiliser, compared to untreated plants. Our study found that, with the support of nano fertiliser, the number of kernels/row and kernel rows/ear and the 1,000 kernel weight were higher than that in the control treatment. In demonstrations, grain moisture in the pilot field was much lower than that of the field without nano fertiliser. The average grain weight of 1,000 kernels in the pilot field with nano fertiliser was also found to be significantly higher than that of the field without the nano application. That is, the grain yield in the pilot field was significantly higher than that in the field without nano fertiliser.

Therefore, our results were similiar to those found by Solanki, et al. (2015), Suriyaprabha, et al. (2012), and Churilov (2010) [8-10].

Thanks to the effect of the nano solution, treatments in which 75% NPK doses and micronano foliar fertiliser were applied attained higher yield, higher income, and higher net benefit than the treatments in which 100% NPK doses without nano foliar fertiliser was applied in all four tested provinces. The cost of production per kilogram of grain maize is not much different for treatments with and without the nano application, even in treatments in which nano foliar fertiliser was applied at 75% NPK doses only. This results from the higher cost of spraying three times per season and the high prices of nano foliar fertiliser.

Conclusions and recommendation

Complex micronano particles manufactured by the Institute of Environmental Technology of Vietnam Academy of Science and Technology are effective for maize growth and development in Vietnam. This kind of nano foliar fertiliser helps maize plants better resist abiotic stresses, and attain a faster drying rate during the grain filling period, as well as higher grain weight and higher yields than the control treatments without the application of nano foliar fertiliser. However, it would be advantageous for producers if the use of nano were simpler and the price cheaper.

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