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Effect of slow-release nitrogen fertilizer on morphologic traits of corn (*Zea mays* L.)

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Abstract

Nitrogen is one of the main elements required for plant growth. Loss of 30-50% of N fertilizers is a frequently debated problem. However, this problem can be mitigated to some extent by application of slow-release fertilizers. Therefore, to investigate the effects of Nano polymer-trapped N fertilizers on morphologic traits of corn, polymer-trapped fertilizer was produced in laboratory. Then, in order to investigate the effects of synthesized fertilizers on morphological traits of corn, an experiment was carried out in a randomized complete blocks design with three replications. The treatments included non-trapped urea fertilizer (Control) and urea fertilizer trapped with nine different ratios of Nano structured polymers such as polyacrylonitrile and cellulose acetate. The results showed that polymer trapping of urea fertilizers led to improvement in morphological traits such as stem diameter, plant height, corn length, diameter and weight of corn stock, number of kernels per ear, seed weight in corn, 1000- seed weight, biologic yield, seed yield, and harvest index. The maximum rate of most traits under investigation was obtained in P1315 treatment. Therefore, due to its slow and long release of nitrogen, porous polymeric nanostructured fertilizer containing Urea provides adequate amounts of nitrogen during corn plant's growth process.

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Introduction

Corn (*Zea mays* L.) is a one-year plant from millet family genetically more various than other cereals. Corn is a short-day plant which can be grown in 58°N and 40°S latitude (Tollenaar and Dwyer, 1999). Nitrogen is a highly consumed nutrient influential in different structures of proteins molecules, enzymes, co-enzymes, nucleic acids, and other cytochromes (Hasegawa *et al.,* 2008) required for growth and development of 1-4 percent of corn plant dry matter (Onasanya *et al.*, 2009). More importantly, the increase in applying nitrogen will lead to an increased chlorophyll content of maize compared to no-nitrogen treatments (Rambo *et al.*, 2010). Previous research shows increased photosynthetic efficiency with high N content as well as improved yield potential. Besides, with increase in N content, leaf canopy increased resulting in increased photosynthesis and more aggregation of dry matter in corn plant (Akmal *et al.*, 2010). Nitrogen uptake in corn starts from early corn growth and lasts until around 3 to 5 weeks after flowering (Rajcan and Swanton, 2001). However, total plant nitrogen (65-80%) is mostly absorbed before flowering stage (Tollenaar *et al.*, 1994). In other words, root is the major sink in corn before flowering, and then seeds are considered the major sink after flowering leading to a decreased stem growth and nitrogen uptake by stem (Rajcan and Swanton, 2001). Although the rate of nitrogen uptake during the grain filling period include only a small portion of the total nitrogen absorbed by the plant (20-35%), it plays a crucial role in determining the final corn yield. Several studies show that, in high yielding corn varieties, N uptake during grain filling period lasts longer than other varieties (Rajcan and Swanton, 2001, Tollenaar *et al.*, 1994). Therefore, availability of this component throughout the growing season is necessary for optimal growth of corn plant, and the main purpose of a fertilization program is to make nutrient available for increasing plant growth and yield during growing season (Jones, 1985).

Loss of 30-50% of N fertilizers is a frequently debated problem. Therefore, application of much more fertilizer is required based on plant'sneed; however, excessive consumption of chemical N fertilizers affects the global water resources leading to lagoon process in aquatic ecosystems (Chinnamth and Boopathi, 2009). One basic solution to this problem is to gradually provide the plant with nitrogen in each stage of plant growth by applying slow-released fertilizers (Akhlaghi, 2008). Slow-released fertilizers supply nutrients slowly throughout the growing season which enables the plant to absorb the maximum amount of nutrient by reducing loss of fertilizer from leaching. Consumption of slow-released fertilizers is more suitable than conventional fertilizers due to their fewer number of application hence they cause no burns due to excess amount of fertilizer even if a large amount of this fertilizer is used (Amany *et al.*, 2006). The purpose of using slow-released fertilizers is to help distribute the fertilizer evenly in a controlled manner, first to maximize their efficiency on the product and second to minimize their negative effects resulted from excessive use of fertilizers. Benefits of slow-released fertilizers include: increased crop yield and agricultural efficiency, decreased labor costs, fewer number of applications, and less contamination of soil and water (Akhlaghi, 2008).

Nanotechnology refers to a study of particles on the atomic scale for their use and control. The main purpose of nanotechnology is to generate new compounds manipulating the material. Using new devices, nanotechnology can transform food and agriculture industry and can also use these devices to identify molecular behavior of disease, to rapidly detect diseases, and to increase the ability of plants to absorb nutrients (Mongillo 2007). In this regard, using Nano fertilizers in order to precisely control the release of nutrients can be an effective step to obtain an environmental-friendly and stable agriculture (Cui *et al.*, 2006). Coating conventional chemical fertilizers with Nano-membranes will provide fertilizers gradually while slowly releasing their nutrients (Chinnamth and

Boopathi, 2009). Coating fertilizers with Nanocompounds can regulate nutrient release (Liu *et al.* 2006). It has been shown that application of Nano compounds having nitrogen, phosphorous, potassium, micronutrients, and amino acids increases absorption and utilization of nutrients for the plant seed (Cui *et al.*, 2006). Advantages of Nano fertilizers include: control -release regulation, release and solubility of mineral micronutrients, efficient nutrient absorption, effective release time of nutrients, and decreased loss of nutrients. It is also reported that fertilizers encapsulated with polymeric membrane not only control fertilizers release but they also minimize loss of fertilizer and environmental pollution (Han *et al.*, 2009). Therefore, the current study addresses an investigation of the effect of nanostructured polymer-coated N fertilizers on morpho-physiologic traits of corn plant.

Materials and methods

To investigate the effects of porous polymeric nanostructured fertilizer containing Urea on morphophysiologic traits of corn single cross 704; polymertrapped fertilizer was produced in central laboratory of University of Tehran. For this purpose, we used polyacrylonitrile (PAN) and cellulose acetate (CA) to produce polymeric trapping. PAN was prepared from Isfahan Polyacryl Company and CA was prepared from Pioneers of Technology Company. The mineral fertilizer used for trapping was a commercial water-soluble granular fertilizer, urea (46% N), produced by Razi Petrochemical Company. Thecoating solutions were prepared by dissolving the solid polymer in adequate solvent (N,N-Dimethylformamide) and the polymer coatings were formed by different ratios of polymer and solvent. The polymer nanoparticles (PNPs) were prepared by Solvent evaporation (Vanderhoff *et al.*, 1979). In this method, (ultrasonic stirrer was utilized, then evaporation of the solvent was performedby continuous magnetic stirring at room temperature) (Allemann *et al.*, 1993 & Anton *et al.*, 2008). The granular fertilizer was gradually added to polymer solution, where it was covered by a thin layer of the solution. Encapsulation process was done by extruder. Encapsulated fertilizers were then dropped into water where the solvent-no solvent exchange proceeded which resulted in the formation of coatings (gelation process). The trapped granules were removed from water and then they were dried under chemical hood in the environment tempera-ture. The coating morphology was examined using a scanning electron microscopy (JEOL JSM-6100) in SEM Laboratory, Faculty of Metallurgy at University of Tehran. Before the measurement, the coatings were frozen in liquid nitrogen, broken to obtain cross sections, and then coated with a gold layer for SEM observation.

Field after producing porous polymeric nanostructured fertilizer containing Urea, in order to investtigate their effects on morpho-physiologic traits of corn, an experiment was performed in a randomized complete blocks design with three replications in college of Aburaihan Research Filed of University of Tehran (2012). The treatments included urea fertilizer trapped with nine different ratios of polymer and non-coated urea (Control treatment) (Table 1).

Table 1. Soluble Polymer Compounds used to produce each of the Polymeric Coatings.

Fertilizer	Polymer		Solvent
	(PAN) wt %	(CA) wt %	N,N-Dimethyl forma-mide (DMF) wt %
P1315	13-15	-	85-87
P1618	16-18	-	82-84
P1921	19-21	-	79-81
PC89	8-9	5-6	85-87
PC1011	10-11	6-7	82-84
PC1112	11-12	2-3	85-87
PC1213	12-13	7-8	79-81
PC1314	13-14	3-4	82-84
PC1516	15-16	4-5	79-81

After plowing and disking, around 300 kg of ammonium phosphate per hectare was distributed uniformly at the farmand the experimental plots were then created with 6 meters long and distance of 75cm from each other. Sterilized seeds of maize (2-3 kernels) were planted in the depth of 3-5cm and a distance of 18 cm from each other on a row, and in a density of 18 thousand plants per hectare in early June. Finally, one month after cultivation, 400 kg of encapsulated urea fertilizers per hectare was distributed at the farm in a row along the rows of seed. Samples cultivation was done at the time of physiologic maturity of the seed considering marginal effect. The traits under investigation included plant height, stem diameter, height of ear from the ground, diameter and weight of the corn wood, number of corn kernels, corn length, number of kernel row in the corn, kernel weight in the corn, 1000-seedweight, biological yield, seed yield, and harvest index (HI). The data obtained from the experiment was statistically analyzed using SAS software and the means were compared with protected LSD test at the 5% probability level).

Results and discussions

Morphology of Prepared Coatings

The microscopic structures of the fertilizer coatings, obtained by using scanning electron microscopy, are shown in Fig. 1. The skin acts as a barrier which reduces the rate of intragranular diffusion of water, the dissolution of ingredients, and fertilizer transfer out of the capsule.

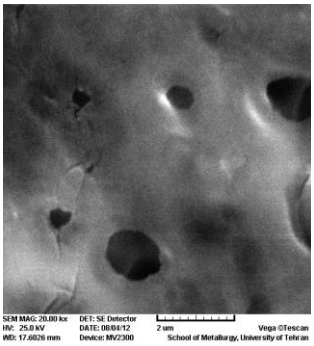

Fig. 1. SEM of cross section of coatings.

Stem Height

Analysis of variance showed that stem height at significant level ($p<0.01$) was affected by fertilizer treatments (Table 2). Minimum stem height was observed in treatment P1618 and PC1112 (mean of 166 cm) which was not significantly different from PC1921 fertilizer treatment. In addition, the maximum stem height was obtained in treatment P1315 (with an average of 206 cm) showing no significant difference with PC1516, PC1213, and PC89 treatments (Table 4). Orthogonal comparison showed that stem height in polyacrylonitrile -coated urea fertilizers was significantly different ($p < 0.01$) from urea fertilizer coated with a combination of (PAN) and cellulose acetate (CA), in other word, average of stem height in urea fertilizers coated with polyacrylonitrile (PAN) and cellulose acetate (CA) (189 cm) was longer compared to the average of PAN-coated urea fertilizers (181 cm) (Table 6). Moreover, urea fertilizers coated with different ratios of PAN were significantly different from one another ($p < 0.01$) and the maximum stem height was observed in P1315 treatment and the minimum stem height was obtained in P1618 treatment which was not significantly different from P1921 treatment (Table 7). A Significant difference ($p < 0.01$) was obtained between urea fertilizers coated with various concentrations of polyacrylonitrile (PAN) and cellulose acetate (CA) as the maximum stem height was observed in PC1516 treatment which was not significantly different from PC1213 treatment and the minimum stem height was obtained in PC1112 treatment (Table 8).

Table 2. Mean squares of analysis of variance for corn characteristics determined under various fertilizer treatments.

S.O.V.	DF	Stem Height	Stem Diameter	Distance of ear from ground	Corn length	Number of rows per ear	Number of kernels per ear

S.O.V.	DF	Stem Height	Stem Diameter	Distance of ear from ground	Corn length	Number of rows per ear	Number of kernels per ear
Rep	2	23.43^{ns}	0.001^{ns}	17.2^{ns}	0.72^{ns}	0.83^{ns}	13811.6^{*}
Fertilizer	9	654.40^{**}	0.079^{**}	83.52^{ns}	16.24^{**}	0.48^{ns}	74723^{**}
The First Kind	1	462.29^{**}	0.023^{**}	24^{ns}	11.67^{**}	0.003^{ns}	47229^{**}
The Second Kind	1	2496.9^{**}	0.049^{**}	460.05^{**}	27.38^{**}	1.03^{ns}	154938^{**}
The Third Kind	1	2170.71^{**}	70.32^{**}	5.38^{ns}	36.99^{**}	0.081^{ns}	165465^{**}
Error	18	37.13^{ns}	0.002^{ns}	34.42^{ns}	0.98	0.38	3112.5
CV		3.3	1.88	6.38	5.99	4.27	13.36
Group Comparisons	The First Kind: Is there a difference between PAN-trapped urea fertilizer and PAN+CA-trapped urea fertilizer? The Second Kind: Is there a difference between PAN-trapped urea fertilizers with each other? The Third Kind: Is there a difference between PAN+CA-coated urea fertilizers?						

Ns, *, ** no significance, significant difference at 5 and 1% levels probability, respectively.

Stem diameter

Stem diameter at significance level ($p < 0.01$) was affected by fertilizer treatments (Table 2). The maximum stem diameter was obtained in PC1112 treatment (with an average of 2/7 cm) which had no significant difference with PC1011 fertilizer treatment (an average of 2/30 cm) (Table 4). Orthogonal comparisons showed a significant difference between stem diameter of PAN-coated urea fertilizers ($p < 0.01$) and urea fertilizers coated with CA and PAN, as adding various ratios of CA to PAN in coating polymer formulation resulted in a decrease in stem diameter (Table 6). Furthermore, PAN-coated urea fertilizers were significantly different from each other ($p < 0.01$), in other words, as PAN ratio increased, stem diameter also increased; therefore, the maximum stem diameter was obtained in P1921 treatment and the minimum stem diameter was obtained in P1315 treatment (Table 7). There was also a significant difference ($p < 0.01$) between PAN and CA-coated urea fertilizers, in other words, the maximum stem diameter was obtained in PC1112 treatment and the minimum stem diameter was obtained in PC89 which was not significantly different from PC1213 treatment (Table 8).

Distance of Ear from Ground

The results obtained from variance analysis showed that the distance of ear from ground was not affected by fertilizer treatments (Table 2). However, the maximum and minimum distances of ear from ground were obtained in P1315 and PC1921, respectively (with an average of 104 & 86, respectively) (Table 4). Orthogonal comparisons showed that the distance of ear from ground was significantly different ($p < 0.01$) only between PAN-coated urea fertilizers (Table 2). The maximum distance of ear from ground was observed in P1315 treatment (with an average of 104 cm) and the minimum distance was observed in P1921 treatment (with an average of 86 cm) (Table 7).

Corn Length

Corn length at 1% level was affected by fertilizer treatments (Table 2). The Comparing the average results showed that the maximum corn length was observed in PC1516 and P1315 treatments (with an average of 21 and 20 cm, respectively); however, the minimum corn length was observed in PC89 treatment (with an average of 13 cm) which was not significantly different from Control (Table 4). Orthogonal comparisons showed that corn length in PAN-coated urea fertilizers ($p < 0.01$) was significantly different from PAN and CA-coated urea fertilizers, in other words, PAN-coated urea fertilizers caused an 8/5% increase in corn length compared to PAN and CA-coated urea fertilizers (Table 6). Moreover, urea fertilizers coated with various ratios of PAN were significantly different ($p < 0.01$) form one another (Table 2), in other words, an increase in PAN ratio (over 15%) caused a decrease in corn length, besides the minimum corn length was observed in P1618 and P1921 treatments (Table 7).

Number of Kernels in Corn

Number of kernels in corn at 1% probability level was affected by fertilizer treatments (Table 2). Comparing the average results showed that the maximum number of kernels in corn was observed in P1315 treatments (with an average of 681 kernels); however, the minimum number of kernels was observed in PC1112 treatment (with an average of 192 kernels) which was not significantly different from Control (Table 4). Orthogonal comparisons showed that number of kernels in corn was significantly different ($p < 0.01$) between PAN-coated urea fertilizers and urea fertilizers coated with PAN and CA , in other words, PAN-coated urea fertilizers (with an average of 495 kernels), compared to PAN- and CA-coated urea fertilizers (with an average of 406 kernels) caused a 21/9% increase in number of kernels in corn (Table 6). Moreover, urea fertilizers coated with various ratios of PAN were significantly different ($p < 0.01$) from each other, in other words, an increase in the ratio of PAN (over 15%) caused a decrease in number of kernels, in addition, the minimum number of kernels was observed in P1618 and P1921 treatments (with an average of 447 & 358, respectively) (Table 7).

Kernel Weight in Corn

Kernel weight in corn was significantly affected by fertilizer treatments ($p < 0.01$) (Table 3). Comparing the average results showed that the maximum kernel weight in the corn was observed in P1315, PC1213, and PC1516 treatments; however, the minimum weight was obtained in PC1112 treatments (Table 5). Kernel weight in corn was significantly different ($p < 0.01$) between PAN- coated urea fertilizers and PAN- and CA- coated urea fertilizers, in other words, PAN-coated urea fertilizers caused a 16/3% increase in kernel weight in corn compared to PAN- and CA-coated urea fertilizers (Table 6). Moreover, urea fertilizers coated with different ratios of PAN were significantly ($p < 0.01$) different from each other, in other words, an increase in PAN ratio (over 15%) caused a decrease in kernel weight in corn (Table 7). Urea fertilizers coated with different ratios of PAN and CA were significantly different ($p < 0.01$) with each other (Table 3), in other words, the maximum kernel weight in corn was obtained in PC1213 and PC1516 treatments while the minimum weight was obtained in PC1112 treatment (Table 8).

1000-seed Weight

1000-seed weight was significantly affected by fertilizer treatments ($p < 0.01$) (Table 3). Comparing the average results showed that the maximum 1000-sed weight was observed in PC1314 treatments which was not significantly different from P1315, P1921, PC1011, and PC1516; however, the minimum amount was observed in Control treatment (with an average of 280 g.) (Table 5). Orthogonal comparisons showed that 1000-seed weight of corn was not affected by various ratios of PAN or CA; however, there observed to be a significant difference ($p < 0.01$) between urea fertilizers coated with a combination of PAN and CA (Table 3). The maximum 1000-seed weight was obtained in PC1011 treatment (with an average of 347 g.) which was only significantly different from PC1112 treatment (with an average of 285 g.) (Table 8).

Corn Stock Diameter

The results obtained from variance analysis showed that corn stock diameter was significantly affected by fertilizer treatments ($p < 0.01$) (Table 3). The maximum stock diameter was observed in PC1314 treatment which was not significantly different from P1921, PC1011, PC1112, PC1516 treatments; however, the minimum diameter was observed in PC89 treatment (Table 5). Orthogonal comparisons showed that corn stock diameter was not affected by type of polymer coating, in other words, the amount of polymer did not cause a significant difference between PAN-coated urea fertilizers and urea fertilizers coated with a combination of CA and PAN (Table 3).

In addition, various ratios of PAN in PAN-coated urea fertilizers formulation did not significantly affect corn stock diameter; however, there appears to be a significant difference ($p < 0.01$) between PAN- and CA-coated urea fertilizers (Table 3). The maximum corn wood diameter was obtained in PC1011 treatment (with an average of 2/2 cm) which was significantly different from treatment PC1112 (with an average of 1/7 cm) (Table 8).

Corn Stock Weight

Corn stock weight was significantly affected by fertilizer treatments ($p < 0.01$) (Table 3). The maximum corn stock weight was observed in PC1516 treatment which was not significantly different from P1315 treatment; however, the minimum amount was obtained in PC1112 treatment (Table 5). Orthogonal comparisons showed that corn wood weight was affected by the type of polymer coating, in other words, its amount showed to cause significant difference ($p < 0.01$) between PAN-coated urea fertilizers and urea fertilizer coated with a combination of PAN and CA (Table 3). PAN- and CA-coated urea fertilizers caused a 92/8% increase in corn stock weight compared to PAN-coated urea fertilizers (Table 6). Various ratios of PAN in PAN-coated urea fertilizers formulation significantly affected ($p < 0.01$) corn stock weight and the maximum corn wood weight was obtained in P1315 treatment, and an increase in the ratio of PAN decreased corn wood weight (Table 7). Furthermore, there was a significant difference ($p < 0.01$) between PAN-coated urea fertilizers and CA-coated urea fertilizers (Table 3), in addition, the maximum corn stock weight was obtained in PC1213 treatment (with an average of 36 g.) and the minimum amount was obtained in PC1516 treatment (with an average of 15 g.) (Table 8).

Biologic Yield

The results obtained from variance analysis showed that biologic yield was significantly affected by fertilizer treatments ($p < 0.01$) (Table 3). The maximum biologic yield was observed in PC1112 treatments (with an average of 357 g.) which was not significantly different from P1315 treatments (with an average of 344 g.); however, the minimum amount was observed in P1618 and Control (averages of 290 g.) (Table 5). Orthogonal comparisons showed that biologic yield was affected by the type of polymer, in other words, its amount caused a significant difference ($p < 0.01$) between PAN-coated urea fertilizers and urea fertilizers coated with a combination of PAN and CA (Table 3). CA- and PAN-coated urea fertilizers caused a 6/1% increase in biologic yield compared to PAN-coated urea fertilizers (Table 6). Various ratios of PAN in PAN-coated urea fertilizers formulation did not significantly affect biologic yield ($p < 0.01$) and the maximum biologic yield was obtained in P1315 treatment; in addition, increasing the ratio of PAN, decreased biologic yield (Table 7). Additionally, there appeared to be a significant difference ($p < 0.01$) between urea fertilizers coated with a combination of PAN and CA. The maximum biologic yield was obtained in PC1516 treatment (with an average of 357 g.) and the minimum amount was obtained in PC89 treatment (with an average of 311 g.) (Table 8).

Seed Yield

Seed yield was significantly affected ($p < 0.01$) by fertilizer treatments (Table 3). The maximum seed yield was observed in P1315 treatment (with an average of 219 g.) which was not significantly different from PC1213 and PC1516; however, the minimum amount was obtained in Control (with an average of 70 g.) (Table 5).Orthogonal comparisons showed that seed yield was affected by ($p < 0.01$) the type of polymer coating used for coating urea fertilizer (Table 3). PAN-coated urea fertilizers caused a16/3% increase in seed yield compared to PAN- and CA-coated urea fertilizers (Table 6). Various ratios of PAN in PAN-coated urea fertilizers formulation significantly affected seed yield ($p < 0.01$) and the maximum seed yield (with an average of 219 g.) was obtained in P1315; moreover, an increase in ratio of PAN (over 15%) decrease seed yield (Table 7). Also, seed yield was significantly different ($p < 0.01$) in PAN- and CA-coated urea fertilizers (Table 7). The maximum seed yield was obtained in PC89 and PC1213 treatments and the minimum amount was obtained in PC1516 treatments (Table 8).

Table 3. Mean squares of analysis of variance for corn characteristics determined under various fertilizer treatments.

S.O.V.	DF	Kernel Weight in Corn	Corn Wood Diameter	Weight of Thousands Seeds	Weight of Corn Wood	Seed Yield	Biologic Yield	Harvest Index
Rep	2	648.13^{ns}	0.007^{ns}	44.1^{ns}	42.35^{ns}	684.13^{ns}	0.23^{ns}	62.38^{ns}
Fertilizer	9	10668^{**}	0.059^{**}	1557.4^{**}	99.93^{**}	10668^{**}	1517.17^{**}	958.3^{**}
The First Kind	1	2889^{**}	0.008^{ns}	271.1^{ns}	57.45^{*}	2889.4^{**}	2178.7^{**}	414.4^{**}
The Second Kind	1	17734^{**}	0.005^{ns}	14.2^{ns}	84.06^{*}	17734^{**}	17734^{**}	914.5^{**}
The Third Kind	1	31997^{**}	0.397^{**}	3776.5^{**}	447.56^{**}	31997^{**}	31997^{**}	3204^{**}
Error	18	334.8	0.0048	392.2	12.81	334.8	72.83	35.68
CV		13.61	3.39	6.27	13.45	13.61	2.65	14.26
Group Comparisons	The First Kind: Is there a difference between PAN-trapped urea fertilizer and PAN+CA-trapped urea fertilizer? The Second Kind: Is there a difference between PAN-trapped urea fertilizers with each other? The Third Kind: Is there a difference between PAN+CA-coated urea fertilizers?							

Ns, *, ** no significance, significant difference at 5 and 1% levels probability, respectively.

Table 4. Mean comparison of corn characteristics determined under various fertilizer treatments.

Treatment	Stem Height (cm)	Stem Diameter (cm)	Distance of Ear from the Ground (cm)	Corn Length(cm)	Number of Rows in Corn	Number of Kernels in Corn
Control	179^{de}	2.46^{cd}	89^{bc}	15^{cd}	14.2^{b}	252ef
P1315	2060^{a}	2.35^{ef}	104^{a}	20^{a}	14.2^{b}	681a
P1618	166^{f}	2.41^{de}	91^{bc}	16^{bc}	14.5^{ab}	447c
P1921	170^{ef}	2.62^{b}	86^{c}	17^{bc}	15.2^{a}	358cd
PC89	193^{abc}	2.16^{h}	96^{ab}	13^{d}	14.9^{ab}	351d
PC1011	191^{bc}	2.30^{fg}	88^{bc}	16^{bc}	15.0^{ab}	389cd
PC1112	166^{f}	2.70^{a}	90^{bc}	17^{b}	14.8^{ab}	192f
PC1213	200^{ab}	2.24^{g}	96^{ab}	15^{c}	14.3^{ab}	615ab
PC1314	183^{cd}	2.47^{cd}	88^{bc}	16^{bc}	14.4^{ab}	331de
PC1516	200^{ab}	2.49^{c}	91^{bc}	21^{a}	14.5^{ab}	560b

Mean in each column having at least a common letter are not significantly different.

Table 5. Mean comparison of corn characteristics determined under various fertilizer treatments.

Treatment	Kernel weight in corn (g)	1000-seed weight (g)	Corn wood diameter (cm)	Corn wood weight (g)	Seed Yield (g)	Biologic Yield (g)	Harvest Index (%)
Control	70^{c}	280^{d}	2.06^{b}	22^{d}	70^{c}	290^{e}	24^{d}
P1315	219^{a}	322^{abc}	2.06^{b}	34^{ab}	219^{a}	344^{ab}	64^{a}
P1618	139^{b}	310^{bcd}	2.06^{b}	28^{bc}	139^{b}	290^{e}	48^{b}
P1921	111^{b}	340^{ab}	2.17^{ab}	27^{cd}	111^{b}	$304d^{e}$	37^{c}
PC89	108^{b}	285^{d}	1.73^{d}	27^{cd}	108^{b}	326^{c}	33^{cd}
PC1011	122^{b}	326^{abc}	2.12^{ab}	26^{cd}	122^{b}	332^{bc}	37^{c}
PC1112	40^{c}	304^{cd}	2.10^{ab}	15^{e}	40^{c}	357^{a}	11^{e}
PC1213	207^{a}	305^{cd}	2.08^{b}	25^{cd}	207^{a}	311^{d}	66^{a}
PC1314	123^{b}	347^{a}	2.21^{a}	28^{bc}	123^{b}	326^{c}	38^{bc}
PC1516	206^{a}	337^{abc}	2.10^{ab}	36^{a}	206^{a}	338^{bc}	61^{a}

Mean in each column having at least a common letter are not significantly different.

Table 6. Mean comparison of corn characteristics determined under PAN-trapped fertilizer with that of PAN+ CA-trapped fertilizers.

Treatment	Stem Height (cm)	Stem Diameter (cm)	Corn Length (cm)	Kernel Weight in Corn (g)	Corn Wood Weight (g)	Seed Yield (g)	Biologic Yield (g)	Harvest Index (%)
PAN-coated fertilizer	181^{b}	2.46^{a}	17.7^{a}	156^{a}	29^{b}	156^{a}	313^{b}	49^{a}
PAN +CA-coated fertilizer	189^{a}	2.40^{b}	16.3^{b}	134^{b}	56^{a}	134^{b}	332^{a}	41^{b}

Mean in each column having at least a common letter are not significantly different.

Table 7. Mean comparison of corn characteristics determined under PAN-trapped fertilizers with each other.

Treatment	Stem Height (cm)	Stem Diameter (cm)	Distance of Ear from the Ground (cm)	Number of Kernels in Corn	Kernel Weight in Corn (g)	Corn Wood Weight (g)	Seed Yield (g)	Biologic Yield (g)	Harvest Index (%)
P1315	206a	2.36b	104a	681a	219a	34a	219a	344a	64a
P1618	166b	2.41ab	103a	447b	139b	28b	139b	290b	48ab
P1921	170b	2.62a	86b	358b	111b	27b	111b	304b	37b

Mean in each column having at least a common letter are not significantly different.

Table 8. Mean comparison of corn characteristics determined under fertilizers trapped with various concentrations of PAN and CA.

Treatment	Stem Height (cm)	Stem Diameter (cm)	Corn Length(cm)	Number of Kernels in Corn	Kernel Weight in Corn (g)	1000-seed weight (g)	Corn Wood Diameter (cm)	Corn Wood Weight (g)	Seed Yield (g)	Biologic Yield (g)	Harvest Index (%)
PC89	192.7^{bc}	2.16^{d}	15^{c}	351^{b}	108^{b}	305^{ab}	2.1^{a}	25^{b}	207^{a}	311^{c}	66^{a}
PC1011	190.7^{c}	2.31^{c}	16^{bc}	389^{b}	122^{b}	347^{a}	2.2^{a}	28^{b}	123^{b}	326^{b}	38^{b}
PC1112	163.7^{e}	2.70^{a}	13^{d}	192^{c}	40^{c}	285^{b}	1.7^{b}	27^{b}	108^{b}	326^{b}	33^{b}
PC1213	199.7^{ab}	2.25^{cd}	21^{a}	615^{a}	207^{a}	337^{a}	2.1^{a}	36^{a}	206^{a}	338^{b}	61^{a}
PC1314	182.7^{d}	2.48^{b}	16^{bc}	331^{b}	123^{b}	326^{ab}	2.1^{a}	26^{b}	122^{b}	332^{b}	37^{b}
PC1516	200.0^{a}	2.49^{b}	17^{b}	560^{a}	206^{a}	304^{ab}	2.1^{a}	15^{c}	40^{c}	357^{a}	11^{c}

Mean in each column having at least a common letter are not significantly different.

Harvest Index

Harvest index was significantly affected ($p < 0.01$) by fertilizer treatments (Table 3). The maximum harvest index was obtained in P1315 treatment (with an average of 64%), PC1213 treatment (with an average of 66%), and PC1516 treatment (with an average of 61%); however, the minimum amount was observed in PC1112 treatment (with an average of 11%) (Table 5). Orthogonal comparisons showed that harvest index was affected by the type of polymer coating ($p < 0.01$) used for coating urea fertilizer (Table 3). PAN-coated urea fertilizers caused a 19/5% increase in harvest index compared to PAN- and CA-coated urea fertilizers (Table 6). Various ratios of PAN in PAN-coated urea fertilizers formulation significantly affected ($p < 0.01$) harvest index and the maximum harvest index was obtained in P1315 treatment (with an average of 64%) and an increase in PAN ratio (over

15%) decreased harvest index (Table 7). Moreover, urea fertilizers coated with a combination of PAN and CA were significantly different from each other ($p < 0.01$) (Table 3), in other words, the maximum harvest index was obtained in PC89 and PC1213 treatments and the minimum amount was observed in PC1516 treatment (Table 8).

The results obtained from the current research showed that coating urea fertilizers with polymeric compounds highly contributed to improved stem height and diameter, corn length, corn stock weight and diameter, number of kernels in corn, kernel weight in corn, 1000-seed weight, biologic yield, seed yield, and harvest index; and the maximum amount of most traits under study was obtained in P1315 treatment. Increasing PAN concentration to over 15% decreased plant height, corn distance from ground, number and weight of corn kernel, corn stock weight, biologic yield, seed yield, and harvest index; however, it increased stem diameter. Moreover, adding CA to PAN formulation decreased stem diameter, corn length, kernel weight in corn, seed yield, and harvest index; however, it increased stem height, corn wood weight, and biologic yield. Increasing PAN concentration may result in a decrease in growth traits of corn due to increasing the thickness of polymer coating urea and decreasing nitrogen release. Furthermore, moisture penetration into coated fertilizer capsule can be controlled through changing the combination of the materials used. Adding CA to PAN formulation may also decrease nitrogen release due to less moisture penetration into coating polymer or it may lead to sudden release of nitrogen due to an increase in moisture penetration into coating polymer which leads to decreased corn growth due to nitrogen loss.

Nitrogen is a vital element for corn required for plant growth and production of 1-4% of dry matter of corn (Onasanya*et al*., 2009). Nitrogen enhances growth in maize (Dahmardeh, 2011). Researchers state that with increasing application of nitrogen fertilizer, stem diameter, plant height, corn length, and also corn stock diameter increase.(Shahid, 2012, Suput *et al*., 1979).Nitrogen highly contributes to creating proteins and proteins are involved in Meristematic cells and cell division. The increase in cell division and the effect of nitrogen on cells size will lead to an increase in plant height, corn length and diameter (Tizdal and Nelson, 1975). Researchers have also reported the increase in corn biologic yield based on different amounts of nitrogen (Cox and Cherney, 2001, Hammad *et al*., 2011, Shahid, 2012, Effa *et al*., 2012). Sajedi*et al. (*2005) relate the increase in dry matter of corn with consuming nitrogen to the increase in activities of enzymes involved in photosynthetic reactions, and as a result, the photosynthetic materials in plant increases leading to an increase in plant biomass. The increase in number of kernels in corn has been reported to be related to the increase in nitrogen level of the fertilizer (Persad-Chinnery and Chinnery, 1995, Reed *et al*., 1988, Haseeb-ur *et al*., 2010). Nitrogen can improve the photosynthetic capacity of sink contributing to high crops productivity (Below, 2002). In maize hybrids with high efficiency of nitrogen, number of kernels in maize is much more (Chun *et al*., 2005). Seed and ear development is highly prohibited with nitrogen deficiency. Decreased yield in stress of nitrogen deficiency stress is highly dependent on increased seed abortion and reduced formation of kernel in ear (Below, 2002). Ghadiri and Majidian (2003) relate the increased kernel weight in corn to increase consumption of nitrogen fertilizer. Nitrogen not only further increases photosynthetic material and its transfer while seed doughing but it also increases kernel weight in corn (Kafi Ghasemi and Esfahani, 2005).

Researches also demonstrate that the increase in consumption of nitrogen fertilizer would increase seed yield in corn plant (Costa *et al*., 2002). Corn seed yield is affected by the number of corns per unit area, number of kernels in the ear, and corn weight. Increase or decrease in each of these elements and also stability of other elements will lead to increase or decrease of seed yield. Dahmardeh (2011) reports that the number of ears in plant, corn length, the number of corn kernels, and 1000-seed weight is directly affected by seed yield and indirectly affected by other factors. The current research also showed that the increase in yield due to P1315 treatment accompanied with the increase in the number of corn kernel, corn length, kernel weight in corn, and 1000-seed weight which was in the same line with the results obtained by other researches (Effa *et al.*, 2012, Shanti *et al.*, 1997, shahid, 2012). Accordingly, it can be said that providing suitable amounts of nitrogen simultaneously with the maximum need of plant to nitrogen will increase corn seed yield (Bundy, 1986; Vetsch and Randall, 2004). It is also reported that harvest index of the seed enhances along with the increase in nitrogen adsorption in plant (Fageria and Baligar, 2005; Fageria *et al.*, 2006). The increase in harvest index in coated urea fertilizers compared to Control treatment shows the further effect of these fertilizers on the increase in seed yield compared to the increased biologic yield.

An ideal fertilizer should provide the plant with enough nutrients throughout the growing season for optimal development; however, the efficiency of consuming conventional N fertilizers in producing corps has been reported to be 33% at the global level (Ron and Jonson, 1999). The nitrogen not absorbed by the plant faces loss due to denitrification, runoff, sublimation, and leaching. Soil nitrogen loss can be controlled through coating soluble fertilizers with insoluble materials, and with reducing their solubility we can reduce nutrient release into water (Paramasivam and Alva, 1997). Several investigations indicate that nitrogen loss in conventional fertilizers such as urea fertilizer is significantly more compared to slow-released fertilizers (Hanafi *et al.*, 2002). In a research, plant height, the number of seeds, the number of plant rows, 1000-seed weight, biologic yield, and corn seed yield was significantly affected by using slow-released N fertilizer (Amany *et al.*, 2006). Other researches also showed that application of slow-released fertilizers further increases growth traits of plants compared to Control treatment (Amans and Slangen, 1994, Amany *et al.*, 2006). Therefore, it can be said that coating urea fertilizers with nano structured polymeric compounds, due to their gradual and slow release of nitrogen, provides this element throughout the growth period of corn plant hence increasing biologic yield and corn seed yield, in addition to the fact that this result is in the same line with the result obtained by other researches (Goertz, 1993, 1995; Fujita and Shoji, 1999; Fujita *et al.*, 1989, 1990; Pursell, 1992, 1994; Shaviv, 2005).

Conclusion

In the current research, coating urea fertilizer with nano structured polymeric compounds, due to slow and gradual release of nitrogen, provided the corn plant with suitable amount of N throughout different periods of corn plant growth, moreover, it was shown that one time application of coated fertilizer, due to its less nitrogen loss than non-coated fertilizer, highly affected the increase in morpho-physiologic traits, biologic yield and corn seed yield. Various ratios of polymeric compounds in coated urea fertilizer formulation affects nutrient release from encapsulated fertilizers, therefore, some of these polymer ratios compared to other used ratios, more affect the increase in the traits under study.

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