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Infuence of Seed Coating with Micronutrients on Growth and Yield of Winter Wheat in Southeastern Coastal Plains

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ABSTRACT

Polymer seed coating with micronutrients may provide important nutrients during plant growth and improve yields. The objective of this study was to determine the effect of three seed application rates (265, 395 and 530 mL 100 kg seeds^{-1}) of polymer based mixture of Copper (Cu), Manganese (Mn) and Zinc (Zn) micronutrients on dryland winter wheat (*Triticum aestivum* L.) near Blackville, SC from 2010 to 2012. Compared to untreated control, seed coating significantly increased grain yields by 5.0 and 2.1% with seed applications at 530 and 395 mL 100 kg seeds^{-1}, respectively. Dry matter yield improved over control by 13.4, 22.6 and 20.7%, N uptake by 13.9, 24.6 and 19.3% and P in plant biomass by 16.0, 23.3 and 21.3% with seed applications at 265, 395 and 530 mL 100 kg seeds^{-1}, respectively. Coating application of 265 mL 100 kg seeds^{-1} increased grain N content by 5.0% compared to control. Grain P uptake was greater with seed application rates of 265 and 395 mL 100 kg seeds^{-1} (0.415 and 0.399%, respectively) than 530 mL 100 kg seeds^{-1} (0.385%). Significantly higher grain Cu uptake was observed at rate of 395 mL 100 kg seeds^{-1} than 265 and 530 mL 100 kg seeds^{-1}. Based on significant linear relationships, increasing dry matter yield and N uptake by 1 kg ha^{-1}, Zn content in plant biomass and grain Cu content by 1 ppm and plant height by 1 cm, increased grain yields by 2.6, 369.3, 27.8, 18.3 and 58.3 kg ha^{-1}, respectively. Grain yields improved by 706.4, 357.4 and 436.2 kg ha^{-1} with increasing plant Normalized Difference Vegetation Index (NDVI) by 0.1 unit at 16, 18 and 21 weeks after planting. These results indicate that polymer seed coating may help improve some nutrient uptake and production of dryland winter wheat in Southeastern Coastal Plains.

Keywords: Wheat Grain, Polymer, Seed Coating, Micronutrients, Normalized Difference Vegetation Index (NDVI), Wheat Growth

1. INTRODUCTION

Micronutrient deficiency in the soil can reduce crop yield and quality (Konkol *et al*., 2012). They reported that micronutrient deficiency may occur due to excessive irrigation or excess application of chemical fertilizers. Nandapure *et al.* (2011) showed that application of chemical fertilizers at optimum rates helped to improve uptake of micronutrients by crops and yields were positively correlated with micronutrient status in the soil. According to Xie *et al.* (2011), Nitrogen (N) application improved shoot Copper (Cu) uptake in corn, but not in soybean (*Glycine max* L.). They observed that phosphorus application decreased copper (Cu) uptake.

Zhang *et al.* (2012a) showed that adequate N supply can improve uptake of iron (Fe), Zinc (Zn), Manganese (Mn) and Cu in wheat grains. Standard N rate of 90 kg ha^{-1} increased potassium (K), Fe, Zn and Cu and 150 kg N ha^{-1} improved Mn uptake in grain of spring wheat (Wozniak and Makarski, 2012). McBeath *et al.* (2011) pointed out that Phosphorus (P) should be applied in early wheat growth to provide essential P and improve grain yields. According to Hassan *et al.* (2012), legumes improved P uptake of the following cereal crops. Wheat grain had higher concentrations of Calcium (Ca), Fe and Zn in cropping system after pea (*Pisum sativum* L.) and improved K and Mn content after soybeans (Wozniak and Makarski, 2012).

Applications of P increased yield, but decreased Zn in shoot and grain while improving uptake of Fe, Cu and Mn in plant biomass (Zhang *et al*., 2012b). Therefore, they recommended applying Zn to soils high in P to improve yield and grain Zn concentration.

Narwal *et al.* (2012) noted that Zn, Fe and Mn insufficiencies affect wheat grown on light soils. Their results showed that applying Zn, Fe and Mn increased yields of susceptible wheat genotypes. Researchers emphasized that plant Zn deficiency is common in the world (Ghandilyan *et al*., 2012) and critical Zn soil status should be revised (Inocencio *et al*., 2012). Pandey *et al.* (2012) reported that Zn deficiency decreased tissue Zn content and dry matter yield of pea. Soybean growth and yields were positively correlated with Zn applications in soils deficient in this micronutrient (Han *et al*., 2011). Moreover, Zn and Cu uptake in the wheat grain may be affected by Sulfur (S) and Fe (Wang *et al*., 2013). Moosavi and Ronaghi (2011) reported that high applications of essential nutrients like Fe and Mn decreased absorption of other nutrients by roots or transportation from roots to plant shoot. However, soybean root or dry matter yield was not affected by Fe or Mn application.

Compared to conventional practices, wheat grain from organic farming had greater concentrations of Mn, Fe, Zn, Ca and Mg (Ciolek *et al*., 2012). However, lower uptake of grain Fe and Zn was determined in organically grown barley and oat. Kobraee and Shamsi (2011a) showed that micronutrients varied in different parts of soybean plant during the growing season from R1 to R8 stages. Nutrients Zn, Fe and Mn were transferred from stem to leaves when soybeans were approaching the full maturity stage (R8) (Kobraee and Shamsi, 2011b).

Fertilizer placement is important in improving nutrient availability (Fernandez and White, 2012), which may also be affected by tillage system. According to Wozniak and Makarski (2012), ploughless tillage system increased content of Zn and Cu, while ploughing improved uptake of K, magnesium (Mg) and Mn in the wheat grain. Zhao *et al.* (2012) reported that both origin and genotype affected contents of Mn, Fe, Cu, Zn and other micronutrients in wheat grain. Higher uptake of N, P, K, Mg, Mn, Zn and Cu and grain yields were reported following wheat grain inoculation with different bacteria (Eleiwa *et al*., 2012).

Abedi-Koupai *et al.* (2012) emphasized that coating with polymer significantly decreased the release rate of iron. Seed coatings with temperature-activated polymer may help protect soybean seed from cold and wet soils and improve emergence (Gesch *et al*., 2012). Guareschi *et al.* (2012) reported that application of superphosphate and potassium chloride coated polymer 15 days before planting increased dry matter and grain yield of soybeans, but application at planting did not produce higher yields.

Not all soils require application of micronutrients to improve soil fertility and crop yields (Mubarak *et al*., 2012). However, it is becoming a more common practice to use micronutrients in the fertilization programs and more research is needed to develop good program (Goncalves *et al*., 2011a; 2011b). Anthony *et al.* (2012) pointed out that fertilizer recommendations depend on nutrients supplied and immobilized by soil and these recommendations are important for nutrient management. Additionally, critical micronutrient status in soils and plants has not been determined for soils with expected nutrient deficiencies.

Very little research focused on seed polymer nutrient coating under dryland environments and limited repors are not conclusive on the effect of seed treatments on wheat crop under insufficient rainfall. Figueiredo *et al.* (2012) emphasized a need to evaluate polymer-coated fertilizer to improve efficiency of nutrients. In the Southeastern Coastal Plain, wheat is mostly grown under dryland conditions. Soils in this region are mostly light and sandy with low holding capacity for water and nutrients. Moreover, precipitation is unpredictable and mostly insufficient, which contributes to lower yields. Therefore the objective was to evaluate polymer micronutrient seed coating on winter wheat under dryland conditions in Southeastern Coastal Plains.

2. MATERIALS AND METHODS

2.1. Site Preparation and Management

This study was initiated on Faceville loamy sand (Fine, kaolinitic, thermic Typic Kandiudults) at Clemson University, Edisto Research and Education Center (REC) near Blackville, SC (33° 21' N, 81°18' W) under dryland conditions in the fall of 2010. These are well drained soils with moderate permeability and soil pH was 6.6. Treatments consisted of 3 rates of 45% seed coating formulations with Cu, Mn and Zn mixture on a polymer backbone at 265, 395 and 530 mL 100 kg seeds^{-1} and an untreated control.

Prior to planting winter wheat following soybean previous crop, the seed coating formulations were applied to wheat seeds. Wheat cv. 'Pioneer 26R12' was planted at 59 seeds per 1 m of row and 19 cm row spacing using a GreatPlains no-till drill (Great Plains Ag, Salina, KS) on 15 November 2010 and 9 December 2011. The plot size was 9.1 m long by 4.0 m wide. Wheat was sidedressed with broadcast application of N at 33.6 kg ha^{-1} in the form of liquid urea-ammonium sulfate (25-S fertilizer with 25% N and 3.5% S) on 21 January 2011 and 25 January 2012 and again at 67.2 kg ha^{-1} on 4 March, 2011 and 23 February 2012. Weed control was based on the South Carolina Extension recommendations.

2.2. Sample Collections and Analyses

Plant tissue samples were collected from above the ground for biomass production and nutrient concentration at Zadoks 21 wheat stage on 19 January 2011 and 9 February 2012. Plant Normalized Difference Vegetation Index (NDVI) was measured in two center rows using handheld GreenSeeker^{TM} (NTech Industries, Inc. Ukiah, CA) instrument once a week starting in late January. Plant height, based on 10 random plants in each plot, was measured from the ground to the tip of the grainhead prior to wheat harvest.

Wheat was harvested from the full length of the plot using Kinkaid 8×P small plot combine (Kinkaid Equip. Mtg, Haven, KS) on 16 May 2011 (about a week earlier that normally due to possibility of the hailstorm damage in the area) and 24 May 2012.

Grain Samples from all harvested plots were evaluated for weight and tested for moisture using a Burrows Model 750 Digital Moisture Computer (Seedburo Equip. Co., Chicago, IL). Seed weight was determined after counting seeds using the Agriculex electronic seed counter model ESC-1 (Agriculex Inc., Guelph, Ont., Canada). Grain yield was converted from each plot to 135 g kg^{-1} moisture content. Additionally, weather data (air temperature and rainfall) were recorded during wheat vegetation using a weather station located near the experimental site.

2.3. Statistical Analysis

The experimental design was Randomized Complete Block with six replications. General linear models in SAS (2011) were used to analyze data and means were separated using Fisher's Least Significant Difference Test at $p \leq 0.05$. A linear or quadratic regression model was fit using PROC REG (SAS, 2011) after cotrast indicated a significant response.

3. RESULTS

3.1. Weather Conditions

Monthly average temperature, precipitation and average from the 20-year average are shown in **Table 1**. The average air temperature was mostly similar to the 20-year average, except for March 2012 when temperature was 3.3°C higher and December 2010 and January 2011 when temperature was 6.0 and 3.2°C lower, respectively.

Precipitation varied between years and affected plant growth. Precipitation was 182 mm lower in 2010/2011 season and 145 mm lower in 2011/2012 season. Insufficient precipitation was recorded for November, December, January and April in both seasons and also May in the first growing season and February in the second season. Slightly higher precipitation was observed in February in the first season, March in both seasons and May in the second season.

3.2. Biomass Production and Nutrient Uptake

Table 2 shows that application of seed coating treatments significantly increased dry matter production, N and P uptake compared to the untreated seeds. Seed treatment applications at 265, 395 and 530 mL 100 kg $seeds^{-1}$ increased dry matter production by 13.4, 22.6 and 20.7%, N uptake by 13.9, 24.6 and 19.3% and P uptake by 16.0, 23.3 and 21.3% over control, respectively. However, Cu, Mn and Zn content in plant biomass was not affected by the seed coating treatment.

3.3. Plant height, Yield and Grain Nutrient Uptake

Application of seed coating at 395 and 530 m 100 kg $seeds^{-1}$ produced significantly higher grain yields of winter wheat (**Table 3**). Compared to control, grain yields increased by 2.1% at 395 ml seed application and 5.0% at 530 mL 100 kg $seeds^{-1}$ of seed coating application. Grain N significantly increased by 5.0% with seed application treatment of 265 mL 100 kg $seeds^{-1}$. Highest grain P content was recorded at 265 mL and 395 mL 100 kg $seeds^{-1}$ and for untreated control, while the highest seed treatment application had lower P content. Grain Cu content was highest for the control and treatment with seed coating application at 395 mL 100 kg $seeds^{-1}$. Seed coating treatment did not significantly affect plant height, grain weight and Mn and Zn content in grain.

3.4. Relationships between Grain Yields and Plant Parameters

Significant relationships were observed between grain yield and plant biomass, N uptake in plant biomass, plant tissue Zn content, Normalized Difference Vegetation Index (NDVI) at 16, 18 and 21 weeks after planting, plant height and grain Cu content (**Fig. 1-8**). Based on these linear relationships, grain yield increased by 2.6 kg ha^{-1} for every 1 kg ha^{-1} increase in plant biomass, 369.3 kg ha^{-1} for 1 kg increase in N uptake, 27.8 kg ha^{-1} for 1 ppm increase in Zn tissue content and 706.4 kg, 357.4 kg and 436.2 kg ha^{-1} with NDVI increase by 0.1 at 16, 18 and 21 weeks after planting, respectively. Additionally, increasing in plant height by 1 cm and grain Cu content by 1 ppm, increased grain yields based on linear relationships by 58.3 kg and 18.3 kg ha^{-1}, respectively.

Table 1. Monthly average air temperature and precipitation near Blackville, SC from 2010 to 2012

	Month							
Year	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Average/Total
Temperature (°C)								
2010/2011	12.6	3.9	5.2	10.9	13.4	19.1	22.3	12.5
2011/2012	13.2	10.8	9.9	11.3	17.3	18.5	23.2	14.9
20-year avg.	12.5	9.9	8.3	10.3	14.1	17.8	21.8	13.5
Precipitation (mm)								
2010/2011	22.0	34.0	49.0	124.0	123.0	57.0	59.0	468.0
2011/2012	49.0	37.0	41.0	42.0	119.0	44.0	173.0	505.0
20-year avg.	69.0	93.0	114.0	102.0	105.0	80.0	87.0	649.0

Table 2. Influence of 45% seed coating polymer formulations with Copper (Cu), Manganese (Mn) and Zinc (Zn) mixture on dry matter, Nitrogen (N) and Phosphorus (P) uptake and Cu, Mn and Zn concentration in biomass of winter wheat near Blackville, SC from 2010 to 2012

Formulation rate (mL 100 kg seeds^{-1})	Dry matter (kg ha^{-1})	N uptake (kg ha^{-1})	P uptake (kg ha^{-1})	Cu (ppm)	Mn (ppm)	Zn (ppm)
Control	319.4	8.56	1.50	3.99	42.4	22.5
265 mL	362.2	9.75	1.74	3.34	41.2	24.6
395 mL	391.8	10.67	1.85	3.65	41.5	22.8
530 mL	385.4	10.21	1.82	3.62	41.3	24.5
$LSD_{(0.05)}$	35.8	1.42	0.19	NS	NS	NS

Table 3. Influence of 45% seed coating polymer formulations with Copper (Cu), Manganese (Mn) and Zinc (Zn) mixture on plant height prior to harvest and grain weight and yield and Nitrogen (N), Phosphorus (P), Cu, Mn and Zn content in grain of winter wheat near Blackville, SC from 2010 to 2012

Formulation rate (mL 100 kg seeds^{-1})	Plant height (cm)	500 grain weight (gms)	Grain yield (Mg ha^{-1})	Grain N (%)	Grain P (%)	Grain Cu (ppm)	Grain Mn (ppm)	Grain Zn (ppm)
Control	91.3	23.7	5.35	1.800	0.4130	4.664	40.3	26.6
265 mL	91.6	24.1	5.39	1.890	0.4150	4.058	39.3	29.1
395 mL	91.2	24.1	5.46	1.780	0.3990	4.108	38.1	26.4
530 mL	90.7	24.6	5.62	1.760	0.3850	3.767	38.5	27.0
$LSD_{(0.05)}$	NS	NS	0.19	0.076	0.0214	0.56	NS	NS

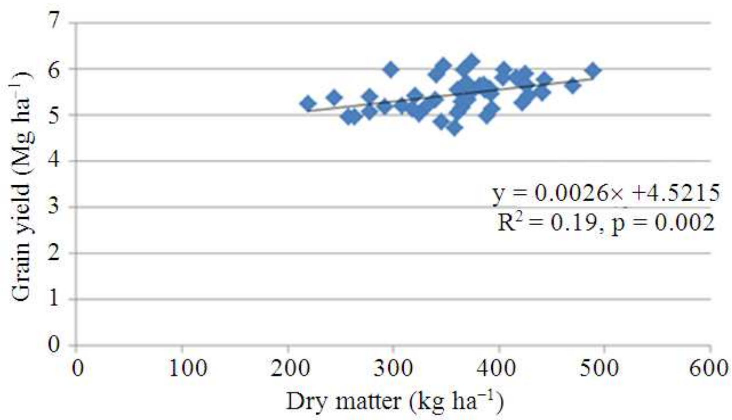

Fig. 1. Relationship between dry matter and grain yield of winter wheat from 2010 to 2012

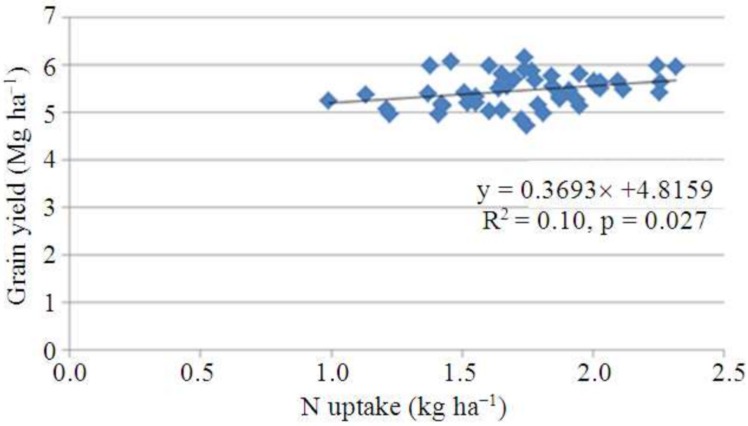

Fig. 2. Relationship between Nitrogen (N) uptake in biomass and grain yield of winter wheat from 2010 to 2012

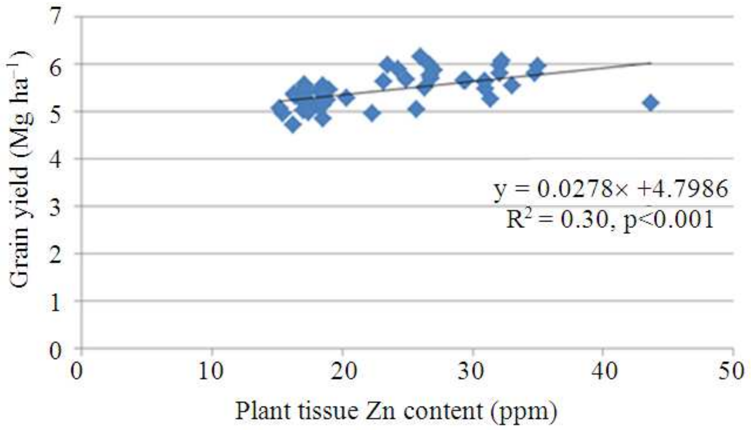

Fig. 3. Relationship between zinc (Zn) content in plant tissue and grain yield of winter wheat from 2010 to 2012

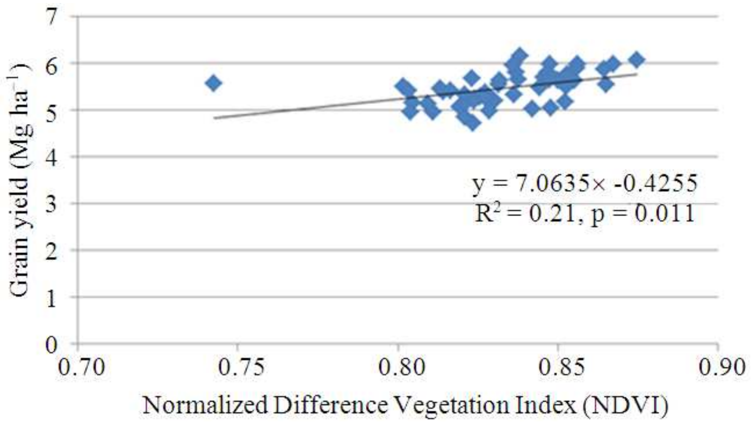

Fig. 4. Relationship between Normalized Difference Vegetation Index (NDVI) at 16 weeks after planting and grain yield of winter wheat from 2010 to 2012

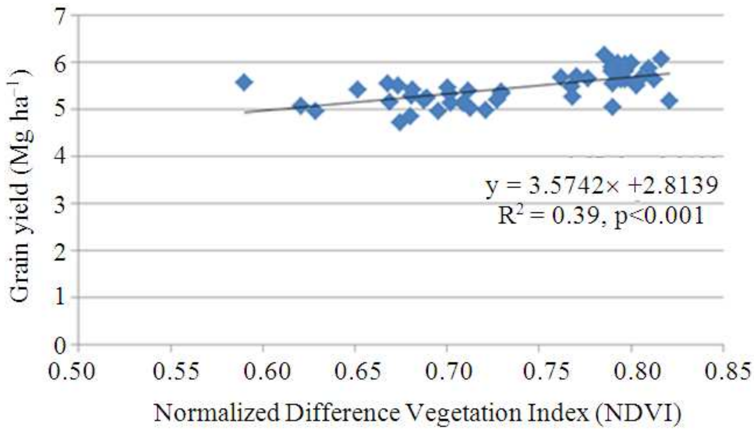

Fig. 5. Relationship between Normalized Difference Vegetation Index (NDVI) at 18 weeks after planting and grain yield of winter wheat from 2010 to 2012

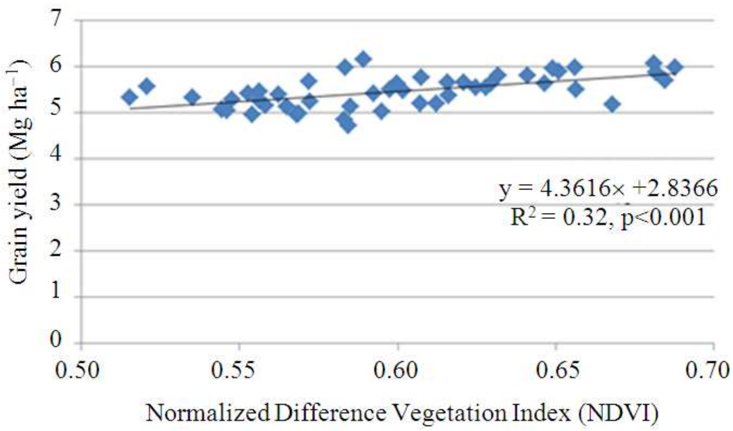

Fig. 6. Relationship between Normalized Difference Vegetation Index (NDVI) at 21 weeks after planting and grain yield of winter wheat from 2010 to 2012

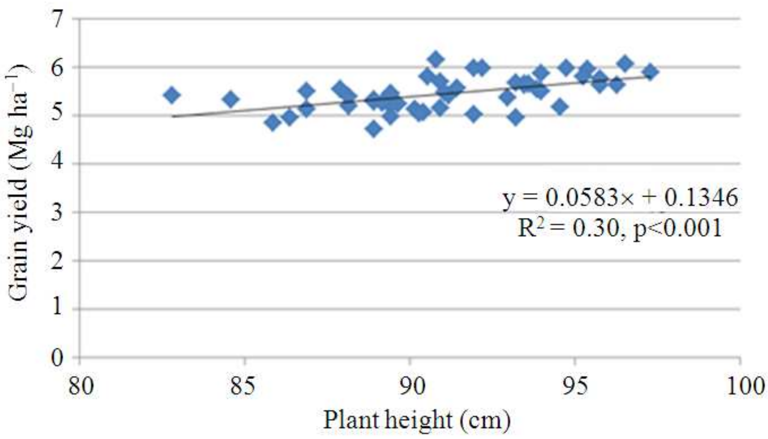

Fig. 7. Relationship between plant height and grain yield of winter wheat from 2010 to 2012

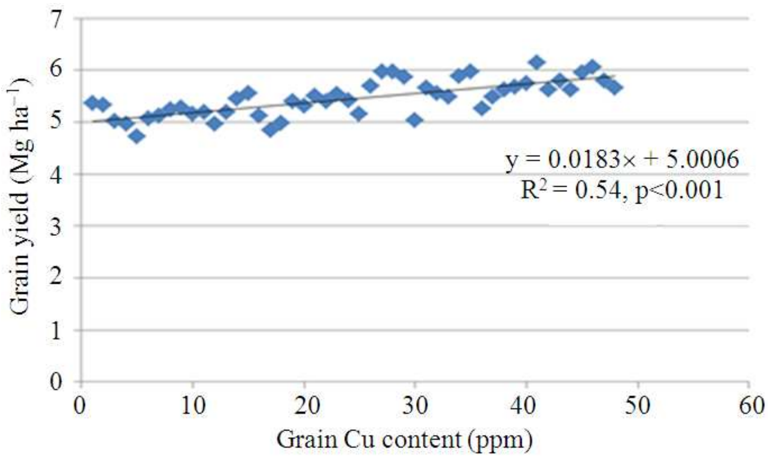

Fig. 8. Relationship between Grain copper (Cu) content and grain yield of winter wheat from 2010 to 2012

4. DISCUSSION

Previous research on seed coating was very limited and not conclusive. Pandey *et al.* (2012) reported that Zn deficiency in the pea crop decreased dry matter yield and tissue Zn concentration. According to Han *et al.* (2011), growth of soybean was generally positively correlated with Zn concentrations. However, Kobraee and Shamsi (2011a) observed that Zn and Mn concentration in leaf and stem at different growth stages of plant were lower than the untreated control. Another study showed that application of Mn did not affect soybean dry matter yield (Moosavi and Ronaghi, 2011). Results from this study indicated that application of polymer seed coating formulations with Cu, Mn and Zn mixture increased dry matter production, N and P uptake of winter wheat compared to untreated seeds.

Arshad *et al.* (2011) observed that grain yield and grain Cu and Zn concentrations of wheat increased with Cu and Zn applications. They also reported significantly increased Zn concentrations in wheat plants with Cu applications. Inocencio *et al.* (2012) added that Zn fertilization increased soybean grain yield. However, Kobraee and Shamsi (2011a) pointed out that Zn, Fe and Mn concentrations in soybean seed were lower than control. This study showed that seed coating application improved grain yields, grain N and P concentrations and affected grain Cu content.

A positive relationship between plant NDVI and grain yields in this study agrees with Raun *et al.* (2001), who also observed a strong relationship between plant NDVI of winter wheat and grain yield. Additionally, positive relationships existed between grain yields and plant biomass, N uptake in plant biomass, plant tissue Zn content, plant height and grain Cu content.

5. CONCLUSION

This study investigated the effects of three polymer seed coating application rates growth, yield and nutrient uptake of winter wheat grown under dryland conditions. Application of seed coating to seeds at 265, 395 and 530 mL 100 kg seeds^{-1} improved dry matter production by 13.4, 22.6 and 20.7%, N uptake by 13.9, 24.6 and 19.3% and P uptake by 16.0, 23.3 and 21.3% over control, respectively. Higher application of seed coating treatment produced significantly higher grain yields. Grain yields increase of 5.0% was obtained with seed coating rate of 530 mL 100 kg seeds^{-1} and 2.1% at rate of 395 mL 100 kg seeds^{-1}. Seed coating rate of 265 mL 100 kg seeds^{-1} significantly improved N uptake in grain of winter wheat. Grain P uptake was lower with highest seed coating rate to seeds, but grain Cu was highest for the control and treatment with seed coating application rate of 395 mL 100 kg seeds^{-1}. Seed coating application did not significantly affect Cu, Mn and Zn content in plant biomass, plant height, grain weight and Mn and Zn content in grain. Significant positive linear relationship showed that for every unit increase in plant biomass, N uptake, Zn in plant tissue, plant height and grain Cu content, grain yields increased by 2.6, 369.3, 27.8, 58.3 and 18.3 kg ha^{-1}, respectively. Increase in plant NDVI by 0.1 at 16, 18 and 21 weeks after planting improved grain yields by 706.4, 357.4 and 436.2 kg ha^{-1}. More research may be needed in the future to evaluate the effect of more micronutrients on wheat growth, nutrient uptake and wheat production.

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7. REFERENCES

Abedi-Koupai, J., J. Varshosaz, M. Mesforoosh and A.H. Khoshgoftarmanesh, 2012. Controlled release of fertilizer microcapsules using ethylene vinyl acetate polymer to enhance micronutrient and water use efficiency. J. Plant Nutr., 35: 1130-1138. DOI: 10.1080/01904167.2012.676126

Anthony, P., G. Malzer, M.C. Zhang and S. Sparrow, 2012. Soil nitrogen and phosphorus behavior in a long-term fertilization experiment. Agron. J., 104: 1223-1237. DOI: 10.2134/agronj2012.0020

Arshad, M., G. Murtaza, M.A. Ali, M. Shafiq and C. Dumat *et al*., 2011. Wheat growth and phytoavailability of copper and zinc as affected by soil texture in saline-sodic conditions. Pakis. J. Bot., 43: 2433-2439.

Ciolek, A., E. Makarska, M. Wesolowski and R. Cierpiala, 2012. Content of selected nutrients in wheat, barley and oat grain from organic and conventional farming. J. Element., 17: 181-189. DOI: 10.5601/jelem.2012.17.2.02

Eleiwa, M.E., E.R. Hamed and H.S. Shehata, 2012. Biofertilizers and/or some micronutrients role on wheat plants grown on newly reclaimed soil. Afr. J. Ecol., 50: 464-475. DOI: 10.1111/j.1365-2028.2012.01342.x

Fernandez, F.G. and C. White, 2012. No-till and strip-till corn production with broadcast and subsurface-band phosphorus and potassium. Agron. J., 104: 996-1005. DOI: 10.2134/agronj2012.0064

Figueiredo, C.C.D., D.V. Barbosa, S.A. De Oliveira, M. Fagioli and J.H. Sato, 2012. Polymer-coated phosphate fertilizer and liming on the production and morphological parameters of corn. Rev. Cienc. Agron., 43: 446-452. DOI: 10.1590/S1806-66902012000300005

Gesch, R.W., D.W. Archer and K. Spokas, 2012. Can using polymer-coated seed reduce the risk of poor soybean emergence in no-tillage soil? Field Crops Res., 125: 109-116. DOI: 10.1016/j.fcr.2011.09.005

Ghandilyan, A., U.B. Kutman, B.Y. Kutman, I. Cakmak and M.G.M. Aarts, 2012. Genetic analysis of the effect of zinc deficiency on arabidopsis growth and mineral concentrations. Plant Soil, 361: 227-239. DOI: 10.1007/s11104-012-1334-0

Goncalves, A.C. Jr., H. Nacke, D. Schwantes, I.A. Nava and L. Strey, 2011a. Phytoavailability of toxic heavy metals and productivity in wheat cultivated under residual effect of fertilization in soybean culture. Water Air Soil Pollut., 220: 205-211. DOI: 10.1007/s11270-011-0747-3

Goncalves, R.F., P.R. Gazolla, A. Perin and J.M.K. Santini, 2011b. Antecipated fertilization on soybean with triple superphosphate and potassium chloride coated with polymers. Cienc. Agrotecnol., 35: 643-648. DOI: 10.1590/S1413-70542011000400001

Guareschi, S., E. Covam, C. Cereda, M. Ceroni and E. Donetti et al., 2012. An over-oxidized form of superoxide dismutase found in sporadic amyotrophic lateral sclerosis with bulbar onset shares a toxic mechanism with mutant SOD1. Proc. Nat. Acad. Sci. USA., 109: 13 5074-5079. DOI: 10.1073/pnas.1115402109

Han, X.Z., X.H. Li, N. Uren and C.X. Tang, 2011. Zinc fractions and availability to soybeans in representative soils of Northeast China. J. Soils Sedim., 11: 596-606. DOI: 10.1007/s11368-011-0336-5

Hassan, H.M., P. Marschner, A. McNeill and C.X. Tang, 2012. Grain legume pre-crops and their residues affect the growth, P uptake and size of P pools in the rhizosphere of the following wheat. Biol. Fert. Soils, 48: 775-785. DOI: 10.1007/s00374-012-0671-8

Inocencio, M.F., A.V.D. Resende, A.E.F. Neto, M.P. Veloso and F.M. Ferraz *et al*., 2012. Soybean response to zinc fertilization in soil with contents above critical level. Pesquisa Agropecuaria Brasileira, 47: 1550-1554. DOI: 10.1590/S0100-204X2012001000020

Kobraee, S. and K. Shamsi, 2011a. Determination of zinc, iron and manganese concentration and partitioning during reproductive stages of soybean grown under field conditions. Res. Crops, 12: 752-760.

Kobraee, S. and K. Shamsi, 2011b. Measurement of zinc, iron and manganese ratios in different parts of soybean plant. Res. Crops, 12: 761-765.

Konkol, N.R., C.J. McNamara, K. Bearce-Lee, H. Kunoh and R. Mitchell, 2012. Novel method of micronutrient application increases radish (raphanus sativus) and shirona (brassica rapa var. Pekinensis) biomass. J. Plant Nutr., 35: 471-479. DOI: 10.1080/01904167.2012.639925

McBeath, T.M., M.J. McLaughlin and S.R. Noack, 2011. Wheat grain yield response to and translocation of foliar-applied phosphorus. Crop Pasture Res., 62: 58-65. DOI: 10.1071/cp10237

Moosavi, A.A. and A. Ronaghi, 2011. Influence of foliar and soil applications of iron and manganese on soybean dry matter yield and iron-manganese relationship in a calcareous soil. Aust. J. Crop Sci., 5: 1550-1556.

Mubarak, S., M. Zia-Ur-Rehman and A. Haque, 2012. Comparative study of micronutrients in soil and plant using microwave extraction in wheat fields of Lahore suburbs. Pakistan. Asian J. Chem., 24: 2279-2282.

Nandapure, S.P., B.A. Sonune, V.V. Gabhane, R.N. Katkar and R.T. Patil, 2011. Influence of long term fertilization on micronutrients availability, their uptake and productivity of sorghum-wheat sequence under semi-arid condition on a vertisol. Crop Res., 42: 35-39.

Narwal, R.P., R.R. Dahiya, R.S. Malik and R. Kala, 2012. Influence of genetic variability on zinc, iron and manganese responses in wheat. J. Geochem. Explor., 121: 45-48. DOI: 10.1016/j.gexplo.2012.06.006

Pandey, N., B. Gupta and G.C. Pathak, 2012. Antioxidant responses of pea genotypes to zinc deficiency. Rus. J. Plant Physiol., 59: 198-205. DOI: 10.1134/s1021443712010141

Raun, W.R., J.B. Soile, G.V. Johnson, M.L. Stone and E.V. Lukina *et al*., 2001. In-season prediction of potential grain yield in winter wheat using canopy reflectance. Agron. J., 93: 131-138. DOI: 10.2134/agronj2001.931131x

SAS, 2011. SAS/STAT® 9.3 User's Guide. Cary, NC: SAS Institute Inc.

Wang, C., Z.F. Yang, X.Y. Yuan, P. Browne and L.X. Chen *et al*., 2013. The influences of soil properties on Cu and Zn availability in soil and their transfer to wheat (*Triticum aestivum* L.) in the Yangtze River delta region, China. Geoderma, 193: 131-139. DOI: 10.1016/j.geoderma.2012.10.004

Wozniak, A. and B. Makarski, 2012. Content of minerals in grain of spring wheat cv. Koksa depending on cultivation conditions. J. Element., 17: 517-523. DOI: 10.5601/jelem.2012.17.3.13

Xie, W.J., J.M. Zhou, H.Y. Wang, Q. Liu and J.B. Xia *et al*., 2011. Cu and Pb accumulation in maize (*Zea mays* L.) and soybean (*Glycine max* L.) as affected by N, P and K application. Afr. J. Agric. Res., 6: 1469-1476. DOI: 10.5897/AJAR10.1086

Zhang, Y.H., Y.P. Zhang, N. Liu, D. Su, Q.W. Xue, B.A. Stewart, *et al*., 2012a. Effect of source-sink manipulation on accumulation of micronutrients and protein in wheat grains. J. Plant Nutr. Soil Sci., 175: 622-629. DOI: 10.1002/jpln.201100224

Zhang, Y.Q., Y. Deng, R.Y. Chen, Z.L. Cui, X.P. Chen, R. Yost *et al*., 2012b. The reduction in zinc concentration of wheat grain upon increased phosphorus-fertilization and its mitigation by foliar zinc application. Plant Soil, 361: 143-152. DOI: 10.1007/s11104-012-1238-z

Zhao, H.Y., B.L. Guo, Y.M. Wei and B. Zhang, 2012. Effects of wheat origin, genotype and their interaction on multielement fingerprints for geographical traceability. J. Agric. Food. Chem., 60: 10957-10962. DOI: 10.1021/jf3021283