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Full Length Research Paper

Superabsorbent polymers (SAP) enhance efficient and eco-friendly production of corn (*Zea mays* L.) in drought affected areas of northern China

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In arid and semiarid regions of northern China, there is an increasing interest in using reduced rate of chemical fertilizer along with water-saving superabsorbent polymer (SAP) for field crop production. The objective was to evaluate the effectiveness of different rates of SAP (low, 0.75; medium, 11.3 and high, 15.0 kg ha^{-1}) against half amount of conventional standard rate of chemical fertilizer for summer corn (*Zea mays* L.) production in a drought-affected field of northern China. Corn yield increased following SAP application by 11.2% under low 18.8% under medium and 29.2% under high rate with only half amount (150 kg ha^{-1}) of fertilizer compared with control plants, which received conventional standard fertilizer rate (300 kg ha^{-1}). At the same time plant height, stem diameter, leaf area, biomass accumulation and relative water content as well as protein and sugar contents in the grain also increased significantly following SAP treatments. The optimum application of SAP in the study area would be 15 kg ha^{-1} as it brings progressive increase in corn growth and also maintain proper nutrients balance in the soil after harvest. Other rates are not sufficient to maintain proper plant growth or soil nutrient balance against half fertilizer. We suggest that, the application of SAP at 15 kg ha^{-1} plus only half the amount of conventional fertilizer rate (150 kg ha^{-1}) would be a more appropriate practice for sustainable corn production under arid and semiarid conditions of northern China or the areas with similar ecologies.

Key words: Corn, drought stress, fertilizer use efficiency, northern China, superabsorbent polymer.

INTRODUCTION

In arid and semiarid regions of northern China, there is an increasing interest in using reduced rate of chemical fertilizer along with water-saving superabsorbent polymer (SAP) for field crop production. China is one of the world's most water-deficient economies and water scarcity is viewed as a major threat to long-term food security. While the agricultural sector is still by far the largest user of China's water resources, rapid economic and popu-lation growth is generating rising demand for urban and industrial use, increasing pressure on water supplies. On the other hand, fertilizer consumption in China is also challenging the acceptance limit of resource and environ-ment.

China has a large region of dry land in the north, which accounts for about 56% of the nation's total land area but only 24% of country's water resources (Xin and Wang, 1999). The North China Plain (NCP) is one of the most important wheat and maize production areas in China. The main cropping system in this region is wheat and

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Abbreviations: SAP, Superabsorbent polymer; **RWC,** relative water content; **WAS,** weeks after sowing; **FW,** fresh weight; **AGB,** above ground biomass accumulation; **CP,** crude protein; ; **NCP,** North China plain.

maize double cropping in a year producing about 29.6% of the nation's food, including about half of the wheat production and third of the maize production (NBSC, 1998). The average requirement of water for crop production is about 810 mm (450 mm for wheat and 360 mm for maize) whereas; the mean annual rainfall is only about 550 mm (Liu et al., 2001). Irrigation is critical for maintaining high crop yield, especially northern China, where about 75% of the agricultural land is irrigated, consuming 70 to 80% of the total water resource allocation in the region (Liu et al., 2001). In recent years, however, increased water deficits associated with over-use use of surface water, declining groundwater levels, water pollution and soil salinization are threatening the sustainability of agricultural production in the region (Hu et al., 2005; Liu et al., 2001; Wang et al., 2001). The water supply for agricultural production will unavoidably decrease with the increasing demands from domestic and industrial water users. At the same time, the agricultural water use efficiency is still very low due to the poor irrigation practices (Hu et al., 2005; Wang et al., 2001).

Excessive application of chemical fertilizer in China is another fear factor for long term farmland efficiency and environmental sustainability. According to the forecast of the Ministry of Agriculture, People's Republic of China, the fertilizer consumption in the country was about 58 million tons in 2006 which accounted for 37.1% of the world's total. During the period of 1992 and 2006, China was the highest contributor for increasing international fertilizer consumption. In arid and semiarid regions of NCP (double cropping wheat and corn areas), there is a common trends of excessive fertilization (about 600 kg ha^{-1}) for better crop production and some recent studies (Yuan et al. 1995; Zhu and Chen, 2002; Li and Li, 2000) have shown that, much of the applied fertilizer was lost through leaching resulting to serious environmental hazards, including soil acidification, heavy metal contamination and greenhouse gas emission. The N fertilizer use efficiency in China is ranging from 30 to 35% compared with 45% of developed countries. The P fertilizer use efficiency in China is as low as 10 to 20%. According to the amount of fertilizer used in the field, if 10% of the applied N fertilizers and 20% of P fertilizers is reduced, the nation's farmers could save 10.4 and 13.7 billion Yuan (1 Chinese Yuan = 0.15 USD) annually, respectively.

Soils in the North China Plain areas are mostly characterized by low water-holding capacity, high evapotranspiration and excessive leaching of the scanty rainfall, leading to poor water and fertilizer use efficiency by crops. As a result, much of the double-cropped wheat and summer corn area (approximately 20 to 50%) in north part of the NCP including Beijing, Tianjin and Hebei has now been replaced by mono-cropped spring corn area (Zhiming et al., 2007; Yu et al., 2006). Agricultural scientist and planers in the area are being confronted with the task of developing timely and viable alternative soil-water-crop management system to counteract the current downward trends in environmental degradation and agricultural productivity.

The problem of inefficient use of fertilizer and irrigation water by crops is most important in semiarid and arid regions in the world and application of water-saving super absorbent polymers (SAP) in to the soil could be an effective way to increase both water and nutrient use efficiency in crops (Lentz and Sojka, 1994; Lentz et al., 1998). When polymers are incorporated with soil, it is presumed that they retain large quantities of water and nutrients, which are released as required by the plant. Thus, plant growth could be improved with limited water and nutrient supply (Gehring and Lewis, 1980). Johnson (1984) reported an increase of 171 to 402% in water retention capacity when polymers were incorporated in coarse sand. Addition of a polymer to peat decreased water stress and increased the time to wilt (Karimi et al., 2009; Gehring and Lewis, 1980). The incorporation of superabsorbent polymer with soil improved soil physical properties (El-Amir et al., 1993), enhanced seed germination and emergence (Azzam, 1983), crop growth and yields (Yazdani et al., 2007) and reduced the irrigation requirement of plants (Blodgett et al., 1993; Taylor and Halfacre, 1986). The use of hydrophilic polymer materials as carrier and regulator of nutrient release was helpful in reducing undesired fertilizer losses, while sustaining vigorous plant growth (Mikkelsen, 1994).

Three classes of superabsorbent polymer are commonly used and are classified as natural, semi-synthetic and synthetic polymers (Mikkelsen, 1994). Synthetic polyacrylamide with potassium salt base manufactured by Beijing Hanlisorb Polywater hi-tech. Co. Ltd. used for this experiment is a cross-linked polymer developed to retain water and fertilizer in the agricultural and horticultural sector. Earlier, polymers were not used in the agricultural field due to their high prices. Recently, many polymer industries developed around northern China and the prices became comparatively cheaper (about 5 USD kg^{-1}) on the other hands, excessive fertilizer consumption leads to an increase in compound (granular) fertilizer price (about 0.4 USD kg^{-1}). Thus, the application of SAP along with reduced rate of compound fertilizer in the agricultural field has become a popular water and fertilizer saving technology for many farmers in arid and semi arid regions of northern China. Therefore, polymers can retain soil moisture and fertilizer up to 3 to 5 years after application, which could also bring some additional economic and environmental advantages. The main objective of this study was to evaluate the effectiveness of different rates of SAP against half amount of chemical fertilization for summer corn production in a drought affected field of northern China.

MATERIALS AND METHODS

Plant material and growth condition

The study was conducted under field conditions in the Shoungyi country (40°13′N, 116°65′E), Beijing, northern China. The soil was

Table 1. Fundamental chemical properties of soil in the studied area.

Item	Value		Unit
	0 to 15 cm	15 to 30 cm	
pH (H_2O)	6.8	6.78	
Electrical conductivity	0.73	0.70	ms/cm
Total nitrogen	107.8	92.6	mg/kg
Available phosphorus	32.8	19.7	mg/kg
Available potassium	72.6	68.9	mg/kg
Organic matter	12.2	8.3	g/kg

sandy loam and the fundamental chemical properties of the soil are presented in Table 1. Plots were marked out with minimal pre-planting land preparation. Treatments comprised super absorbent polymers (SAP) applied in the row mixing with fertilizer during seed sowing at low (7.5 kg ha^{-1}), medium (11.3 kg ha^{-1}) and high (15 kg ha^{-1}) rate. The levels of SAP applications (low, medium and high) were determined with manufacturer's recommendation. The control plot received only compound granular fertilizers (NPK 15:15:15) at standard rate (300 kg ha^{-1}), whereas all treatments with SAP received half amount (150 kg ha^{-1}) of standard rate. Jing Dan 958, a commonly grown corn variety (*Zea mays* L.) in northern China was used for the experiment. Treatments were arranged into a completely randomized design with three replications; each treatment occupied a plot area of 3 × 8 m. Seeds were sown on 23rd June and harvested on 29th September in 2009. Standard seed rate and row spacing (60 cm) were used during seeding and irrigated once (within one week) after sowing.

Phenological measurements and calculation

Determination of plant growth (plant height, leaf area, grain yield and biomass accumulation) was carried out during harvest. Relative water content (RWC) of leaves was measured on fully expanded leaves at 8 weeks after sowing (WAS). Leaves were cut and collected at midday to determine fresh weight (FW). Leaf blades were then, placed with their cut end pointing down into a falcon tube containing about 15 ml of 1 mM $CaCl_2$. The $CaCl_2$ was used to increase leaf cell integrity, with the aim of reducing cell lysis due to excessive rehydration. The turgid weight (TW) was then, recorded after overnight rehydration at 4℃. For dry weight (DW) determination, samples were oven-dried at 70℃ for 48 h. Relative water content was calculated according to Schonfeld et al. (1988) thus:

$$RWC (\%) = [(FW – DW) / (TW – DW)] \times 100 \quad (1)$$

The (1000) grains weight was calculated from randomly sampled grains after harvest. At maturity, a sample of 4 m^2 area for each plot was harvested for grain yield and biomass determination.

Soil analysis

Soils were sampled at the 0 to 15 cm and 15 to 30 cm soil depths from the sowing rows after harvest. Samples were air-dried and passed through 1 mm sieve. Total N was determined by Kjeldhal method (AOAC, 1990). Available P was determined by molybdenum blue colorimetry after Bravay-1 extraction (AOAC, 1990). Available K was measured by analyzing the filtered extract on an atomic absorption spectrophotometer set on emission mode at 776 nm (AOAC, 1990).

Grain quality determination

Dried samples were ground and passed through a 1 mm sieve before analysis. Nitrogen content (%) was determined by the Kjeldhal method (AOAC, 1990) and crude protein (CP) content was obtained by multiplying the Kjeldahl N values by 6.25. Starch and soluble sugar contents were also determined by official AOAC method.

Climatic measurement

An automatic weather station was installed in the experimental field to record daily air temperature, rainfall and relative humidity during corn growing period (Figure 1). Air temperature ranged from 12.0 to 38.1℃ and mean temperature was 17.5℃. Total precipitation was 248 mm in 33 rainy days which is 112 mm lower than corn requirements (Liu et al., 2001). Relative air humidity (daily average) ranged from 31 to 89% and mean value was 68.1%.

Statistical analysis

An analysis of variance was performed using the STATEVIEW (SAS Institute Inc., Cary, NC, USA) software. Treatment means were compared using the Fisher's protected least significant differences (LSD) at the 5% level of probability.

RESULTS

Plant height

Plant heights were more or less increased by applying different rates of SAP and the effects are less noticed under low application of SAP, whereas it increased remarkably by 10.3 and 18.0% under medium and high application rate (Table 2).

Stem diameter

Stem diameter increased with increasing rate of SAP (Table 2) but the value was not significant under low application level. However, under medium and high application of superabsorbent polymer, the values increased by 15.2 and 18.6%, respectively.

Leaves area

Leaves area under different treatments in corn plant also

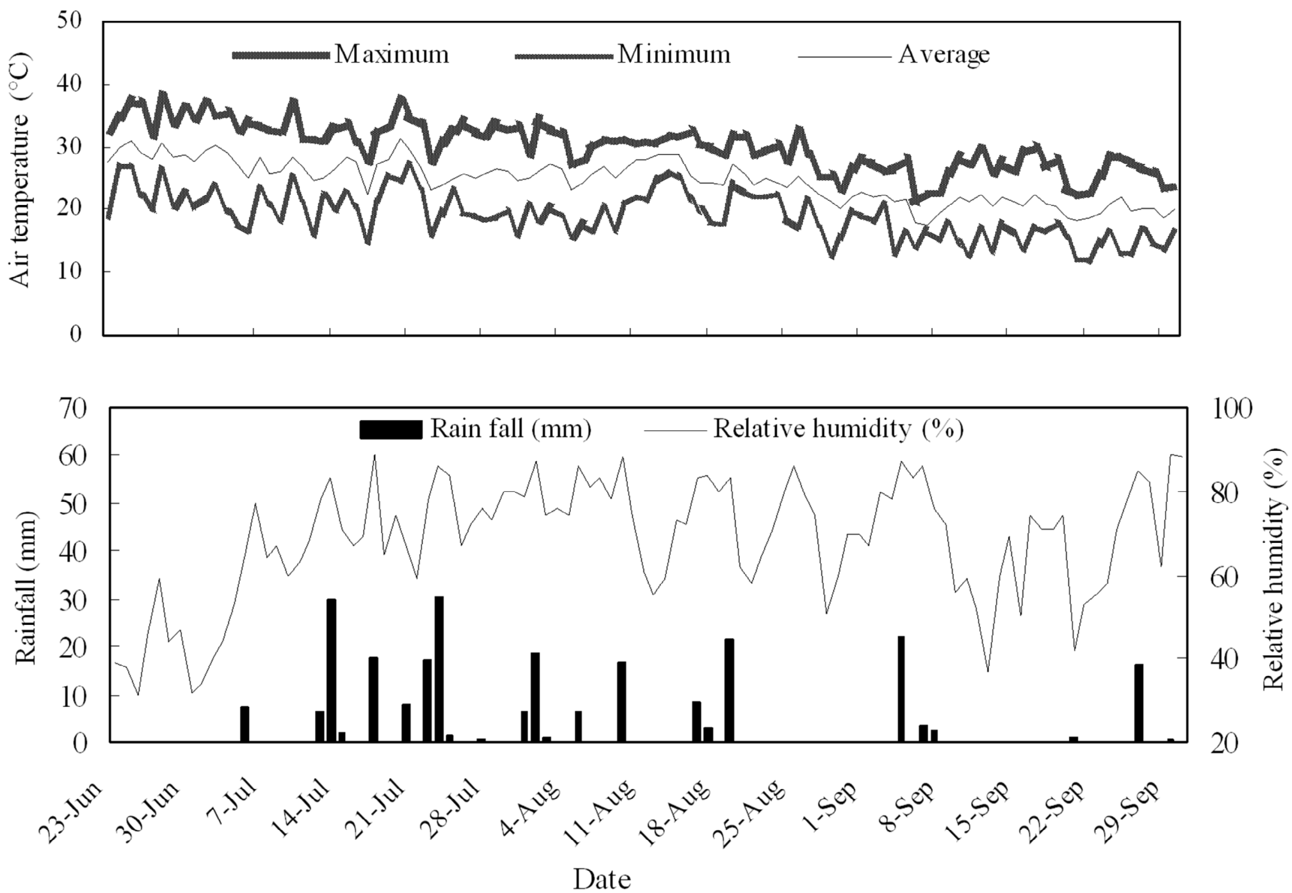

Figure 1. Daily air temperature, rainfall and relative humidity during corn growing season (23rd June to 29th September, 2009).

Table 2. Plant height, stem diameter, leaf area, grains per plant and 1000 grains weight of corn under different superabsorbent polymer (SAP) treatments.

Treatment	Plant height (cm)	Stem diameter (cm)	Leaf area (m^2)	Grains/plant	1000 grain weight (g)
CK	246.1	1.907	0.459	521.1	223.8
Low	259.4	2.007	0.458	510.9	241.3
Medium	271.5	2.197	0.546	569.7	249.7
High	290.3	2.257	0.608	607.7	246.3
Mean	266.8	2.095	0.518	552.4	240.3
LSD (0.05)	20.55	0.227	0.071	42.7	15.9

CK, Control; LSD, least significant difference.

presented in Table 2, did not changed under low application of superabsorbent polymer but increased remarkably following SAP application at medium and high rate by 18.9 and 32.5%, respectively.

Number of grains per plant

The number of grains per plant reduced marginally (2.0%) under low application of superabsorbent polymer (Table 2), whereas under medium and high application, it increased by 9.3 and 16.6%, respectively, compared with plant without SAP or control.

1000 grain weight

Although, no marked changes were noted in 1000 grain weight due to superabsorbent polymer application, seeds of corn treated with SAP were slightly heavier than those

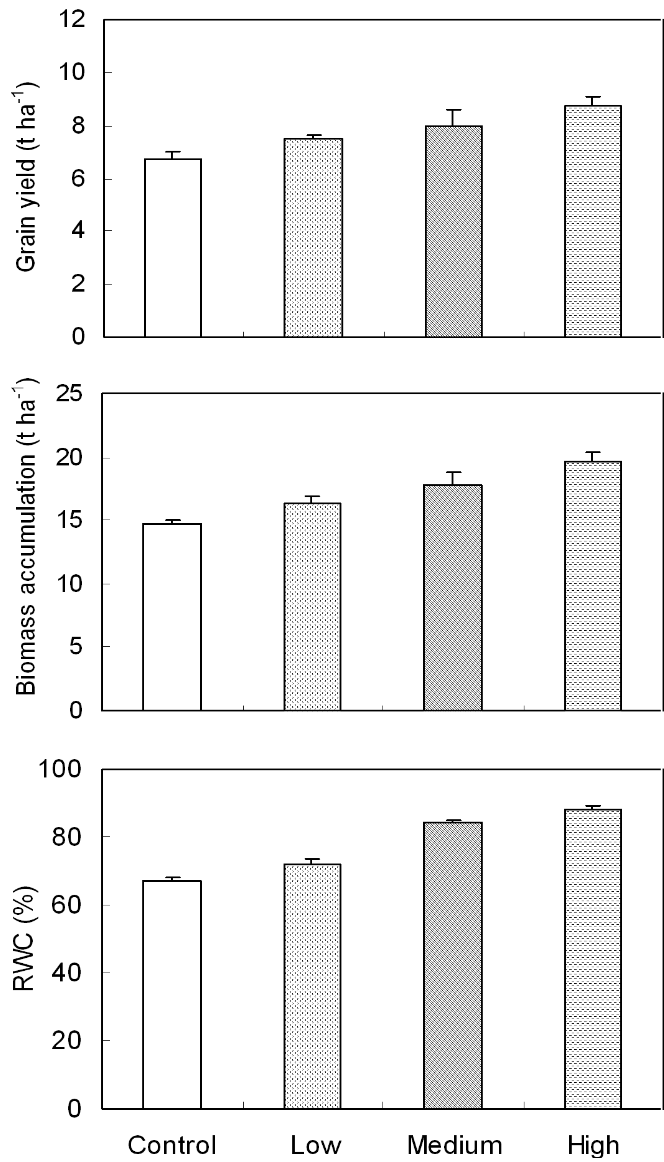

Figure 2. Grain yield, biomass accumulation and relative water contents (RWC) in corn at different superabsorbent polymer rates.

not treated (Table 2).

Dry matter yield

The above ground biomass accumulation (AGB) increased with increasing rate of superabsorbent polymer (Figure 2). The value increased by only 10.4% with low application of SAP, while it increased significantly by 20.5 and 32.9% with medium and high application, respectively.

Grain yield

Figure 2, also shows the grain yield of corn under different treatments. The application of SAP increased the grain yield by 11.2% under low, 18.8% under medium and 29.2% under high rate.

Relative water content

The relative water content (RWC) in plant leaves at grain feeling stage was much higher in plants with SAP (Figure 2). Although, the value increased slightly under low application of SAP, it increased remarkably by 25.8 and 31.9% under medium and high application, respectively.

Soil nutrient content

Total N contents at 0 to 15 cm depths reduced under low superabsorbent polymer application and increased slightly under medium and significantly (25.2%) under high application (Table 3). Total N content at 15 to 30 cm depth in the soil was found lower than surface level (0 to 15 cm) and values showed similar trends following different treatments.

Available P contents at 0 to 15 depth reduced by 22.2% under low and 15.1% under medium superabsorbent polymer level and remain same under high SAP level (Table 3). Available P contents at 15 to 30 cm depths were also reduced by 19.0 and 9.5% under low and medium superabsorbent polymer levels, but not in a statistically significant manner.

Available K contents in the soil also presented in Table 3, reduced by 16.8 and 7.6% under low and medium superabsorbent polymer at 0 to 15 cm depth and 12.6 and 4.2%, respectively at 15 to 30 cm depth. However, K contents with application of SAP at high rate more or less remain stable in both soil depths.

Grain quality

Crude protein contents

Crude protein (CP) contents in the grain reduced slightly (4.4) under low application of superabsorbent polymer and remain unchanged under medium application level (Table 4). However, the value increased significantly by 8.0% under high application of SAP.

Soluble sugar contents

Soluble sugar contents in the grain did not change in a statically significant manner due to SAP application (Table 4). It reduced slightly under low SAP application and increased marginally under medium and high application levels.

Starch contents

Starch contents in the grain also presented in Table 4 did

Table 3. Variation in total N, Available P and Available K contents in different depths of soil under various super absorbent polymer (SAP) treatments.

Treatment	Total N (mg/kg)		Available P (mg/kg)		Available K (mg/kg)	
	0 to 15 cm	15 to 30 cm	0 to 15 cm	15 to 30 cm	0 to 15 cm	15 to 30 cm
CK	105.2	89.9	22.23	14.73	72.30	60.38
Low	97.0	84.8	17.31	11.92	60.17	52.56
Medium	112.5	100.4	18.87	13.33	66.80	57.83
High	131.7	119.7	22.73	17.13	73.30	59.23
Mean	111.6	98.7	20.29	14.27	68.14	57.50
LSD (0.05)	19.22	12.19	3.49	3.58	12.05	10.83

CK, Control; LSD, least significant difference.

Table 4. Crude protein, soluble sugar and starch content in corn grain under different superabsorbent polymer (SAP) treatments.

Treatment	Protein (%)	Soluble sugar (%)	Starch (%)
CK	8.68 ± 0.65	3.72 ± 0.23	65.45 ± 2.42
Low	8.29 ± 0.11	3.49 ± 0.11	61.14 ± 5.57
Medium	8.71 ± 0.27	3.74 ± 0.32	70.09 ± 5.68
High	9.37 ± 0.21	3.87 ± 0.16	75.59 ± 4.12
Mean	8.76	3.71	68.07
LSD (0.05)	0.59	0.711	15.14

CK, Control; LSD, least significant difference.

not change remarkably following superabsorbent polymer treatments. It reduced slightly (6.6) under low SAP application and increased marginally (7.1 and 15.5%) under medium and high application levels.

DISCUSSION

Super absorbent polymers (SAP) have been used as water-retaining materials in the agricultural and horticultural fields (Islam et al., 2009; Johnson, 1984; Mikkelsen, 1994; Yazdani et al., 2007) because when incorporated with soil, they can retain large quantities of water and nutrients. These stored water and nutrients are released slowly as required by the plant to improve growth under limited water supply (Azzam, 1983; Huttermann et al., 1999; Yazdani et al., 2007). Our data have shown that, the applied superabsorbent polymer had a remarkable effect on corn growth (Table 2 and Figure 2), although all the treatments with SAP received only half amount of fertilizer than control plants.

Application of superabsorbent polymer could be an effective way of corn cultivation in the soils characterized by low water holding capacity where, rain or irrigational water and fertilizer leached below the root zone within a short period of time, leads poor water and fertilizer use efficiency by crops (Johnson, 1984; Mikkelsen, 1994; Yazdani et al., 2007). Under this situation, excessive fertilization would not bring any progressive change in crop performance and may rather cause some negative impact on the environment. Application of superabsorbent polymer along with reduced fertilization could change the fertilization strategy in arid and semiarid regions of China.

When aqueous, nutrient-containing solutions are used to hydrate a polymer, a considerable amount of nutrient enters into the polymer structure during expansion (Martin et al., 1993; Woodhouse and Johnson, 1991). Hydrophilic polymers generally contain micro pores that allow small molecules (such as NH_4) to diffuse through the hydrogel, (Johnson and Veltkamp, 1985).The subsequent release of nutrient is then based on the diffusive properties of the polymer, its decomposition rate and the nature of the nutrient salt. Mikkelsen et al. (1993) found that, addition of polymer to the fertilizer solutions reduced N leaching losses from soil columns as much as 45% during the first four weeks in heavily leached conditions compared with N fertilizer alone at the same time Fescue (*Festuca arundinacea* L.) growth was also increased as much as 40% and tissue N accumulation increased up to 50% when fertilized with polymer compared with fertilizer alone. In a similar study Magalhaes et al. (1987) also found a remarkable reduction of NH_4, P and K leaching due to the presence of the polymer.

Differences in the responses of corn subjected to SAP application were evident during our observation. Although, control plot received double amount fertilizer (or conventional standard rate), corn yield increased following superabsorbent polymer application by 11.2% under low, 18.8% under medium and 29.2% under high rate with only half amount of fertilizer (Figure 2). At the same time, protein and sugar contents in the grain also increased. Low (7.5 kg ha^{-1}) application of superabsorbent polymer might not be enough to meet water and nutrient demands of corn, because it could not bring any remarkable progress in crop performance. On the other hands, medium application (11.2 kg ha^{-1}) can bring some remarkable change in crop performance, but both rates could not be recommended due to reduction in soil nutrient balance (especially P and K content) after harvest (Table 3). However, high application rate (15 kg ha^{-1}) could be an optimum rate for corn cultivation under studied areas as it brings remarkable increase in yield, biomass accumulation, protein and sugar contents in the grain and also maintain proper soil nutrient balance. Previously, the use of superabsorbent polymer for the amendment of agricultural soils was considered not economical. The application of SAP at our recommendation (15 kg ha^{-1}) will cost an additional 75 USD ha^{-1} (15 kg × 5 USD), whereas, it can save initially half the fertilizer cost or 60 USD ha^{-1} (150 kg × 0.4 USD). Moreover, superabsorbent polymer can retain soil moisture and fertilizer up to 3 to 5 years after application; at the same time, it also increases quantity and quality of yield. Polymers are safe and non-toxic, it also reduce excessive nutrient loss from soil thereby preventing pollution of agro-ecosystem.

Conclusions

Differences in responses of corn subjected to SAP application against half amount of chemical fertilizer were evident during our observations. Although, control plot received double amount fertilizer (or conventional rate), corn yield increased following SAP application by 11.2% under low, 18.8% under medium and 29.2% under high rate with only half amount of fertilizer. Low and medium application can bring some remarkable change in corn growth performance, but both rates could not be recommended due reduction in soil nutrient balance after harvest. However, application of superabsorbent polymer at 15 kg ha^{-1} against half amount of chemical fertilizer could result to an optimum rate of increase for corn cultivation under the studied areas as it brings remarkable increase in plant height, stem diameter, leaves area, biomass accumulation, grain yield and relative water content as well as protein and sugar contents in the grain. Also, it maintains proper soil nutrients balance after harvest. Thus, the use of superabsorbent polymer could be an effective means for corn production under the arid conditions of northern China or the areas with similar ecologies. Further research on superabsorbent polymer application should consider the duration of its effect and its environmental and economic advantages on the soil and plants.

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