Feasibility of summer corn (*Zea mays* L.) production in drought affected areas of northern China using water-saving superabsorbent polymer

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ABSTRACT

In arid and semiarid regions of northern China, there is an increasing interest in using water-saving superabsorbent polymer (SAP) for field crop production. Experiments were conducted during 2009 and 2010 to study the growth and yield characteristics of summer corn (*Zea mays* L.) under different (control, 0; low, 10; medium, 20; high, 30 and very high, 40 kg/ha) rates of SAP in a drought-affected field of northern China. Corn yield increased slightly following SAP application at low and medium rate, but significantly at high and very high rates by 22.4 and 27.8%. At the same time, plant height, stem diameter, leaf area, biomass accumulation, harvest index and relative water content as well as protein, sugar and starch contents in the grain increased significantly following SAP treatments. The optimum application of superabsorbent polymer for corn cultivation in the study area would be 30 kg/ha as it best increased the grain yield and quality and maintained higher levels of soil nutrients. Lower rates (10 and 20 kg/ha) or higher (≥ 40 kg/ha) rates would neither be sufficient nor economical. We suggest that the application of SAP at 30 kg/ha could be an efficient and economic soil management practice for summer corn production in the drought affected regions of northern China or other areas with similar ecologies.

Keywords: drought stress; soil water conservation; grain yield; soil fertility

Corn (*Zea mays* L.) requires water and minerals to grow and to develop its organs (Orosz et al. 2009). In arid and semiarid regions of northern China, there is an increasing interest in using water-saving superabsorbent polymer (SAP) for field crop (such as corn) production. 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 maize double cropping in a year producing about 29.6% of the nation's food, including about half of the wheat production and a 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 in northern China, where about 75% of the agricultural land is irrigated, consuming 70–80% of the total water resource allocation in the region (Liu et al. 2001). In recent years, however, increased water deficits associated with overuse of surface water, declining groundwater levels, water pollution, and soil salinization

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are threatening the sustainability of agricultural production in the region (Hu et al. 2005). 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 and undeveloped infrastructure (Wang et al. 2007).

Soils in the NCP areas are mostly characterized by low water-holding capacity, high evapo-transpiration 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).

In arid and semiarid regions of the world, use of superabsorbent polymers (SAP) may effectively increase water and fertilizer use efficiency in crops. 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 supply (Islam et al. 2011). 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). The incorporation of SAP with soil improved soil physical properties (El-Amir et al. 1993), enhanced seed germination and emergence (Azzam 1983), crop growth and yield (Yazdani et al. 2007) and reduced the irrigation requirement of plants (Blodgett et al. 1993). 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).

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. Polymers are safe and non-toxic and it will finally decompose to carbon dioxide, water, ammonia, and potassium ion, without any remainder (Mikkelsen 1994). Although the manufacturers' recommended rate of SAP for corn production varied between 15 to 30 kg/ha, there is no particular scientific study to evaluate and document the appropriate rate of SAP to be applied in the field. Therefore, the main objective of this study was to evaluate the effectiveness of different rates of superabsorbent polymer (0, 10, 20, 30, and 40 kg/ha) on growth, biomass production, grain yield plus quality of summer corn in a drought affected field of northern China.

MATERIALS AND METHOD

Plant material and growth condition. The field experiments were conducted at the National Experimental Station for Precision Agriculture, Xiaotangshan (40°10'N, 116°27'E), Beijing, P.R. China, during summer corn growing seasons of 2009 and 2010. The background soil characteristics of the experimental plot, determined at the beginning of the experiment, were as follows: sand 516 g/kg, total N 1.02 g/kg, available phosphorus (P) 23.4 mg/kg, exchangeable potassium (K) 98.7 mg/kg, organic matter 13.4 g/kg, pH 7.3 and bulk density 1.43 g/cm^3.

Climate of the area is continental type and winter temperatures can be as low as –25°C and summer temperature can rise above 40°C; total rainfall is about 543 mm, being concentrated mainly in June–July. Figure 1 shows monthly rainfall and temperatures at the experimental site over the two-year study. Mean annual rainfall for both study years was below (by 48 and 26 mm in 2009 and 2010, respectively) the mean value for the area over the last 30 years. Although there was a difference in rainfall distribution over the growing season, variation in mean annual rainfall between the two study years was marginal. Monthly mean temperatures (not presented) and relative humidity in both years were similar to those of the long-term period.

Plots were marked out with conventional pre-planting land preparation. Treatments comprised super absorbent polymers (SAP) applied in the row mixing with granular fertilizer during seed sowing at low, 10; medium, 20; high, 30 and very high, 40 kg/ha. The control plots received only compound granular fertilizer (NPK 15:15:15). Treatment were replicated three times and arranged into a completely randomized design. JingDan 28, a commonly grown corn variety (*Zea mays* L.) in northern China was used for the experiment. Each treatment occupied a plot area of 6 m × 8 m. Seeds were sown on 21st June and harvested on 30th September of either year (2009 and 2010). Standard seed rate and row spacing (0.60 m) were used during seeding. Plots were irrigated once (within one week) after sowing.

Phenological measurements and calculation. Determination of plant growth (plant height, leaf

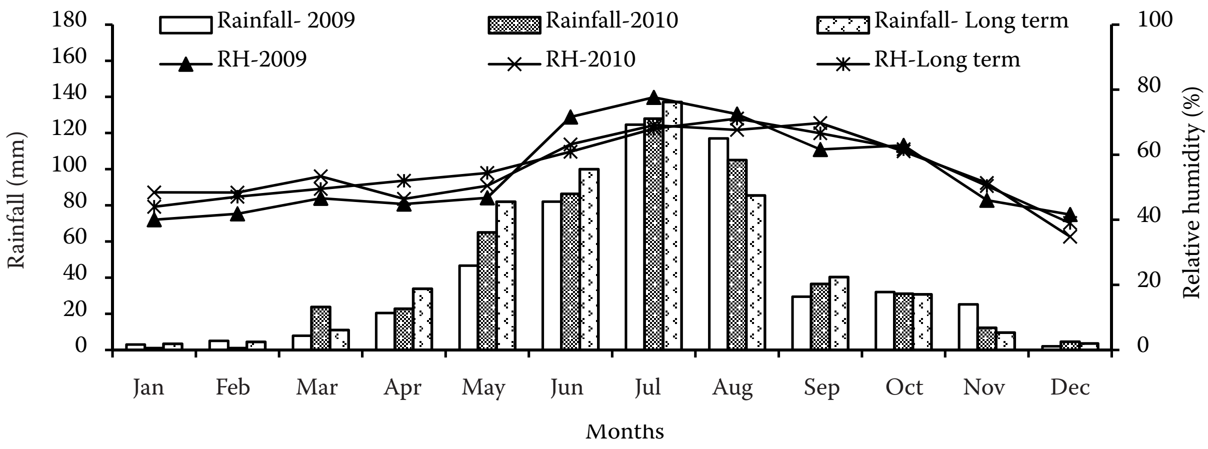

Figure 1. Monthly mean relative air humidity (lines) and rainfall (bars) during the two- experimental seasons versus long-term period. RH – relative humidity

area, grain yield and biomass accumulation) was carried out during harvest. Relative water content (RWC) of leaves was measured on fully expanded leaves at 4, 6, and 8 weeks after sowing (WAS) according to Schonfeld et al. (1988).

The (1000) grain weight was calculated from randomly sampled grains after harvest. At maturity, a sample of 6 m^2 area for each plot was harvested for grain yield and biomass determination. Harvest index was calculated as the ratio between grain yield and shoot biomass.

Soil analysis. Soils were sampled at the 0 to 0.15 m and 0.15 to 0.30 m depths from the sowing rows after harvest. Air-dried soil samples were ground and passed through 1 mm sieve before analysis. Total N was determined by Kjeldhal method (AOAC 1990). Available P was determined by the method of Olsen et al. (1954). Available K was measured by analysing the filtered extract on an atomic absorption spectrophotometer set on emission mode at 776 nm.

Grain quality determination. Dried samples were ground and pass 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 according to standard procedures (AOAC 1990).

Statistical analysis. An analysis of variance was performed using the STATEVIEW software to statistically partition the effect of superabsorbent polymer rates. 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 but the effects were less noticed under low and medium rates when it increased by 7.9 and 8.3% for high and very high SAP rates (Table 1).

Stem diameter. Stem diameter increased with increasing rate of SAP (Table 1) but the values were not significant under low, medium and high SAP rates. The value increased significantly by 10.1% for the very high rate of SAP.

Leaf area. The corn leaf area under different treatments also presented in Table 1 did not change under low and medium SAP rates but it increased remarkably for high and very high rates by 26.3 and 30.4%, respectively.

Grain per plant. The number of grains per plant changed little under low and medium SAP rates (Table 1) whereas, under high and very high application, it increased significantly by 21.8 and 31.7%.

1000-grain weight. Although no marked changes were noted in 1000-grain weight due to low, medium and high SAP rates, the grain weight under the very high rate increased significantly (Table 1).

Dry matter yield. The above-ground biomass accumulation (AGB) increased following SAP application (Figure 2) but the effect was less noticed for low and medium SAP rate. However, application of SAP increased biomass accumulation by 13.3 and 17.4% for high and very high rate, respectively.

Grain yield. Grain yield of corn increased with increasing rate of SAP (Figure 2) and the effect was also less noticed for low rate. Application of

Table 1. Plant height, stem diameter, leaf area, number of grains per plant and 1000 grains weight of corn under different superabsorbent polymer (SAP) treatments

Treatments	Plant height (cm)	Leaves area (m^2)	Stem diameter (cm)	Number of grains/plant	1000 grain weight (g)
Control	208	0.39	1.76	359	239
Low	212	0.42	1.81	398	247
Medium	217	0.44	1.82	415	248
High	225	0.49	1.87	436	254
Very high	225	0.50	1.93	472	255
Mean	217	0.45	1.84	416	249
LSD (0.05)	7.6	0.05	0.09	45.6	9.5

LSD – least significant difference

SAP increased grain yield by 14.4, 22.4, and 27.8% for medium, high and very high rates.

Harvest index. Figure 2 also shows the trends of harvest index (HI) under different treatments. Although the effect of SAP were less noticed under low and medium rate, the HI increased by 8.1 and 8.9% under high and very high SAP rates.

Relative water content. Table 2 shows the changes in relative water content (RWC) of fully expanded leaves for SAP treatments at 4, 6, and 8 weeks after sowing (WAS). Although low or medium rates of SAP had little effects the high and very high rates increased the RWC by 16.7 and 20.4 at 4 WAS, 18.2 and 22.3% at 6 WAS and 14.1 and 15.5% at 8 WAS.

Grain quality. Crude protein (CP) contents in the grain increased with SAP treatments in both seasons (Table 3). Although the effect was less noticed for low and medium SAP rates, the value increased significantly by 22.8 and 32.5% at high and very high SAP rates. Soluble sugar contents in the grain did not change for low and medium SAP rates (Table 3) but increased significantly (31.6 and 40.1%) at the high and very high rates. Starch contents in the grain (Table 3) did not change following SAP treatment at low, medium and high rate. It increased significantly for only very high SAP rate.

Soil nutrient status. Total N (TN) contents at the 0 to 0.15 m soil depth increased slightly under

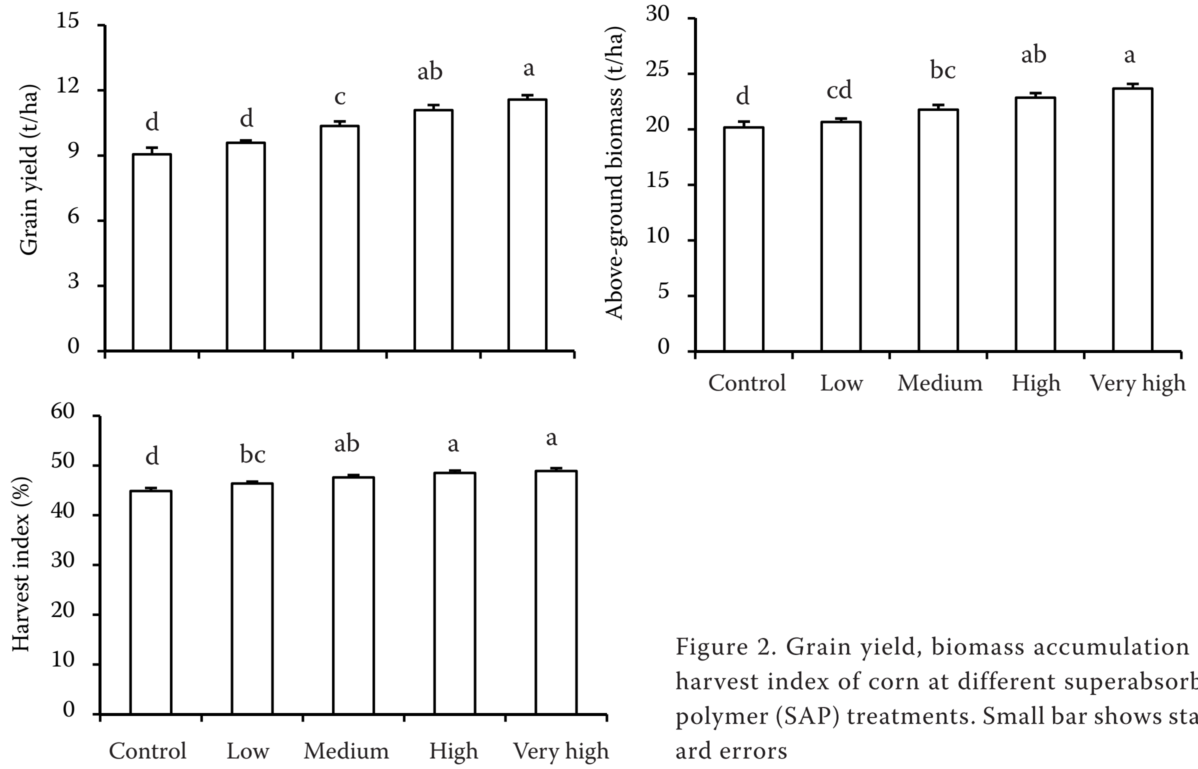

Figure 2. Grain yield, biomass accumulation and harvest index of corn at different superabsorbent polymer (SAP) treatments. Small bar shows standard errors

Table 2. Variations in relative water contents (RWC) in corn leaves at different growth stages under different superabsorbent polymer (SAP) treatments

Treatments	RWC (4 WAS)	RWC (6 WAS)	RWC (8 WAS)
Control	68.2	65.9	76.3
Low	69.5	67.5	81.2
Medium	74.8	71.6	82.6
High	79.6	77.9	87.1
Very high	82.1	80.6	88.1
Mean	74.8	72.7	83.1
LSD (0.05)	6.5	4.8	3.5

WAS – weeks after sowing; *LSD* – least significant difference

Table 3. Variations in crude protein (CP), soluble sugar and starch content in corn grain under different superabsorbent polymer (SAP) treatments

Treatments	Protein (%)	Soluble sugar (%)	Starch (%)
Control	7.1	4.9	40.8
Low	7.2	5.2	41.5
Medium	7.9	5.9	46.8
High	8.7	6.4	45.7
Very high	9.4	6.8	46.9
Mean	8.1	5.8	44.3
LSD (0.05)	0.6	0.6	4.2

LSD – least significant difference

the low SAP rate but it increased remarkably by 19.3, 36.6, and 35.8% for medium, high and very high SAP rates (Table 4). Total N content at the 0.15 to 0.30 m depth was lower than surface level (0 to 0.15 m) and varied almost similarly across SAP treatments.

Available P contents at the 0–0.15 m depth increased under medium, high and very high SAP rates by 20.5, 44.3, and 55.6%, respectively (Table 4). At the 0.15–0.30 m depth, the increase ranged from 10.5 to 56.8%. Exchangeable K increased remarkably at 0–0.15 m depth for high and very high SAP rates but the content the at 0.15–0.30 cm did not changed with SAP treatments (Table 4).

DISCUSSION

Superabsorbent polymers (SAP) have been used as water-retaining materials in the agricultural and horticultural fields (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 (Yazdani et al. 2007). Our data have shown that the applied SAP had a remarkable effect on corn growth, yield and quality (Table 1 and Figure 2) compared with control plants.

Relative water content (RWC) is an appropriate measure of plant water status in terms of the physiological consequence of cellular water deficit (Kramer 1988). We found that the application of SAP substantially increased the RWC in corn leaves at different growth stages (Table 3). Application of SAP could conserve different amounts of water in itself thereby increasing the soil's capacity for water storage, ensuring more available water; thus the RWC content in leaves as well as plant growth and yield increased under water stress.

Table 4. Variations in total N, available P and exchangeable K contents with soil depths under different superabsorbent polymer (SAP) treatments

Treatments	Total N (g/kg)		Available P (mg/kg)		Exchangeable K (mg/kg)	
	0–0.15 m	0.15–0.30 m	0–0.15 m	0.15–0.30 m	0–0.15 m	0.15–0.30 m
Control	1.01	0.95	22.1	17.1	127.7	119.2
Low	1.09	0.93	21.7	18.8	132.8	124.9
Medium	1.20	1.09	26.7	22.4	141.6	122.5
High	1.37	1.19	32.1	24.2	148.4	132.4
Very high	1.36	1.30	34.3	26.1	151.9	136.1
Mean	1.21	1.09	27.4	21.7	140.5	127.0
LSD (0.05)	0.24	0.18	4.7	3.19	16.1	10.1

LSD – least significant difference

Application of SAP could be an effective management practice for corn cultivation in soils characterized by low water holding capacity where rain or irrigation water and fertilizer often leach below the root zone within a short period of time, leading to poor water and fertilizer use efficiency by crops (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 SAP along with 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 (Islam et al. 2011). 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. Thus plant growth, yield and quality increased following SAP application. 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 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) found a remarkable reduction in NH_4, Ca, Mg, and K leaching due to the presence of the polymer. Our results also showed a remarkable increase in soil nutrients in presence of SAP (Table 4), possibly due to reduction in leaching losses from soil.

Differences in the responses of SAP-treated corn were evident during our observation. Although corn yield increased slightly under low SAP application, it increased by 14.4, 22.4, and 27.8% for medium, high and very high rates, respectively (Figure 2). At the same time protein and sugar contents in the grain also increased. Low (10 kg/ha) and medium (20 kg/ha) rate of SAP might be not enough to meet water and nutrient demands of corn, because it could not bring any remarkable progress in crop performance. Although the high (30 kg/ha) and very high rate (40 kg/ha) rates increased corn yield and harvest index as well as soil fertility, we recommend the high rate or 30 kg/ha for economic reasons. The application of SAP could be an effective drought mitigation strategy for field crop production and its application at 30 kg/ha would be appropriate for corn production in the arid and semiarid regions of northern China or other areas with similar ecologies. Further research on SAP application should consider the duration of the effect on the soil and plants and its environmental and economic advantages.

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