Hindawi
Advances in Polymer Technology
Volume 2022, Article ID 6554918, 12 pages
https://doi.org/10.1155/2022/6554918

Research Article

Multifunctional Superabsorbent Polymer under Residue Incorporation Increased Maize Productivity through Improving Sandy Soil Properties

Rong Li, Xianqing Hou, Peifu Li, and Xi'na Wang

School of Agriculture, Ningxia University, Yinchuan 750021, China

Correspondence should be addressed to Xianqing Hou; houxianqing1981@126.com

Received 1 July 2022; Revised 15 October 2022; Accepted 28 October 2022; Published 13 December 2022

Academic Editor: Kinga Pielichowska

Superabsorbent polymer (SAP) is a new water-retaining and nutrient-holding material with the potential to improve soil properties and promote crop growth in arid and semiarid areas. This study investigated the effects of multifunctional SAP on the sandy soil properties and maize productivity in Yanghuang irrigated area of Ningxia where residue incorporation was a common agricultural practice, we tested multifunctional SAP at different doses of 0, 30, 60, 90, and 120 kg ha^{-1} under the residue incorporation to the field. The soil bulk density in the 0–0.40 m layer was significantly lower by 6.2–8.2% under SAP at 60–120 kg ha^{-1} compared with no SAP, but the total soil porosity was improved significantly by 8.5–11.2%, where the SAP at 90 and 120 kg ha^{-1} had the greatest effects. The applications of SAP at 60 and 90 kg ha^{-1} significantly improved soil organic matter, and available P and K contents in the 0–0.40 m soil layer. The soil water storage (0–1.0 m) under SAP at 60–120 kg ha^{-1} was significantly increased by 17.1–18.7% compared with no SAP throughout the whole maize growing season. The SAP at 60–90 kg ha^{-1} significantly promoted crop growth and maize yield formation, and increased grain yield, whereas the net income were the highest with applying SAP at 30–60 kg ha^{-1}. In combination with the soil physicochemical property, crop productivity and economic benefit comprehensive analysis of this two-year study, we recommended that the application of multifunctional SAP at 30–60 kg ha^{-1} under residue incorporation significantly improved the sandy soil properties, as well as increasing maize growth, crop productivity, and obtain the higher net income for farmers in Yanghuang irrigation area of Ningxia, China.

1. Introduction

In the dryland farming region of northern China, maize (*Zea mays* L.) is the main grain and forage crop, and the area planted with maize is growing more rapidly than that with other crops. The yield of maize accounts for about half of the total grain production in Ningxia and it is the highest of all the grain-producing crops [1]. Therefore, improving maize productivity is very important for ensuring food security in Ningxia. The abundant light and heat resources in the Yanghuang irrigation area of Ningxia are advantageous for maize productivity [2]. However, the planting of maize in this area is affected by water shortages and by the soil type, which is dominated by the gray-calcium soil formed under the desert steppe vegetation type. Thus, soil infertility and water deficiency are major constraints on maize productivity in this region [3].

Water-saving techniques have been developed to overcome the challenges caused by the limited availability of water resources for agriculture [4]. Among the many water-saving techniques that have been developed, the use of chemical water-saving materials is important for facilitating water-saving agriculture in arid areas [5, 6]. Superabsorbent polymers (SAPs) have been developed as chemical water-saving agents and applied widely [7]. SAPs are hydrophilic network polymers with a super-high capacity for water absorption and retention, and a slow water release [8]. Previous studies have shown that the application of SAPs to soils can reduce the water evaporation from the soil surface and water infiltration [9], and the soil porosity and structural stability can also be improved [10]. Meanwhile, SAPs also can improve the conservation of soil water, prevent deep percolation and soil nutrient losses, and maximize the water and fertilizer use efficiency [6, 11]. Maize belonged to the crop with high water consumption, whereas SAPs have the stronger effect on increasing maize productivity [12, 13]. Recently, most commoditized polymers are mainly in polypropylic acid (PAA) or polyacylamide (PAM), but the high prices of SAPs limits its applications in agriculture [14]. Attapulgite and other clay minerals are incorporated in SAPs to reduce production cost, and also to improve the properties (e.g., swelling ability, gel strength, and mechanical and thermal stability) of the SAPs (e.g., organic–inorganic hybrid multifunctional SAP) [15, 16]. Thus, the application of multifunctional SAP in agriculture has become a popular water-saving technology for farmers in arid and semiarid regions of northern China.

Droughts occur often in the Yanghuang irrigation area of Ningxia, where the infertility of the sandy soils and severe losses of water and fertilizer greatly affect the growth and development of maize [3]. Returning crop residue to the field is an important practice for enhancing crop production with a favorable soil environment [17], as well as alleviating the soil degradation caused by intensive and continuous conventional tillage [18]. The beneficial effect on water and nutrient holding capacity by adding multifunctional SAP to sandy soils has been well documented in short-time lab studies [19, 20]. However, less is known about its performances under repeated cycles of irrigation and residue incorporation in the field. In field applications, SAPs are also affected by environmental conditions, such as the soil temperature, humidity, microbes, and soil wetting and drying cycles [5, 11, 21]. Many studies on SAPs for use in agriculture have focused on the research and development of new materials and products [22, 23], the comparison and evaluation of physical and chemical characteristics [24, 25], and the effects on soil and plant growth [8, 26]. Combining the water and fertilizer conservation functions of multifunctional SAP with the soil fertility improvements obtained by residue incorporation to the soil under the drip irrigation condition in order to enhance the soil properties and agricultural production has important practical significance, especially for improving sandy soil with the bulk density over 1.5 kg cm^{-3} and the organic matter below 5.0 g kg^{-1} in the Yanghuang irrigation area. However, few studies have considered the effects of multifunctional SAP on improving the sandy soil properties and maize productivity when residue is returned to sandy soil in irrigated areas. Thus, in the present study, we conducted a continuous two-year field experiment to determine the application effects of multifunctional SAP different doses combined with the return of residue to the soil on the physical and chemical properties of the soil, as well as the growth, and crop productivity for maize. We tested multifunctional SAP at different application rates, and the multifunctional SAPs were mixed with air-dried soil and used by spot application around the root during the maize seedling stage. The main objective of this study was to clarify the soil amelioration and fertility effects and maize productivity of applying multifunctional SAPs at different rates. Our results should provide a reference to support the rational application of multifunctional SAPs to enhance the fertility of sandy soil and maize productivity under conditions with the residue incorporation to the soil in Yanghuang irrigation area of Ningxia, China.

2. Materials and Methodology

2.1. Site Description. This study was conducted between 2015–2017 in Sandunzi Village, Yanchi County, Ningxia Province (37°40′N, 106°51′E), which is located in eastern Ningxia. The study site was a typical Yanghuang irrigation area with an average elevation of 1300 m. The experimental site was located in a warm temperate zone with an annual mean air temperature of 9.4°C. The mean annual precipitation was 280 mm, where it mainly occurred during June–September, and the average annual pan evaporation was about 2500 mm. The total annual sunshine was 2800 h and the frost-free period was 151 days. Weather data were obtained from a weather station at the experimental site. The monthly precipitation and air temperature distributions during the experimental period are shown in Figure 1. The precipitation rates during the maize growing season (April–September) were 224.2 and 184.8 mm in 2016 and 2017, respectively.

Reclaiming virgin land and plowing cropland in the experimental area destroy soil structure and accelerate the loss of soil organic carbon, the top layer of the original sierozem was covered by deep aeolian sandy soil. The upper layer of the soil (0–0.40 m) was sandy loam and the lower layer (0.40–1.0 m) was light sierozem [3]. The physical and chemical properties at the 0–1.0 m soil depth are shown in Table 1. The soil was classified according to the United States Department of Agriculture (USDA) Soil Texture Classification Standard [27, 28]. The topsoil (0–0.40 m) at the experimental site had the following characteristics (Table 1): soil bulk density 1.54 g cm^{-3}, total salt 0.43 g kg^{-1}, organic matter 4.7 g kg^{-1}, available N 35.2 mg kg^{-1}, available P 4.6 mg kg^{-1}, and available K 67.5 mg kg^{-1}. The site was sown with spring maize prior to the experiment in 2016.

2.2. Field Management and Experimental Design. Before mixing with the soil, maize residue was chopped into segments with a length of 0.05 m and then applied to the soil at six months before the crop was sown to facilitate residue decomposition. The 9000 kg ha^{-1} maize residue was incorporated into the 0.20 m soil layer on October 7, 2015 and after the crop was harvested during 2016–2017. Before sowing, a basic fertilizer (DAP) at a rate of 300 kg ha^{-1} was spread evenly over each plot and plowed into the soil layer. Maize (cv. Longdan 9 in 2016, Yinyu 439 in 2017) was sown at a rate of 95,250 plants ha^{-1} on April 20, 2016 and April 22, 2017 using an air-suction precision planter. Each treatment had the same row width spacing of 0.70 m and a narrow plant spacing of 0.30 m, and a thin-walled drip irrigation hose was laid near the plant row. Irrigation and fertilizer were applied in the key maize growing period (Table 2). Irrigation water was applied every 10 days after sowing the

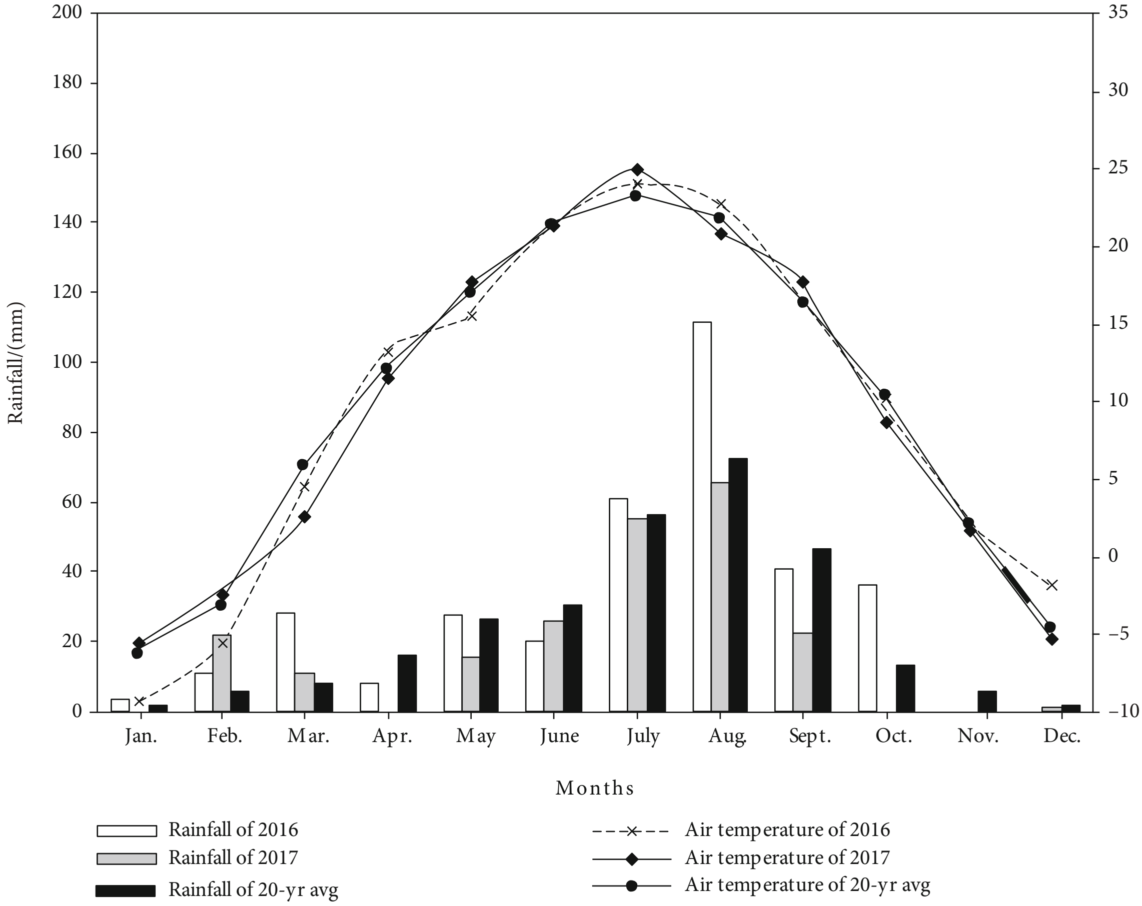


Figure 1: Monthly rainfall and average daily air temperature distribution at experimental site during the study.

maize. A differential pressure tank was connected to the drip irrigation system to inject fertilizer via irrigation. The irrigation frequency and amount during the maize growing season were 12 times and 2400 m^3 ha^{-1}. Nitrogen fertilizer was added in the form of urea (N 46%) at a rate of 780 kg ha^{-1}. Potassium sulfate (K_2O 50%) was added at a rate of 165 kg ha^{-1}. Maize was harvested on September 28, 2016 and September 30, 2017.

SAPs have different effects on the soil porosity and crop production according to their type, application method, and application dose [21]. Previous studies have shown that the application of SAP at 60 kg ha^{-1} and a depth of 0.20 m significantly improved crop growth and yield, and this method is recommended for oil sunflower cultivation in the arid area of central Ningxia [29]. However, the use of a multifunctional SAP at 30 kg ha^{-1} at the seeding stage is more suitable for potato production in the mountainous area of south Ningxia [30]. In order to determine the application effects of multifunctional SAP doses on the soil properties and maize productivity under the residue incorporation conditions in Yanghuang irrigation area, this experiment tested multifunctional SAP, Wote SAP as an organic-inorganic hybrid SAP, consists of a negatively charged acrylic-acrylamide polymer synthesized with a attapulgite (composition: 70% negatively charged acrylic–acrylamide polymers with 20% hydrolysis synthesized with 30% attapulgite; water absorbency = 500 – 600 g g^{-1}; bead size =0.4–1.5 mm; pH = 6.0 – 8.0; and life span = 3 – 5 years; manufactured from polyacrylamide and acrylic acid by Dongying Huaye New Material Co., Ltd., in Shandong) at different application rates.

According to the recommended dosage of the Wote SAPs from the manufacturers and the former studies, the five treatments tested in this study comprised: SAP 0 kg ha^{-1} (SAP0), SAP 30 kg ha^{-1} (SAP30), SAP 60 kg ha^{-1} (SAP60), SAP 90 kg ha^{-1} (SAP90), and SAP 120 kg ha^{-1} (SAP120). Each treatment comprised three replicated plot and each plot measured 12 m long × 10.0 m wide. The multifunctional SAP was evenly mixed with air-dried soil before its application at different rates. To combat drought and protect the seedlings, spot application around the root under normal farming conditions was often used in maize production of seedling stage. The SAP was added to the soil at the maize five-leaf stage at the depth with root development by making 0.20 m deep holes in the soil. A 0.15 m soil–SAP mixed layer was placed 0.20 m below the soil surface. The holes were filled with a mixture of soil and SAP. Soil was compacted around the roots manually. Manual weeding was performed as required throughout the experiment.

2.3. Sampling and Analysis. Immediately after the harvest in 2015 and 2017, three random soil samples were collected

Table 1: Physical and chemical properties at the 0–1.0 m soil depth in the experimental site.

Depth cm	Particle size (%) Sand (%) 2.0-0.05 mm	Silt (%) 0.05-0.005 mm	Clay (%) <0.005 mm	Classification	BD ($g\,cm^{-3}$)	OM ($g\,kg^{-1}$)	TS ($g\,kg^{-1}$)	AN ($mg\,kg^{-1}$)	AP ($mg\,kg^{-1}$)	AK ($mg\,kg^{-1}$)	pH
0-40	69.8	19.6	10.6	Sandy loam	1.54	4.7	0.43	35.2	4.6	67.5	8.8
40-100	56.2	30.4	13.4	Light sierozem	1.44	2.3	0.64	18.8	1.8	28.0	9.3

BD, bulk density; OM, organic matter; TS, total salt; AN, available nitrogen; AP, available phosphorus, AK: available potassium.

TABLE 2: Irrigation water and fertilizer applications during the maize growing season.

Growth stage	Irrigation date	Irrigation frequency	Irrigation amount ($m^3 ha^{-1}$)	Topdressing amount ($kg ha^{-1}$)	
				Urea	Potassium sulfate
Sowing (0 DAS)	Late April	1	120	0	0
Seedling (25 DAS)	Middle May	1	150	60	0
Jointing (50–75 DAS)	Early June	1	225	75	0
	Middle June	1	200	75	0
	Late June	1	205	75	75
Tasseling (75–100 DAS)	Early July	1	375	75	0
	Middle July	1	225	75	45
	Late July	1	150	100	0
Filling (100–125 DAS)	Early August	1	300	100	45
	Middle August	1	125	100	0
	Late August	1	100	45	0
Maturity (125–150 DAS)	Early September	1	225	0	0
Total		12	2400	780	165

from the middle of two planting rows in each plot using a 54 mm diameter steel core sampling tube, which was driven down manually to depths of 0.20 m and 0.40 m. The soil cores were weighed wet, dried at 105°C for 48 h, and weighed again to determine their bulk density [31].

Soil samples were collected from two depths (0–0.20 and 0.20–0.40 m) in each treatment after the maize harvest in 2015 and 2017. A soil sample was taken from each plot to determine the soil nutrient indexes. Soil organic matter was determined using the H_2SO_4–$K_2Cr_2O_7$ oxidation method [32]. Available N was analyzed using the cadmium reduction method [33]. Available P was extracted with a $NaHCO_3$ solution adjusted to pH 8.5 [32]. Available K was determined by flame photometry [34].

The soil water content was determined in the middle of two planting rows in each plot seven times during the season before irrigation by collecting three random soil core samples using a 54 mm diameter steel core sampling tube, which was driven manually to a depth of 1.0 m during each maize growing season (sowing 0 days after sowing, DAS; seedling 25 DAS; jointing 50 DAS; tasselling 75 DAS; silking 100 DAS; filling 125 DAS; and maturity 150 DAS) in 2016–2017. The soil cores were weighed wet, dried in a fan-assisted oven at 105°C for 48 h, and weighed again to determine the soil water content and bulk density. The soil water storage (*SWS*) was calculated using the following equation [35]:

$$\mathrm{SWS} = \sum_{i}^{n} hi \times pi \times bi/10, \quad (1)$$

where h_i (cm) is the thickness of a measured soil layer; p_{i} ($g\,cm^{-3}$) is the soil bulk density of each soil layer; b_{i} is the soil water content of each soil layer; n is the number of soil layers, and $i = 10, 20, 40 \cdots, 100$.

Growth was recorded at different stages in each plot. Ten maize plants were selected randomly and marked to measure their height, stem diameter, and aboveground biomass during each maize growing season. The stems and leaves of five plants were measured to determine their fresh mass, before drying in an oven at 105°C for 1 h and then at 75°C for at 72 h to obtain the dry mass.

The following yield components were measured at the maize maturity stage between 2016 and 2017: heads per square meter, kernels per head, and 100 kernel weight. Heads per square meter were determined using 3 square meter area (1.0 m × 3.0 m) for each treatment with three replicates in each plot. Kernels per harvested area were calculated by dividing the harvested grain weight by the weight per grain. Kernels per head were calculated by dividing the number of kernels per harvested area by the number of heads per harvested area. After oven drying and weighing, grain was threshed from the straw, cleaned, and weighed. Weights per kernel were measured by counting and weighing 100 kernel samples taken from the harvested grain of each plot. The maize grain yield was measured at 12% water content by manually harvesting from a 3 square meter area (1.0 m × 3.0 m) for each treatment with three replicates in each plot.

2.4. Statistical Analysis. The data were analyzed by analysis of variance (ANOVA) using the SAS 8.02 package (SAS Institute Inc., North Carolina, USA). The significance of F values was determined from ANOVA tables. Multiple comparisons of the annual mean values were performed using Duncan's multiple range tests. In all of the analyses, $P < 0.05$ was considered to indicate a significant difference. Graphs and tables were prepared using Excel 2003.

3. Results and Discussion

3.1. Soil Physicochemical Characteristics. SAPs can change the soil basic physical properties because of their strong water-absorbing capacity and changes in volume during wetting and drying cycles [5]. Proper use of SAP could reduce the soil bulk density, improve the soil permeability, and could help superfluous organic matter aggregate into the soil layer, so as to prevent it being immediately decomposed or lost [36]. Before the experiment (in 2015), the mean soil bulk density in the topsoil (0–0.40 m) was 1.54 g cm^{-3}. After the two-year experiment, the soil bulk density in SAP60, SAP90, and SAP120 decreased significantly compared with the initial background value (before treating), whereas it decreased slightly in SAP30 and SAP0 (Table 3). The mean soil bulk densities with SAP60, SAP90, and SAP120 decreased significantly ($P < 0.05$) by 6.2%, 7.6%, and 8.2% compared with SAP0, respectively. The soil total porosities in all the treatments increased significantly compared with the pretreatment level (Table 3). The soil total porosities in SAP60, SAP90, and SAP120 were 8.5%, 10.4%, and 11.2% higher ($P < 0.05$) than that in SAP0, respectively. Thus, the application of multifunctional SAP significantly increased the soil porosity by maintaining lower bulk density levels in the topsoil (0–0.40 m) compared with no SAP. This was attributed to the fact that applying the multifunctional SAP with topsoil layer could form large numbers of macropores during the water absorption process, and improve the topsoil pore structure [36]. This could have been related to the composition of the multifunctional SAP with the high water absorbency and volume expansibility rate [37]. The difference in root density, soil organic matter contents and the external mechanical forces during SAP fertilization (residue incorporation with superabsorbent polymer) may also the possible reasons. SAP with crop straw and residue under deep ploughing measure were helpful in promoting crop root growth, thus forming the root network, root rot, and root secretion, which led to an enhancement in large numbers of soil macropores [38, 39]. However, we also found that when the SAP dose exceeded 90 kg ha^{-1}, the effects on further improvements in the soil bulk density and porosity were not obvious because an appropriate dose of SAP could form large numbers of macropores in the water absorption process, and improve the soil physical properties and soil pore structure [25, 36].

Soils amended with a suitable concentration of SAP can absorb more water and nutrients can be released slowly, thereby increasing the retention of soil nutrients [40]. Improving the release of the soil available nutrients after the application of SAP enhance the use of nutrients during the crop growing season [41]. The changes in the soil nutrient contents (0–0.40 m) in each treatment are shown in Table 3. Two years after returning residue to the soil, the soil organic matter contents with SAP60 and SAP90 were 8.5–16.4% ($P < 0.05$) higher compared with the pretreatment level. The soil available P and available K contents in all the SAP treatment were significantly higher than the pretreatment levels. However, the soil available N content in each treatment was lower than the pretreatment level. The soil organic matter and available N contents with the SAP treatments were increased significantly compared with SAP0, where the most significant ($P < 0.05$) increases occurred in the SAP60 and SAP90 treatments. The soil organic matter with SAP60 and SAP90 was increased by 34.4% and 25.3% ($P < 0.05$), and the soil available N contents with SAP60 and SAP90 increased by 52.0% and 27.3% ($P < 0.05$), compared with SAP0, respectively. The SAP30, SAP60, and SAP90 treatments increased the soil available P contents by 36.1%, 48.6%, and 21.9%, respectively ($P < 0.05$), compared with the SAP0 treatment. The SAP treatments increased the soil available K contents by 39.7–43.1% ($P < 0.05$) compared with no SAP. Therefore, the application of SAP effectively increased the soil organic matter and available P and K contents, and the application of SAP at 60 and 90 kg ha^{-1} obtained the greatest effects, which may be explained by the following reasons. First, residue incorporation could effectively improve the soil fertility, increase the contents of organic matter and total nitrogen to some extent, and improve the soil fertility conservation and supply capacity [42]. Second, the application of multifunctional SAPs could improve the sandy soil physicochemical properties [43], and facilitated the transformation of fertilizers or soil nutrients into a slowly available nutrient source, thereby preventing the immediate decomposition or loss of nutrients [36]. Third, the suitable concentrations of SAP can absorb more water, nutrients can be released slowly, and nutrient retention in topsoil can be increased [6, 42]. Also, excessive application of SAP (SAP at 90 and 120 kg ha^{-1}) could also cause the soil structure to be hardened and the soil quality to be reduced [43, 44], which may result in lower microbial activity [39] and the decreased soil organic matter and available N contents.

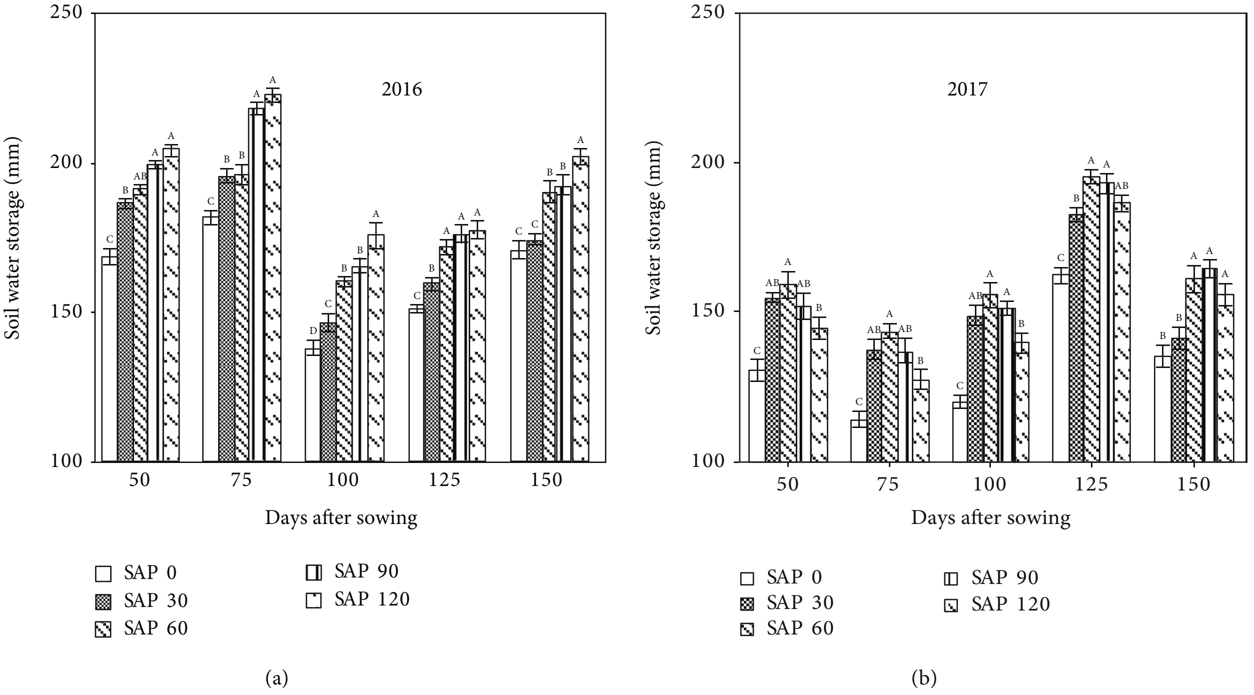
3.2. Soil Water Storage. The application of SAP could affect the soil water retention, migration, and redistribution [45]. Due to differences in precipitation, irrigation, and the multifunctional SAP dose, the soil water storage in the 0–1.0 m layer in all treatments varied greatly during the maize growing season, but they tended to fluctuate less as the growth of the maize continued (Figure 2). The soil water storage was the same (data not shown) in each treatment before the application of multifunctional SAP at 25 DAS. The SAP treatments significantly improved the soil water storage at 50 DAS compared with no SAP. The soil water storage with SAP90 and SAP120 in 2016 were 18.4% and 21.5% ($P < 0.05$) higher compared with SAP0. In 2017, the SAP30, SAP60, SAP90, and SAP120 treatments improved the soil water storage by 18.3%, 21.7%, 16.1%, and 10.6% ($P < 0.05$) at 50 DAS, when compared with SAP0, respectively.

During the middle growing stage (from 75–100 DAS), the soil water storage decreased sharply in each treatment as maize growth entered a vigorous period and the consumption of water by the crop increased (Figure 2). In 2016, the soil water storage was increased significantly higher in the SAP treatments. At 75 DAS, the SAP90 and SAP120 treatments significantly ($P < 0.05$) increased the soil water storage by 20.1% and 22.4% compared with SAP0, and the soil water storage with SAP60, SAP90, and SAP120 were 16.2%, 19.9%, and 27.3% higher ($P < 0.05$) compared with SAP0 at 100 DAS. During 2017, the SAP30, SAP60, and SAP90 treatments significantly ($P < 0.05$) increased the soil water storage by 22.2%, 27.7%, and 22.9% from 75–100 DAS compared with SAP0, respectively.

Table 3: Effects of multifunctional SAP doses on soil physicochemical characteristics in 0–0.40 m layer.

Treatment	Soil bulk density ($g\,cm^{-3}$)	Total porosity (%)	Soil organic matter ($g\,kg^{-1}$)	Soil available N ($mg\,kg^{-1}$)	Soil available P ($mg\,kg^{-1}$)	Soil available K ($mg\,kg^{-1}$)
Before treating	1.54 ± 0.02a	41.89 ± 1.53c	4.70 ± 0.15a	35.20 ± 1.12a	4.60 ± 0.34ab	67.50 ± 2.74a
SAP0	1.53 ± 0.02ab	42.30 ± 1.28bc	4.07 ± 0.07c	22.51 ± 1.21b	5.02 ± 0.13cd	55.95 ± 3.62c
SAP30	1.49 ± 0.01b	43.66 ± 0.31b	4.51 ± 0.14bc	26.65 ± 0.88b	6.83 ± 0.36ab	78.14 ± 2.85ab
SAP60	1.43 ± 0.04c	45.89 ± 1.09a	5.47 ± 0.08a	34.21 ± 0.84a	7.46 ± 0.43a	84.88 ± 3.72a
SAP90	1.41 ± 0.03c	46.68 ± 1.05a	5.10 ± 0.16a	28.65 ± 1.35ab	6.12 ± 0.38bc	89.09 ± 4.08a
SAP120	1.40 ± 0.02c	47.02 ± 0.70a	4.31 ± 0.10bc	24.48 ± 0.98b	5.36 ± 0.29c	80.08 ± 3.96a

SAP0 = SAP 0 kg ha^{-1}; SAP30 = SAP 30 kg ha^{-1}; SAP60 = SAP 60 kg ha^{-1}; SAP90 = SAP 90 kg ha^{-1}; and SAP120 = SAP 120 kg ha^{-1}. Values followed by the same lowercase letter in the same column are not significant according to the least significant different test (LSD 0.05).



(a)

(b)

Figure 2: Effects of multifunctional SAP doses on soil water storage (0–1.0 m) during the maize growing season in 2016–2017. SAP0 = SAP0 kg ha^{-1}; SAP30 = SAP 30 kg ha^{-1}; SAP60 = SAP 60 kg ha^{-1}; SAP90 = SAP 90 kg ha^{-1}; and SAP120 = SAP 120 kg ha^{-1}. Horizontal bars represent significant difference at the 0.05 probability level according to the least significant different test (LSD 0.05).

During the later growth stage (from 125–150 DAS), there was an increase in rainfall and a decrease in crop water use, and the soil water storage increased in each treatment (Figure 2). In 2016, the SAP treatments improved the soil water storage at 150 DAS, especially the average soil water storage with SAP60, SAP90, and SAP120 were 12.4%, 14.3%, and 17.7% higher ($P < 0.05$), respectively, compared with SAP0. In 2017, the SAP60 treatment obtained the best effect of water-holding capacity (20.2%) at 150 DAS compared with SAP0, followed by SAP90 and SAP120 with 19.9% and 15.1% higher ($P < 0.05$) than SAP0, respectively. Therefore, the soil water storage with SAP at 60–120 kg ha^{-1} throughout the entire maize growing season was significantly increased compared with no SAP. This was because an appropriate range of SAP doses could have improved the soil structure and water-holding capacity, stored more water in the soil, and increased the soil water content, where the soil water storage increased with SAPs applying in a certain range [46], whereas excessive or low doses failed to achieve beneficial effects [11, 37, 47].

3.3. Crop Growth. The application of SAP could conserve the soil water and make it available to plants to allow increased crop growth and biomass accumulation, especially under severe water stress conditions [48]. The maize plant height, stem diameter, and aboveground biomass were affected by multifunctional SAP applying, as shown in Figure 3. The mean plant heights in SAP60 and SAP90 were 13.2% and 12.1% higher ($P < 0.05$) than that in SAP0, respectively, during the whole growth stage. However, there were no significant differences in the plant height between SAP30, SAP120, and SAP0 at 50 DAS and 150 DAS. The maize stem

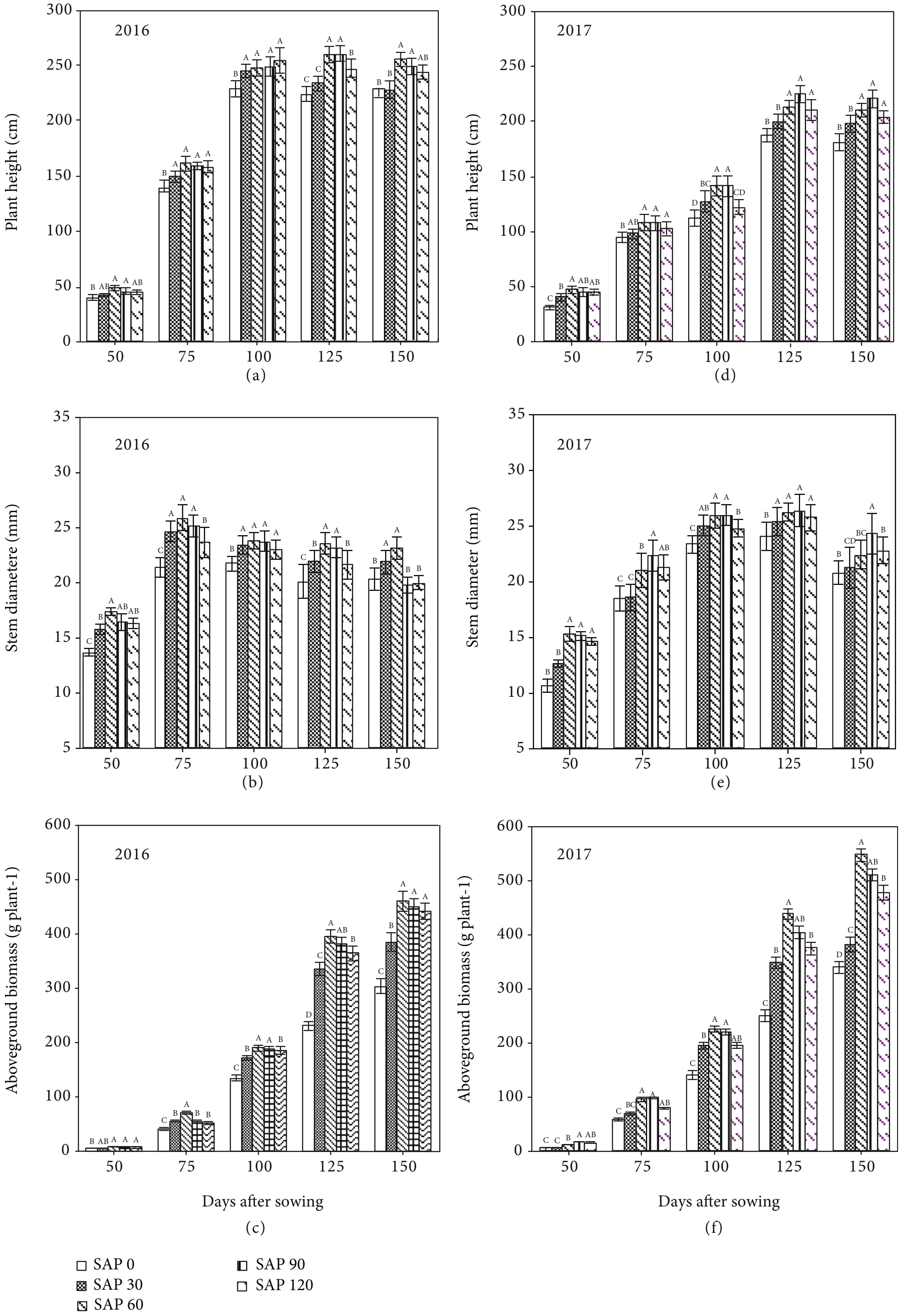


Figure 3: Maize plant height, stem diameter, and aboveground biomass under multifunctional SAP doses during the maize growing season in 2016–2017. SAP0 = SAP 0 kg ha^{-1}; SAP30 = SAP 30 kg ha^{-1}; SAP60 = SAP 60 kg ha^{-1}; SAP90 = SAP 90 kg ha^{-1}; and SAP120 = SAP 120 kg ha^{-1}. Horizontal bars represent significant difference at the 0.05 probability level according to the least significant different test (LSD 0.05).

diameters in SAP30, SAP60, and SAP90 were 10.7%, 17.0%, and 11.3% higher ($P < 0.05$) than that in SAP0, respectively, during the whole growth period. The aboveground biomass in SAP60 was significantly ($P < 0.05$) higher than that in SAP0 during the whole growth period. At 50 DAS, the SAP60, SAP90, and SAP120 treatments increased the aboveground biomass by 70.8%, 54.2%, and 43.8% ($P < 0.05$), respectively, compared with the SAP0 treatment. At 75 DAS, the aboveground biomass in SAP60 was 76.8% higher ($P < 0.05$) that in SAP0. At 100–125 DAS, the mean aboveground biomass in SAP60 and SAP90 was 56.4% and 52.8% higher ($P < 0.05$) than that in SAP0, respectively. At 150 DAS, the aboveground biomass in SAP60, SAP90, and SAP120 was 51.4%, 48.2%, and 45.7% higher ($P < 0.05$) than that in SAP0, respectively.

During 2017, the maize plant height and stem diameter in the multifunctional SAP treatments were significantly higher than those in no SAP treatment during the whole growth period, and the SAP60 and SAP90 treatments had the most significant improvement effects. The plant heights in SAP60, SAP90, and SAP120 were 18.9%, 20.4%, and 13.7% higher ($P < 0.05$) than those in SAP0, respectively, and the stem diameters were 15.2%, 18.6%, and 13.5% higher ($P < 0.05$). The SAP60 and SAP90 treatments had the most significant effects on the maize aboveground biomass during the whole growth period, followed by SAP120 and SAP30. There were no significant differences in the aboveground maize biomass between SAP60 and SAP90, and between SAP30 and SAP120, but the aboveground biomass is each SAP treatment was significantly higher than that in SAP0. The maize aboveground biomass in SAP30, SAP60, SAP90, and SAP120 was 23.9%, 66.7%, 58.3%, and 45.0% higher ($P < 0.05$) than that in SAP0, respectively. In the present study, the application of multifunctional SAP under conditions where the residue was returned to the soil could promote the growth of maize, and the best effect was obtained when the SAP was applied at 60–90 kg ha^{-1}. This was because residue incorporation had beneficial improvement effects on the soil physical and chemical properties [49], and the appropriate application of SAP improved the soil structure as well as enhancing the absorption and retention of soil nutrients to promote plant growth [50]. However, the effect of the SAP was not obvious when the dosage was excessively low and it inhibited crop growth when the dosage was excessively high [45, 51].

3.4. Maize Productivity and Economic Benefits. Using SAPs could significantly increase the maize yield by enhancing the soil physical properties and crop productivity in arid lands [52]. Under the conditions where residue was returned to the soil, there were significant differences in the maize yield formation (heads, kernels per head, and 100 kernel weight) under the multifunctional SAP application rates, and the applications of SAP60 and SAP90 achieved the best yield productivity in 2-year study (Table 4). During the 2-year study, the numbers of heads per square meter with each SAP treatments was significantly different with no SAP, and the SAP60 treatment was the most significant, which with an average increased by 19.0% ($P < 0.05$) compared with SAP0. The kernels per head with SAP60 and SAP90 were increased significantly ($P < 0.05$) by 29.7% and 21.5%, followed by SAP120 and SAP30, which were increased by 19.8% and 14.6% ($P < 0.05$), respectively, compared with SAP0. The 100 kernel weight with all the treatments were ranked as follows: SAP60 > SAP90 > SAP120 > SAP30 > SAP0, and the 100 kernel weight with SAP60, SAP90, SAP120, and SAP30 was significantly ($P < 0.05$) increased by 11.1%, 8.4%, 5.7%, and 5.3%, respectively, compared with SAP0. During 2016, the maize grain yield followed the order of: SAP60 > - SAP90 > SAP30 > SAP120 > SAP0. The maize grain yields in SAP30, SAP60, and SAP90 were 26.5%, 41.8%, and 39.8% higher ($P < 0.05$) than that in SAP0, respectively, but there was no significant difference between those in SAP120 and SAP0. During 2017, the maize grain yields in all treatments were ranked as follows: SAP60 > SAP90 > - SAP120 > SAP30 > SAP0. The maize grain yields in SAP30, SAP60, SAP90, and SAP120 were significantly higher ($P < 0.05$) than that in SAP0, but there were no significant differences between those in SAP30, SAP90, and SAP120. The maize grain yields with SAP30, SAP60, SAP90, and SAP120 were 23.5%, 34.5%, 29.1%, and 20.3% higher ($P < 0.05$) compared with that in SAP0, respectively, where the SAP60 treatment obtained the most significant effect on increasing maize grain yield. Therefore, the application of multifunctional SAP at 60 kg ha^{-1} could significantly improve the maize productivity because the application of multifunctional SAP enhanced the absorption and release of water as well as the retention of fertilizer to improve the soil water and nutrient microenvironment for crop growth [5], thereby significantly enhancing the crop productivity. However, the excessive use of SAP (120 kg ha^{-1}) decreased the crop productivity in our study and the following two possible reasons could explain these results. First, the optimal SAP does is affected by many factors, such as the soil and crop species [8, 53]. Second, if the SAP is applied at an excessive rate, it might compete with the crops for part of the water under drought conditions to increase the drought stress in plants, thereby increasing the membrane permeability and causing damage to affect the yield [13, 54].

There were obvious differences in the input costs for the various treatments because of the requirements for the SAP materials and labor, but the application of SAP obtained improved economic benefit (Table 4). During the two-year study, the input costs for all the treatments were ranked as follows: SAP120 > SAP90 > SAP60 > SAP30 > SAP0. The output values with the different treatments were ranked as follows: SAP60 > SAP90 > SAP30 > SAP120 > SAP0. The net income was the highest with SAP60, followed by SAP30 and SAP90. The mean net incomes with SAP30, SAP60, and SAP90 were 17.5%, 24.7%, and 11.6% higher ($P < 0.05$) compared with SAP0, respectively. However, SAP120 significantly ($P < 0.05$) decreased the mean net income by 17.0%. In the present study, the application of multifunctional SAP at 60 kg ha^{-1} was the best since the net income was obviously higher than SAP30. Optionally, the application of SAP at 30 kg ha^{-1} could be also worthy under situations where input cost is limited. Previous studies also suggested that applying large amounts of SAP to soil was not recommended and that

Table 4: Crop productivity and economic benefit of maize under multifunctional SAP doses.

Year	Treatment	Heads ($\times 10^4$ ha^{-1})	Kernels per head (no.)	100–Kernel weight (g)	Grain yield (kg ha^{-1})	Input	Output	Net income
						(Chinese yuan ha^{-1})		
2016	SAP0	8.37 ± 0.61c	388 ± 11.7b	34.6 ± 0.98c	7482.0 ± 347.2c	2100	11971.2 ± 472.6 d	9871.2 ± 398.2c
	SAP30	8.97 ± 0.20b	383 ± 18.8b	35.3 ± 1.75b	9462.0 ± 276.4b	3400	15139.2 ± 526.1 b	11739.2 ± 457.6 ab
	SAP60	9.86 ± 0.29a	430 ± 7.4ab	36.4 ± 0.94ab	10612.5 ± 301.9 a	4300	16980.0 ± 499.6 a	12680.0 ± 412.8 a
	SAP90	8.88 ± 0.32b	445 ± 35.6a	37.2 ± 0.52a	10456.5 ± 415.3 ab	5200	16730.4 ± 512.3 ab	11530.4 ± 384.9 b
	SAP120	8.86 ± 0.25b	443 ± 15.6a	35.3 ± 1.02b	8521.5 ± 368.0 bc	6100	13634.4 ± 422.4 c	7534.4 ± 382.6d
2017	SAP0	7.67 ± 0.12 d	454 ± 25.8c	35.4 ± 0.76c	8383.4 ± 315.8c	2100	13413.4 ± 389.0 c	11313.4 ± 342.8 c
	SAP30	8.55 ± 0.23c	582 ± 29.2b	38.4 ± 0.55b	10350.8 ± 384b	3400	16561.3 ± 458.2 b	13161.3 ± 414.5 b
	SAP60	9.22 ± 0.38a	662 ± 14.4a	41.4 ± 0.79a	11277.5 ± 308.1 a	4300	18044.0 ± 474.6 a	13744.0 ± 426.3 a
	SAP90	8.97 ± 0.32b	578 ± 23.8b	38.7 ± 0.66b	10820.2 ± 391.6 b	5200	17312.3 ± 388.7 b	12112.3 ± 323.4 b
	SAP120	8.67 ± 0.30c	566 ± 32.6b	38.7 ± 0.45b	10090.7 ± 298.8 b	6100	16145.1 ± 436.4 b	10045.1 ± 411.6 c

The price of maize was 1.6 Chinese Yuan kg^{-1}, SAP price was 30 Chinese Yuan kg^{-1}. Labour cost was 400 Chinese Yuan ha^{-1}, seed and fertilizers costs were 600 Chinese Yuan ha^{-1}, and drip irrigation materials costs were 1500 Chinese Yuan ha^{-1}. Net income (CNYha^{-1}) = Output value – Input value. Where Output value = Maize grain yield × Market price. Input value of SAP treatments = Labor costs + SAP costs + Seed and fertilizer costs + Drip irrigation materials costs. However, Input value of CK = Seed and fertilizer costs + Drip irrigation materials costs + Tractor farming fee (tillage, residue incorporation, and harvesting). SAP0 = SAP 0 kg ha^{-1}; SAP30 = SAP 30 kg ha^{-1}; SAP60 = SAP 60 kg ha^{-1}; SAP90 = SAP 90 kg ha^{-1}; and SAP120 = SAP 120 kg ha^{-1}. Values followed by the same lowercase letter in the same column are not significant according to the least significant different test (LSD 0.05).

farmers should consider the input cost, absorption characteristics, and the actual effects of applying SAPs.[21] Further studies of these effects are required.

4. Conclusions

The results of our 2-year study showed that the application of multifunctional SAP under the residue returning conditions effectively reduced the bulk density, improved the soil total porosity, and increased the soil organic matter and available nutrient contents in the topsoil (0–0.40 m) compared with no SAP. The applications of SAP at 60 and 90 kg ha^{-1} had the greatest effects on the improvements in soil physicochemical characteristics, and they significantly promoted maize growth. The applications of SAP at 60 and 90 kg ha^{-1} significantly increased the maize productivity (yield formation and grain yield) compared with no SAP, whereas the net income were the highest with applying SAP at 30–60 kg ha^{-1}. Based on the improved properties of the sandy soils, maize growth, productivity, and economic benefits, farmers could be recommended to use multifunctional SAP 30–60 kg ha^{-1} to improve the physical and chemical properties of sandy soils, and increase maize productivity and obtain the higher net income. It was potentially possible to use the method under the condition in an irrigated area of northwest China where residue incorporation was common agricultural practice.

Data Availability

The data used to support the findings of this study are included within the article. Further data or information is available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

This work was supported by the Natural Science Foundation of Ningxia (2021AAC03003 and 2022AAC03061), the National Natural Science Foundation of China (31860362 and 32160515), and the National Science & Technology Pillar Program (2015BAD22B05-03).

References

[1] L. Chen, *Simulation of the Impact of Climate Change on Maize Production in the Middle Arid Region in Ningxia*, Journal of Nanjing University of Information Science & Technology, Nanjing, Jiangsu Province, 2016.

[2] R. Lai, H. Yu, and J. Huang, “Effects of climate changes on spring maize's climate potential productivity in middle arid region of Ningxia,” *Journal of China Agricultural University*, vol. 19, no. 3, pp. 108–114, 2014.

[3] X. W. Li, Q. Sun, C. Y. Hao, and Z. Y. Bao, “Study on the optimal application rates of fertilizer of the drip-irrigated maize in the arid area of the central Ningxia,” *Journal of Yulin University*, vol. 26, pp. 26–30, 2016.

[4] X. Chen, L. Huang, X. Y. Mao, Z. W. Liao, and Z. L. He, “A comparative study of the cellular microscopic characteristics and mechanisms of maize seedling damage from superabsorbent polymers,” *Pedosphere*, vol. 27, no. 2, pp. 274–282, 2017.

[5] W. B. Bai, H. Z. Zhang, B. C. Liu, Y. F. Wu, and J. Q. Song, “Effects of super-absorbent polymers on the physical and chemical properties of soil following different wetting and drying cycles,” *Soil and Use Management*, vol. 26, no. 3, pp. 253–260, 2010.

[6] Y. B. Cao, B. T. Wang, H. Y. Guo, H. J. Xiao, and T. T. Wei, “The effect of super absorbent polymers on soil and water conservation on the terraces of the loess plateau,” *Ecological Engineering*, vol. 102, pp. 270–279, 2017.

[7] M. R. Islam, Y. G. Hu, S. S. Mao, P. F. Jia, A. E. Eneji, and X. Z. Xue, “Effects of water-saving superabsorbent polymer on antioxidant enzyme activities and lipid peroxidation in corn (Zea mays L.) under drought stress,” *Journal of the Science of Food and Agriculture*, vol. 91, no. 5, pp. 813–819, 2011.

[8] X. Li, J. Z. He, Y. R. Liu, and Y. M. Zheng, “Effects of super absorbent polymers on soil microbial properties and Chinese cabbage (brassica chinensis) growth,” *Journal of Soils and Sediments*, vol. 13, no. 4, pp. 711–719, 2013.

[9] A. Karimi, M. Noshadi, and M. Ahmadzadeh, “Effects of super absorbent polymer (igeta) on crop, soil water and irrigation interval,” *Journal of Agricultural Science and Technology*, vol. 12, pp. 415–420, 2009.

[10] K. Watanabe, S. Saensupo, Y. Na-iam, P. Klomsa-ard, and K. Sriroth, “Effects of superabsorbent polymer on soil water content and sugarcane germination and early growth in sandy soil conditions,” *Sugar Tech*, vol. 28, pp. 1–7, 2019.

[11] X. Q. Hou, R. Li, W. S. He, X. H. Dai, K. Ma, and Y. Liang, “Superabsorbent polymers influence soil physical properties and increase potato tuber yield in a dry-farming region,” *Journal of Soils and Sediments*, vol. 18, no. 3, pp. 816–826, 2018.

[12] M. R. Islam, S. S. Mao, X. Z. Xue, A. E. Eneji, X. B. Zhao, and Y. G. Hu, “Alysimeter study of nitrate leaching, optimum fertilisation rate and growth responses of corn (Zea mays L.) following soil amendment with water-saving super-absorbent polymer,” *Journal of Agricultural Science and Technology*, vol. 91, pp. 1990–1997, 2011.

[13] S. Shahram and R. Felora, “Investigation of superabsorbent polymer and water stress on physiological indexes of maize,” *Journal of Advances in Biology*, vol. 4, no. 3, pp. 455–460, 2014.

[14] M. R. Islam, Y. G. Hu, S. S. Mao, J. Z. Mao, A. E. Eneji, and X. Z. Xue, “Effectiveness of a water-saving super-absorbent polymer in soil water conservation for corn (Zea mays L.) based on eco-physiological parameters,” *Journal of the Science of Food and Agriculture*, vol. 91, no. 11, pp. 1998–2005, 2011.

[15] A. Li, A. Wang, and J. Chen, “Studies on poly (acrylic acid) attapulgite superabsorbent composites. II. Swelling behaviors of superabsorbent composites in saline solutions and hydrophilic solvent-water mixtures,” *Journal of Applied Polymer Science*, vol. 94, no. 5, pp. 1869–1876, 2004.

[16] A. Li, J. Zhang, and A. Wang, “Preparation and slow-release property of a poly(acrylic acid)/attapulgite/sodium humate superabsorbent composite,” *Journal of Applied Polymer Science*, vol. 103, no. 1, pp. 37–45, 2007.

[17] P. Zhang, T. Wei, Z. K. Jia, Q. F. Han, and X. L. Ren, “Soil aggregate and crop yield changes with different rates of straw incorporation in semiarid areas of northwest China,” *Geoderma*, vol. 230, pp. 41–49, 2014.

[18] Y. L. Lou, M. G. Xu, W. Wang, X. L. Sun, and K. Zhao, “Return rate of straw residue affects soil organic C sequestration by chemical fertilization,” *Soil and Tillage Research*, vol. 113, no. 1, pp. 70–73, 2011.

[19] J. Yu, I. Shainberg, Y. L. Yan, J. G. Shi, G. J. Levy, and A. I. Mamedov, “Superabsorbents and semiarid soil properties affecting water absorption,” *Soil Science Society of America Journal*, vol. 75, no. 6, pp. 2305–2313, 2011.

[20] R. K. Liao, W. Y. Wu, S. M. Ren, and P. L. Yang, “Effects of superabsorbent polymers on the hydraulic parameters and water retention properties of soil,” *Journal of Nanomaterials*, vol. 2016, Article ID 5403976, 11 pages, 2016.

[21] W. B. Bai, J. Q. Song, and H. Z. Zhang, “Repeated water absorbency of super-absorbent polymers in agricultural field applications: a simulation study,” *Acta Agriculturae Scandinavica Section B-soil And Plant Science*, vol. 63, no. 5, pp. 433–441, 2013.

[22] H. Andry, T. Yamamoto, T. Irie, S. Moritani, and M. H. Inoue Fujiyama, “Water retention, hydraulic conductivity of hydrophilic polymers in sandy soil as affected by temperature and water quality,” *Journal of Hydrology*, vol. 373, no. 1-2, pp. 177–183, 2009.

[23] Z. X. Liu, Y. G. Miao, Z. Y. Wang, and G. H. Yin, “Synthesis and characterization of a novel super-absorbent based on chemically modified pulverized wheat straw and acrylic acid,” *Carbohydrate Polymers*, vol. 77, no. 1, pp. 131–135, 2009.

[24] D. M. Devine and C. L. Higginbotham, “Synthesis and characterisation of chemically crosslinked _N_ -vinyl pyrrolidinone (NVP) based hydrogels,” *European Polymer Journal*, vol. 41, no. 6, pp. 1272–1279, 2005.

[25] Y. Wang, D. W. Jing, X. Y. Fu et al., “Effects of application amount of super-absorbent polymer on soil physical characteristics and microbial activity under poplar seedlings,” *Bulletin of Soil and Water Conservation*, vol. 37, pp. 53–58, 2017.

[26] W. J. Busscher, D. L. Bjorneberg, and R. E. Sojka, “Field application of PAM as an amendment in deep-tilled US southeastern coastal plain soils,” *Soil and Tillage Research*, vol. 104, no. 2, pp. 215–220, 2009.

[27] Soil Survey Staff, *Soil Taxonomy. A Basic System of Soil Classification for Making and Interpreting Soil Surveys*, Department of Agriculture, Washington DC, 1975.

[28] Soil Survey Staff, *Soil Taxonomy USDA Agricultural Handbook*, Natural Resources Conservation Service, Washington DC, 1999.

[29] L. G. Xu, X. J. Liu, L. Du, D. H. Tang, and R. Tang, “Application research on multifunctional water-keeping agent for oil-sunflower cultivation,” *Ningxia Engineering Technology*, vol. 13, pp. 138–142, 2014.

[30] J. L. Liao, F. L. Xu, and S. W. Zhao, “Effect of different aquasorbent on growth and yield of potato in Ningnan mountain,” *Acta Agriculturae Boreali-occidentalis Sinica*, vol. 18, no. 3, pp. 238–242, 2009.

[31] G. R. Blake and K. H. Hartge, *Bulk Density*, SSSA Book Series, Madison, Wisconson, USA, 2018.

[32] S. R. Olsen and L. E. Sommers, “Phosphorous,” in *Methods of Soil Analysis. Part 2. Chemical and Microbiological Properties*, A. L. Page and M. R. H. Keeney, Eds., pp. 403–430,

American Society of Agronomy, Soil Science Society of America, Madison, WI, 2nd Edition edition, 1982.

[33] R. A. Dorich and D. W. Nelson, "Evaluation of manual cadmium reduction methods for determination of nitrate in potassium chloride extracts of soils," *Soil Science Society of America Journal*, vol. 48, no. 1, pp. 72–75, 1984.

[34] M. L. Jackson, *Soil Chemical Analysis*, Prentice-Hall, Englewood Cliffs, NJ, 4th edn edition, 1964.

[35] R. F. Dam, B. B. Mehdi, M. S. E. Burgess, C. A. Madramootoo, G. R. Mehuys, and I. R. Callum, "Soil bulk density and crop yield under eleven consecutive years of corn with different tillage and residue practices in a sandy loam soil in central Canada," *Soil and Tillage Research*, vol. 84, no. 1, pp. 41–53, 2005.

[36] Y. G. Han, P. L. Yang, Y. P. Luo, S. M. Ren, L. X. Zhang, and L. Xu, "Porosity change model for watered super absorbent polymer-treated soil," *Environmental Earth Sciences*, vol. 61, no. 6, pp. 1197–1205, 2010.

[37] X. Q. Hou, W. S. He, K. Ma, X. H. Dai, and J. W. Zhao, "Comparative effects of two super absorbent on soil physical properties of dryland and potato yield," *Journal of Nuclear Agricultural Sciences*, vol. 29, pp. 2410–2417, 2015.

[38] Q. S. Wu, M. Q. Cao, Y. N. Zou, and X. H. He, "Direct and indirect effects of glomalin, mycorrhizal hyphae and roots on aggregate stability in rhizosphere of trifoliate orange," *Science Report*, vol. 4, no. 1, p. 5823, 2015.

[39] Y. Yang, J. Wu, S. Zhao et al., "Effects of long-term super absorbent polymer and organic manure on soil structure and organic carbon distribution in different soil layers," *Soil and Tillage Research*, vol. 206, article 104781, 2021.

[40] L. X. Yang, Y. Yang, Z. Chen, C. X. Guo, and S. C. Li, "Influence of super absorbent polymer on soil water retention, seed germination and plant survivals for rocky slopes eco-engineering," *Ecological Engineering*, vol. 62, pp. 27–32, 2014.

[41] W. X. Ti, "Effect of the application of drought-resistant agents on soybean growth," *Soybean Science & Technology*, vol. 4, pp. 44–46, 2011.

[42] X. J. Wang, Z. K. Jia, L. Y. Liang et al., "Changes in soil characteristics and maize yield under straw returning system in dryland farming," *Field Crops Research*, vol. 218, pp. 11–17, 2018.

[43] H. S. Yang, R. F. Liu, J. P. Zhang, and A. Q. Wang, "Effect of paam-atta composite water retaining agent on water holding capacity and physical properties of soil," *Journal of Soil and Water Conservation*, vol. 19, no. 3, pp. 38–41, 2005.

[44] E. S. Abrisham, M. Jafari, A. Tavili et al., "Effects of a super absorbent polymer on soil properties and plant growth for use in land reclamation," *Arid Land Research and Management*, vol. 32, no. 4, pp. 407–420, 2018.

[45] J. F. Zhang, T. N. Zhao, B. P. Sun, H. J. Shen, and J. Wu, "Effects of biofertilizers and super absorbent polymers on plant growth and soil fertility in the arid mining area of Inner Mongolia, China," *Journal of Mountain Science*, vol. 15, no. 9, pp. 1920–1935, 2018.

[46] S. N. Du, G. S. Bai, S. W. Zhao, and X. L. Hou, "Effects of Wote super absorbent and PAM absorbent on soil moisture and growth of potato," *Transactions of the Chinese Society of Agricultural Engineering*, vol. 32, pp. 240–248, 2007.

[47] Y. H. Yang, P. T. Wu, J. C. Wu et al., "Impacts of water-retaining agent on soil moisture and water use in different growth stages of winter wheat," *Transactions of the Chinese Society of Agricultural Engineering*, vol. 6, no. 12, pp. 19–26, 2010.

[48] R. Q. Fan, J. Luo, S. H. Yan, Y. L. Zhou, and Z. H. Zhang, "Effects of biochar and super absorbent polymer on substrate properties and water spinach growth," *Pedosphere*, vol. 25, no. 5, pp. 737–748, 2015.

[49] S. Mousavi, M. Moazzeni, B. Mostafazadeh-Fard, and M. Yazdani, "Effects of rice straw incorporation on some physical characteristics of paddy soils," *Journal of Agricultural Science and Technology*, vol. 14, pp. 1173–1183, 2012.

[50] J. C. Wu, X. J. Guan, and Y. H. Yang, "Effects of ground cover and water-retaining agent on winter wheat growth and precipitation utilization," *Journal of Applied Ecology*, vol. 22, no. 1, pp. 86–92, 2011.

[51] H. Y. Li, R. Zhang, and F. X. Wang, "Effects of water-retaining agent on soil water movement and water use efficiency of maize sowed with absolved water-storing irrigation," *Transactions of the Chinese Society of Agricultural Engineering*, vol. 27, no. 3, pp. 37–42, 2011.

[52] R. Kumar, *Evaluation of Hydrogel on the Performance of Rabi Maize. Ph. D. Diss*, Department of Agronomy, BAU, Sabour, 2015.

[53] X. Li, J. Z. He, J. M. Hughes, Y. R. Liu, and Y. M. Zheng, "Effects of super-absorbent polymers on a soil–wheat (Triticum aestivum L.) system in the field," *Applied Soil Ecology*, vol. 73, pp. 58–63, 2014.

[54] J. X. Mu, X. M. Cao, and S. C. Liu, "Effects of combined application of water-retaining agent and nitrogen fertilizer on growth and water and fertilizer utilization of potato," *Journal of Henan Agricultural Sciences*, vol. 45, no. 9, pp. 35–40, 2016.