Effects of Different Efficiency-Enhanced DAP Types on Maize Growth in Xinjiang Soils

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Abstract [**Objectives**] To investigate the performance of different efficiency-enhanced Diammonium phosphate (DAP) fertilizers in Xinjiang soils and identify new low-nutrient DAP formulations that promote maize growth in the region. [**Methods**] Using 64% DAP (additive-free high-nutrient fertilizer) as the control, it compared with low-nutrient fertilizers: 57% DAP additive Formula A, 57% DAP additive Formula B, 57% DAP additive Formula C, 57% DAP additive Formula D, 57% DAP additive Formula E, and 57% DAP additive Formula F. By measuring maize growth morphology, physiological indicators, and biomass under different treatments, the measured parameters were evaluated using statistical methods such as regression analysis. [**Results**] The addition of enhancing additives can promote root development in maize plants and increase physiological indicators such as chlorophyll content and plant height. Low-nutrient DAP with additives shows a trend of being superior to high-nutrient DAP fertilizers in promoting maize growth. Different additive formulas exert varying effects on maize, with 57% DAP additive Formula A, 57% DAP additive Formula E, and 57% DAP additive Formula F demonstrating positive effects on maize promotion. [**Conclusions**] This study provides practical guidance for DAP selection and application in Xinjiang maize cultivation while establishing a foundation for cutting-edge research on high-utilization, low-nutrient fertilizers in arid regions.

Key words Diammonium phosphate (DAP), Xinjiang soils, Ecological adaptability, Maize, Efficiency-enhanced additive, New fertilizer, Nutrient utilization, Low nutrient level

0 Introduction

Maize is one of the most important crops in the world, and its planting area is second only to wheat in all cereals[1]. According to statistics, from 2018 to 2020, the global maize yield was 1.137 billion t, which was about 50% higher than wheat[2]. China is the world's second largest maize producer, accounting for 24% of the world's maize production in 2020[3]. The planting area of maize in China is extensive. In Xinjiang, maize is a crop with large planting area and high yield. The annual yield of maize in Xinjiang is 9.28×10^6 t, accounting for 59% of the total yield of grain crops[4]. However, at present, the enhancement of agricultural product yield and quality increasingly relies on chemical fertilizers, which are extensively utilized in agriculture[5]. Concurrently, excessive application of chemical fertilizers contributes to soil degradation and environmental issues such as water eutrophication[6]. Addressing the problem of fertilizer overuse in agricultural production has thus become a focal point of public concern[7-8]. Fertilizer synergists, primarily composed of water-soluble polymers, can be incorporated into fertilizers to enhance nutrient uptake by plants, optimizing nutrient effectiveness and utilization efficiency[9]. Additionally, these synergists increase soil nutrient availability and improve soil physicochemical properties[10]. Diammonium phosphate (DAP), a high-concentration quick-acting fertilizer rich in the macronutrients nitrogen and phosphorus essential for plant growth, significantly contributes to promoting plant development and improving crop yield and quality. DAP is extensively utilized in agriculture. Incorporating synergists into low-nutrient DAP to formulate environmentally friendly fertilizers not only fulfills crop growth requirements but also mitigates environmental damage. Different synergists exert varying effects on crops, while the same synergist shows regional adaptability differences. Screening high-efficiency DAP fertilizers synergized with broadly adaptable, premium-grade synergists holds demonstrated significance for fertilization practices and crop cultivation in Xinjiang.

Previous studies on diammonium phosphate (DAP) have primarily focused on two aspects: production-phase control of DAP fertilizers, such as coating and slow-release technologies to improve utilization efficiency[11], and the effects of different DAP application methods on crop economic yield, biomass, and physiological indicators[12]. Currently, research on DAP formulations incorporating synergists remains limited. This study employed pot experiments to assess the effects of various DAP synergists on maize growth in Xinjiang. By comparing different DAP synergists, we establish a scientific basis for fertilizer management and DAP selection in the region. Furthermore, we identify the optimal low-nutrient, high-efficiency B-DAP formulation adapted to Xinjiang's soil conditions. This provides a premium fertilizer formula for Xinjiang agriculture, reduces chemical fertilizer usage while maintaining agricultural output, and safeguards regional soil integrity.

1 Materials and methods

1.1 Test fertilizer DAP fertilizers: 64% DAP, polyglutamic

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acid 57% DAP, biochemical fulvic acid + polyglutamic acid 57%, chitosan oligosaccharide 57% DAP, nitrofulvic acid 57% DAP, additive-free 57% DAP, seaweed polysaccharide + F57% DAP, chitosan oligosaccharide + F57% DAP.

1.2 Test soil Soil samples were collected from the same plot of Qitai of Xinjiang in the 0 – 20 cm tillage layer. The quincunx method was used to collect soil samples. After removing sundries, 80 kg of soil samples were collected from each location. The specific method is shown in Fig. 1.

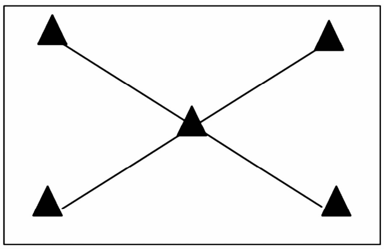


Fig. 1 Soil samples collected by quincunx method

1.3 Test treatment As shown in Table 1, the experiment was set up with 7 treatments, and each treatment was repeated 3 times. The maize was planted in a pot, the data were measured once every week during the planting period, and the fertilizer was applied once. 0.92 g of DAP fertilizer was applied in each pot, and 0.58 g of urea + 0.35 g of potassium sulfate + water was applied in each pot.

2 Results and analysis

2.1 Chlorophyll content of maize under different treatments The effect of Xinjiang soil synergist treatment on maize chlorophyll content was analyzed. As shown in Fig. 2, after 2 weeks of planting, the SPAD value of XJ3 treatment was significantly lower than that of XJ2, XJ4, XJ5 and XJ6 treatments; 4 weeks after planting, the SPAD values of XJ6 and XJ1 were significantly lower than those of XJ7, and also tended to be lower than those of other synergistic low-nutrient DAPs, but the difference was not significant. Six to nine weeks after planting, the SPAD values of XJ1 and XJ7 were significantly lower or lower than those of other synergistic low-nutrient DAPs.

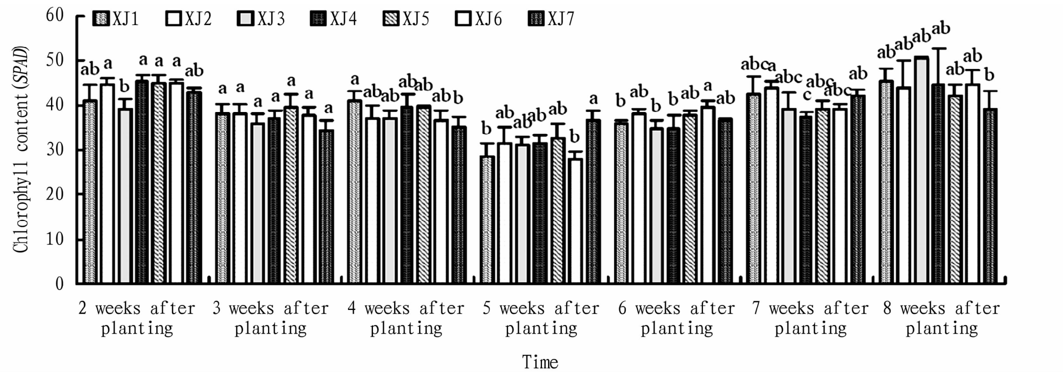
2.2 Plant height of maize under different treatments Analyzing the effect of synergist treatments on maize plant height in Xinjiang soil, the results are shown in Fig. 3. At 2 weeks after planting, plant heights for 64% DAP, chitosan 57% DAP, and additive-free 57% + F30 + seaweed treatments were significantly lower than other enhanced low-nutrient DAP treatments. At 5 weeks after planting, plant heights for additive-free 57% + F30 + seaweed and chitosan 57% DAP + F30 treatments were significantly lower than those for 64% DAP and biochemical fulvic acid + polyglutamic acid 57% DAP. During other growth stages, plant heights for biochemical fulvic acid + polyglutamic acid 57% DAP, polyglutamic acid 57% DAP, nitro humic acid 57% DAP showed no significant difference compared with 64% DAP, but additive-free 57% + F30 + seaweed, chitosan 57% DAP, and optimized treatments had plant heights lower than or significantly lower than 64% DAP.

2.3 Maize stem diameter under different treatments Analyzing the effect of synergist treatments on maize stem diameter in Xinjiang soil, the results are shown in Fig. 4. At 2 weeks after planting, stem diameters for 64% DAP, biochemical fulvic acid + polyglutamic acid 57% DAP, and chitosan 57% DAP treatments were significantly lower than chitosan 57% DAP + F30. At 4 weeks after planting, stem diameter for chitosan 57% DAP + F30 treatment was significantly lower than polyglutamic acid 57% DAP, and also tended to be lower than the remaining treatments. During 5 to 9 weeks after planting, stem diameters for low-nutrient DAP treatments with added synergistic additive all tended to be higher than 64% DAP, but the differences were not significant.

Table 1 Different DAP test treatments

Soil	Treatment	Additive	DAP fertilizer	Topdressing
Qitai of Xinjiang	XJ1	No	64% DAP	Application of urea + potassium sulfate mixed with water
Qitai of Xinjiang	XJ2	Biochemical fulvic acid	57% DAP	Application of urea + potassium sulfate mixed with water
Qitai of Xinjiang	XJ3	Polyglutamic acid	57% DAP	Application of urea + potassium sulfate mixed with water
Qitai of Xinjiang	XJ4	Nitrofulvic acid	57% DAP	Application of urea + potassium sulfate mixed with water
Qitai of Xinjiang	XJ5	Chitosan oligosaccharide	57% DAP	Application of urea + potassium sulfate mixed with water
Qitai of Xinjiang	XJ6	Seaweed polysaccharide, F30	57% DAP	Application of urea + potassium sulfate mixed with water
Qitai of Xinjiang	XJ7	Chitosan oligosaccharide, F30	57% DAP	Application of urea + potassium sulfate mixed with water

2.4 Maximum leaf length of maize under different treatments Based on Fig. 5 showing the effects of synergist treatments on the maximum leaf length of maize in Xinjiang soil: At 2 – 3 weeks after planting, the maximum leaf lengths under 64% DAP, biochemical fulvic acid + polyglutamic acid 57% DAP, and chitosan oligosaccharide 57% DAP treatments were significantly lower than under chitosan oligosaccharide 57% DAP + F30 (attributed to F30 efficacy); at 4 weeks, 64% DAP, no additive 57% + F30 + seaweed, chitosan oligosaccharide 57% DAP, and optimized treatments showed significantly lower maximum leaf lengths than biochemical fulvic acid + polyglutamic acid 57% DAP and nitrofulvic acid 57% DAP; at 5 weeks, no additive 57% + F30 + seaweed, chitosan oligosaccharide 57% DAP + F30, and polyglutamic acid 57% DAP treatments had significantly lower values than biochemical fulvic acid + polyglutamic acid 57% DAP and 64% DAP; at 6 – 8 weeks, the maximum leaf length under chitosan oligosaccharide 57% DAP + F30 treatment was significantly lower or inferior to other treatments.



NOTE XJ1 is adding 64% DAP 0.92 g without additive; XJ2 is adding biochemical fulvic acid + polyglutamic acid 57% DAP 0.92 g; XJ3 is adding polyglutamic acid 57% DAP 0.92 g; XJ4 is adding nitrofulvic acid 57% DAP 0.92 g; XJ5 is adding chitosan oligosaccharide 57% DAP 0.92 g; XJ6 is adding 57% DAP 0.92 g without additive + seaweed polysaccharide0.3% + 0.3% F30; XJ7 is adding chitosan oligosaccharide 57% DAP 0.92 g + 0.3% F30. The same below.

Fig. 2 Chlorophyll content of maize planted in Xinjiang soil under different treatments

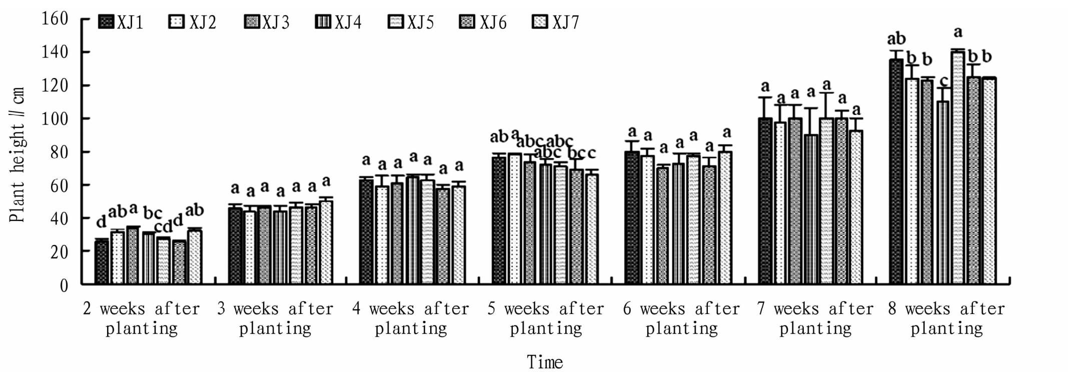


Fig. 3 Plant height of maize planted in Xinjiang soil under different treatments

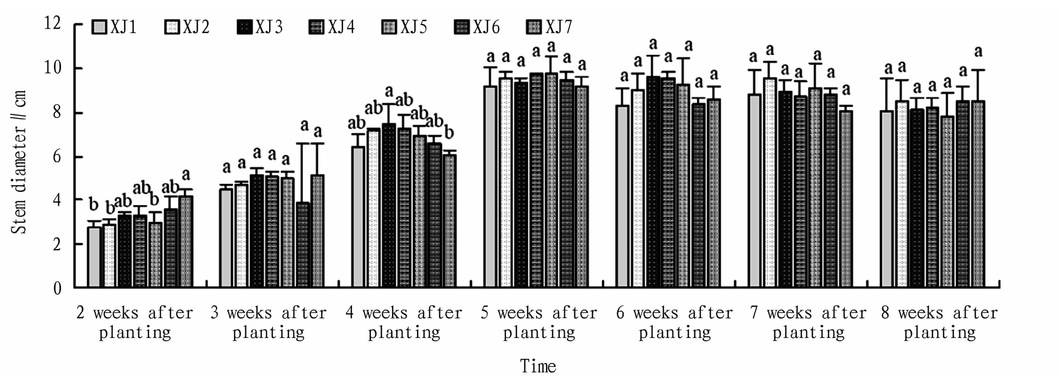


Fig. 4 Stem diameter of maize planted in Xinjiang soil under different treatments

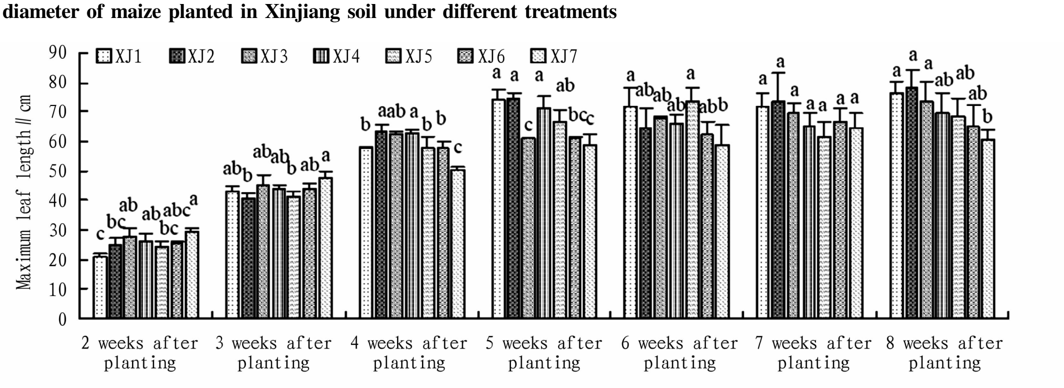


Fig. 5 Maximum leaf length of maize planted in Xinjiang soil under different treatments

2.5 Maximum leaf width of maize under different treatments Based on Table 2 showing the effects of synergist treatments on the maximum leaf width of maize in Xinjiang soil: at 2 weeks after planting, the maximum leaf width under 64% DAP treatment was lower than that under synergized low-nutrient DAP; at 4 weeks, the maximum leaf widths under 64% DAP, Yuntianhua chitosan oligosaccharide 57% DAP + F30, and additive-free 57% DAP + seaweed + F30 treatments were lower than those under other synergized low-nutrient DAP.

Table 2 Leaf width of maize planted in Xinjiang soil under different treatments cm

Treatment	2 weeks after planting	3 weeks after planting	4 weeks after planting	5 weeks after planting	6 weeks after planting	7 weeks after planting	8 weeks after planting
XJ1	1.63 ±00.31 b	2.37 ±0.17 a	3.97 ±0.29 b	4.23 ±0.45 a	5.17 ±0.24 a	4.53 ±0.76 ab	5.80 ±0.73 a
XJ2	1.80 ±0.08 ab	2.63 ±0.31 a	4.27 ±0.33 ab	4.25 ±0.24 a	5.07 ±0.37 a	4.17 ±1.89 b	5.47 ±0.12 a
XJ3	2.03 ±0.17 a	2.60 ±0.51 a	4.53 ±0.05 a	4.43 ±0.26 a	4.83 ±0.46 a	4.83 ±0.62 ab	5.07 ±0.25 a
XJ4	2.00 ±0.08 ab	2.70 ±0.36 a	4.47 ±0.17 a	4.20 ±0.70 a	5.30 ±0.24 a	5.60 ±0.29 a	5.70 ±0.45 a
XJ5	1.93 ±0.17 ab	2.43 ±0.26 a	4.43 ±0.05 a	4.73 ±0.66 a	5.33 ±1.10 a	5.63 ±0.61 a	5.83 ±0.77 a
XJ6	1.87 ±0.09 ab	2.23 ±0.17 a	3.87 ±0.09 b	4.47 ±0.39 a	5.30 ±0.85 a	5.53 ±0.37 ab	5.20 ±0.16 a
XJ7	1.83 ±0.12 ab	2.50 ±0.22 a	3.97 ±0.05 b	4.47 ±0.12 a	4.80 ±0.14 a	5.20 ±0.16 ab	4.80 ±0.41 a

2.6 Biomass of maize under different treatments Based on Fig. 6 showing the biomass of maize under different treatments in Xinjiang soil: the fresh leaf weights of polyglutamic acid 57% DAP, nitrofulvic acid 57% DAP, additive-free 57% DAP + seaweed polysaccharide + F30, and chitosan oligosaccharide 57% DAP + F30 treatments were significantly lower than 64% DAP; the fresh root weights of additive-free 57% DAP + seaweed polysaccharide + F30 and chitosan oligosaccharide 57% DAP + F30 treatments were significantly lower than 64% DAP and biochemical fulvic acid + polyglutamic acid 57% DAP; the root dry weight of synergized low-nutrient DAP showed a trend toward being higher than 64% DAP with no significant difference; the dry leaf weights of 64% DAP and polyglutamic acid 57% DAP were significantly higher than other treatments.

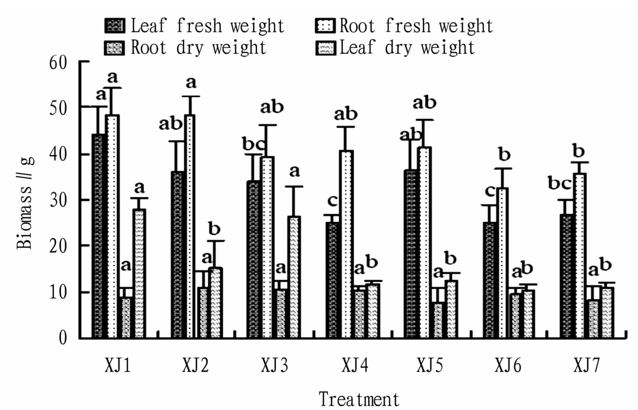


Fig. 6 Biomass of maize planted in Xinjiang soil under different treatments

3 Conclusions

The biochemical fulvic acid + polyglutamic acid 57% DAP, polyglutamic acid 57% DAP, and nitrofulvic acid 57% DAP all promoted the improvement of physiological indices in Xinjiang maize, being higher or significantly higher than the 64% DAP treatment, while showing no significant differences among these treatments. Moreover, in Xinjiang soil, the application of fulvic acid and polyglutamic acid with low-nutrient fertilizers demonstrated effects surpassing those of high-nutrient fertilizers.

4 Discussion

China is the largest producer and consumer of phosphate fertilizer in the world, but the reserves of phosphate rock as the main source of phosphate fertilizer are very limited, so it is of great significance to improve the utilization efficiency of phosphate fertilizer[13-14]. Fulvic acid, polyglutamic acid and other synergistic additives can be used together with fertilizers or alone. It is reported that humic acid as an activator applied to soil can also improve the availability of soil phosphorus[15]. The synergistic additive is added to the fertilizer to improve the nutrient utilization rate, and plays a very important role in the quality guarantee and yield promotion of agricultural products at present, different synergists have different growth promotion effects, and the same synergist has different effects on different parts of plants. We analyzed the effects of different synergistic additives on the growth of maize in Xinjiang soil, and the results showed that low nutrient DAP and 64% DAP with synergistic additives were applied as maize base fertilizer within 2 months of planting. Fulvic acid, polyglutamic acid, chitosan oligosaccharide, Both seaweed polysaccharide and low-nutrient DAP could promote the increase of maize physiological indexes in different degrees, and the effect was better than that of 64% DAP with high nutrient, but the effect of seaweed polysaccharide and low-nutrient DAP on maize growth was not significant. Studies have shown that exogenous fulvic acid is helpful to increase the content of organic carbon in soil. In acidic soil, long-term application of fulvic acid can improve the stability of soil organic matter more than application of manure[16]. The addition of fulvic acid to low-nutrient fertilizers shows a trend toward superior promotion effects on maize compared to high-nutrient fertilizers. This may be attributed to fulvic acid's intrinsic soil-enhancing properties, which increase soil activity, thereby achieving low-nutrient, high-efficiency outcomes. Polyglutamic acid is a naturally occurring biopolymer[17]. Fertilizers containing polyglutamic acid enhance yield increase and quality improvement in crops. Research by Chang Yun *et al.* [18] demonstrated that polyglutamic acid fertilizers improve apple quality and economic benefits. Studies by Lian

Xiaojuan *et al*. [19] indicated that polyglutamic acid application enhances yield and quality in greenhouse cucumbers.

Based on comparative analysis of experimental results, we found that polyglutamic acid exhibits significant efficacy in promoting leaf growth and development. It likely facilitates plant growth by influencing leaf physiology. Research by Cao Liru *et al*. [20] demonstrated that foliar application of carbon-adsorbed polyglutamic acid water-soluble fertilizer substantially enhances photosynthetic intensity in maize leaves, aligning with our findings. As an exceptional fertilizer additive, chitosan oligosaccharide is widely utilized in agriculture and acclaimed as "a fertilizer without being a fertilizer, a pesticide without being a pesticide". It not only improves crop quality and yield but also exhibits pest and disease control effects. Studies indicate that chitosan oligosaccharide combined with nitrogen fertilizers promotes cotton growth even under reduced nitrogen application[21]. In our research, its growth-promoting effects on maize corroborate prior studies. Seaweed polysaccharide, a vital component in algal bioresource utilization[22], is extensively applied in chemical and pharmaceutical industries. Our experimental data analysis reveals that treatments applying seaweed polysaccharide demonstrate advantages over synergist-free treatments.

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