Research Findings

Photo 1. Peanut (*Arachis hypogaea* L.) at 111 days after emergence. Photo by the authors.
Left to right: T4 NPK+525 kg ha^{-1} polyhalite; T2 NPK+225 kg ha^{-1} polyhalite; T5 NPK+375 kg ha^{-1} Sofipoly; and T1 Control NPK.

Effects of Combined Application of NPK Compound Fertilizer with Polyhalite Fertilizers on Peanut Yield, Nutrient Content and Partitioning in Henan Province, China

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Abstract

China is the world-leading peanut (*Arachis hypogaea* L.) producer accounting for 35.93% of overall world production (in 2019), followed by India (13.80%) and Nigeria (9.13%). Within China, Henan is the leading peanut producing province producing 5.767 million metric tons in 2019, followed by Shandong and Guangdong regions with 2.848 and 1.087 million metric tons, respectively. Peanut is therefore an economically important crops in this province. The common fertilizer application practice in Henan province is dominated by NPK, which has been contributing to yield increments. However, the continuous application of the same nutrients over many years has resulted in unbalanced nutrient supply, and stagnant yield. Peanut, being a legume, meets most of its nitrogen requirement through nitrogen fixation. While it only requires a small rate of nitrogen (N) as a starter, an adequate supply of phosphorus (P), potassium (K),

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calcium (Ca), and sulfur (S) are essential to obtain higher yields and quality. Polyhalite is a sedimentary marine evaporate which consists of a hydrated sulfate of K, Ca and Mg with the formula: $K_2Ca_2Mg(SO_4)_4 \cdot 2(H_2O)$. Polyhalite contains 48% S and is being used in China as a source of K, S and other nutrients. The objective of this study in Henan, China, was to evaluate the effects of different polyhalite application rates on yield and nutrient content of different peanut plant parts at different growth stages. Eight fertilization treatments were tested: current practice (NPK) as the control, and seven combinations of NPK and polyhalite fertilizers. Results indicated that application of polyhalite in addition to the current practice produced higher leaf, stem and nut yields, and relatively higher nutrient contents at different growth stages. Highest leaf dry weight was obtained at 67 days after emergence (DAE) while highest stem and nut dry weight was obtained at 111 DAE. Different plant parts responded differently to different treatment combinations. Total leaf dry weight was the highest in T2 (NPK + 225 kg ha^{-1} polyhalite) and lowest in T1 (control), the increase being 43%. Stem weight was the highest in T3 (NPK + 375 kg ha^{-1} polyhalite) and lowest in T5 (NPK + 375 kg ha^{-1} Sofipoly). T3 gave 37.8% more stem total dry weight yield over T5 and 20% more over the control (T1). Similarly, total nut yield was highest in T6 (90% NPK + 375 kg ha^{-1} polyhalite) and lowest in T7 (80% NPK + 375 kg ha^{-1} polyhalite). T6 yielded 28.9% more yield over T7 and 27% more yield over the control (T1). Application of NPK with 375 kg ha^{-1} polyhalite gave higher stem dry weight while application of 70% NPK with 375 kg ha^{-1} polyhalite gave the lowest dry matter yield indicating that optimum application of NPK is required to benefit from nutrients from polyhalite application. However, further multi-location and multi-year experiments are required to make optimum rate recommendations. Economic analysis of the fertilizer combinations is also required.

Keywords: Peanut; Fertilizer; Polyhalite; Growth stage; Plant parts.

Introduction

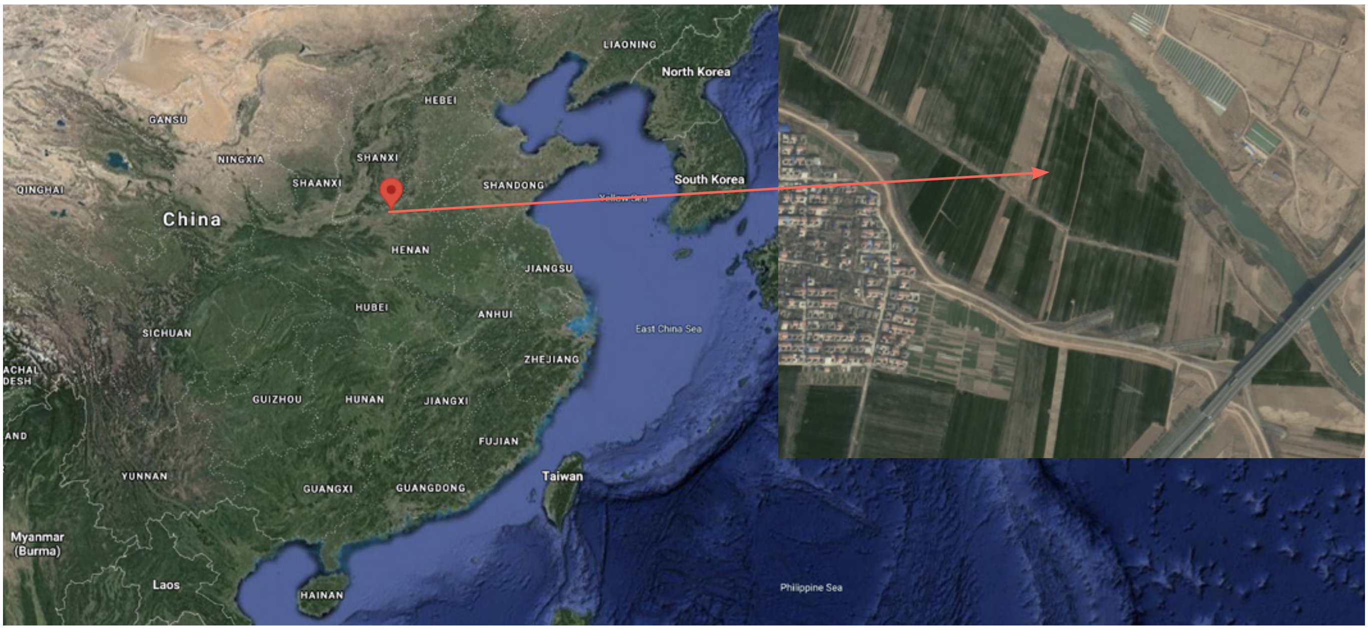
Peanuts (*Arachis hypogaea*), also referred to as groundnuts, are an annual herbaceous legume with an indeterminate growth habit. As these alternate names imply, this unique plant produces its fruit (peanut) below ground. Peanut is an economically important oilseed, feed, and food crop and widely cultivated in tropical and subtropical regions of the world. Although a legume; it is generally included amongst the oilseeds due to its high oil content. Peanuts are rich in protein, oil, and fibers (Suchoszek-Lukaniuk *et al.*, 2011). For human consumption, the crop is cultivated primarily as whole seeds or as a processed product. Peanuts are key oilseed and food-legume crops for both humans and livestock in tropical and subtropical regions, and globally they are the fourth largest source of edible oil (Mondal *et al.*, 2020). China leads in the production of peanuts, 35.93% of world production, followed by India (13.80%) and Nigeria (9.13%) in 2019 (FAOSTAT, 2019). According to Statista report, Henan is the leading producer of peanut in China with production of 5.767 million metric tons in 2019 (Statista.com, 2020) followed by Shandong and Guangdong regions.

Balanced fertilization is one of the most critical groundnut production management strategies to improve crop yield and quality. Assessing pod yield and plant nutrient demand can provide theoretical guidance for fertilization management of high-yielding peanut. Being a legume, peanut gets most of its N from nitrogen-fixing bacteria (*Bradyrhizobium*) colonizing the plant's roots, however, peanut does require a small rate of N as a starter fertilizer. Adequate rates of P, K and S application are essential to obtain considerable yields and quality. Sulfur is now recognized as the fourth major plant nutrient after N, P and K, and an integral part of balanced fertilization and nutrition for oilseed crops including groundnut. Calcium is another critical nutrient in groundnut production (Baughman and Dotray, 2015). Various research results indicated that peanut responds to P (Dzomeku *et al.*, 2019), K (Pradyut *et al.*, 2006; Reddy *et al.*, 2011; Sharma *et al.*, 2011; Lobo *et al.*, 2012), Ca (Xiao-long *et al.*, 2018), S (Ariraman and Kalaichelvi, 2020) and B (Singh *et al.*, 2009) especially when these nutrients are deficient in the soil where peanut is grown and where there is sufficient supply of other nutrients.

Polyhalite is a sedimentary marine evaporate fertilizer that supplies multiple essential primary, secondary and micronutrients. Mined in the UK by ICL Fertilizers, and marketed under the trademark Polysulphate®, polyhalite consists of a hydrated sulfate of K, Ca and Mg with the formula: $K_2Ca_2Mg(SO_4)_4 \cdot 2(H_2O)$, which contains 48% S. Sofipoly on the other hand is a granulated fertilizer produced from polyhalite and SOP (sulphate of potash) and consists of 30% K_2O, 15.7% S, 5.8% CaO, 10.2% MgO and 0.3% B. Both fertilizers have attracted strong interest in China as they can provide the nutrients needed to help farmers increase yields and become more productive.

Currently, the practice of blanket fertilization in peanut production is widespread, especially in rural areas of China. This continuous and higher dose use of nitrogen and phosphate fertilizers, and lower use of other essential nutrients like potassium would result in unbalanced nutrient input and low fertilizer efficiency (Swarup, 1998; Mahajan and Gupta, 2009). In peanut, N, P and K compound fertilizers have been widely used in production and have greatly boosted peanut yield in the past. However, recently the yield of peanuts has not increased much, even with an increased use of N, P and K compound fertilizers indicating that other essential nutrients are becoming limiting. Use of fertilizers containing Ca, Mg and S is rare in the study area.

Previous studies have shown that NPK combined with calcium and magnesium sulfate fertilizers significantly increased the yield of rape (Tian *et al.*, 2019), rice (Zhao *et al.*, 2014), pakchoi, tea, and watermelon (Lin *et al.*, 2005). In Jinzhou, Fujian and other places, experiments applying calcium, magnesium and sulfur containing fertilizers to peanut have shown that peanut yield has increased significantly (Huang *et al.*, 2014). However, there is limited information on the effect of NPK combined with Ca, Mg and S nutrients on yield, nutrient content and partitioning of peanut in Henan province of China. The objective of this experiment is therefore to



Map 1. Location of the experiment site in Henan, China. Source: Google Earth.

study the effects of combined application of conventional NPK fertilizer with polyhalite and Sofipoly fertilizers on peanut yield, nutrient content and partitioning, and quality in Henan province of China.

Materials and methods

The field experiment was conducted at the experimental farm of Henan University of Science and Technology (33°35'-35°05'N, 111°8'-112°59'E), Henan, China in 2019. Combinations of conventional NPK and polyhalite fertilizer treatments, and conventional NPK fertilizer as the control treatment, were tested. Details of the treatment combinations used in the experiment are presented in Table 1.

The test site is in a temperate zone, with a semi-humid and semi-arid continental monsoon climate. The site has a mean annual temperature between 12.1-14.6°C, mean annual rainfall of 600 mm, annual average evaporation 2,113.7 mm, and annual average radiation 491.5 kJ cm^{-2}. The annual sunshine hours are 2,300-2,600 hours, and the frost-free period is 215-219 days. Monthly mean temperature and precipitation from 2010 to 2020 are displayed in Table 2. The soil of the test site is characterized as yellow fluvo-aquic, the main soil type in the North China Plain which produces almost 60-80% of China's wheat and 35-40% of China's maize every year (Kong *et al.*, 2014). Preplant soil samples were collected at 0-20 cm depth to determine selected physicochemical properties. The soil samples were air dried, ground to pass 2 mm, and analyzed for soil alkaline N using alkaline diffusion method (Mulvaney and Khan, 2001), available P using $NaHCO_3$ method (Olsen *et al.*, 1954), available (exchangeable) Ca, Mg and Fe using EDTA extraction-ICP method (Barrows and Simpson, 1962), available S using calcium chloride solution extraction-ICP method (Houba *et al.*, 2000) and available potassium using 1N ammonium acetate extraction-ICP method (Johnson and Goulding, 1990; Normandin *et al.*, 1998). The physicochemical properties of the experiment soil are displayed in Table 3.

Table 1. Treatment descriptions on combined application of polyhalite and NPK on peanut experiment in Henan China.

Treatments		Fertilizer			Nutrients						
Code	Description	NPK	Polyhalite	Sofipoly	N	P_2O_5	K_2O	S	Ca	Mg	B
			-----------------	-----------------	-----------------	-------*kg ha^{-1}*-------	-----------------	-----------------	-----------------	-----------------	
T1	Control (NPK)	600	0	0	108	108	108	0	0	0	0
T2	NPK + 225 kg ha^{-1} polyhalite	600	225	0	108	108	140	43	8	27	0
T3	NPK + 375 kg ha^{-1} polyhalite	600	375	0	108	108	161	72	14	46	0
T4	NPK + 525 kg ha^{-1} polyhalite	600	525	0	108	108	182	101	19	64	0
T5	NPK + 375 kg ha^{-1} Sofipoly	480	0	375	86	86	199	59	23	15	1.2
T6	90% NPK + 375 kg ha^{-1} polyhalite	540	375	0	97	97	150	72	14	46	0
T7	80% NPK + 375 kg ha^{-1} polyhalite	480	375	0	86	86	139	72	14	46	0
T8	70% NPK + 375 kg ha^{-1} polyhalite	420	375	0	76	76	129	72	14	46	0

Table 2. Monthly mean temperature and precipitation from 2010 to 2020.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation (mm)	10.7	13.5	17.3	47.1	54.0	71.6	108.3	99.9	101.9	49.1	33.0	4.5
Temperature (°C)	0.8	3.6	10.4	16.1	21.7	25.8	27.1	25.7	21.2	15.6	9.0	3.0

Table 3. Physicochemical properties of the experiment soil in Henan, China.

Soil property	Value	Rating
Sand (%)	12.5	Loam texture
Silt (%)	64.2	Loam texture
Clay (%)	23.3	Loam texture
pH	7.56	Alkaline
Bulk density (g cm^{-3})	1.31	Low (Hunt and Gilkes, 1992)
Alkali hydrolyzable nitrogen (mg kg^{-1})	33.86	Low
Available phosphorus (mg kg^{-1})	18.46	Low (Marx *et al.*, 1999)
Available iron (mg kg^{-1})	5.98	Low
Organic matter (g kg^{-1})	10.72	Very high: https://njaes.rutgers.edu/soil-testing-lab/organic-matter-levels.php

Peanut variety Huayu 16 was used as the test material for the experiment. The experiment plot size was 3.5 × 5 m. Seeds were planted at a row spacing of 35 cm with 20 cm between planting holes and two seeds were planted in each hole. Ridge planting was adopted with bottom and top ridge width of 70 cm and 45 cm, respectively. The experiment had 8 treatments arranged in a randomized complete block design with three replications. Fertilizers for each treatment were broadcast applied before ploughing. The peanut planting and harvesting dates were 16 June 2019 and 22 October 2019, respectively.

Plant samples were collected at four different growth stages (32, 50, 67 and 111 DAE) for leaves and stems, and at 67 and 111 DAE for nuts, to determine plant fresh weight, dry weight and concentration of N, P, K, Ca, Mg and S following standard procedures for each. Four randomly selected plants from two holes were sampled from each plot at each stage. The concentration of phosphorus, potassium, calcium, magnesium, and sulfur in the plants were determined by inductively coupled plasma (ICP) after digestion in a mixture of concentrated HNO_3 and H_2O_2 in a microwave oven. Nitrogen was determined by Kjeldahl after digestion in a mixture of concentrated H_2SO_4 and H_2O_2.

The effects of different combinations of the applied NPK and polyhalite fertilizers on the biomass accumulation and partitioning were statistically analyzed using ANOVA.

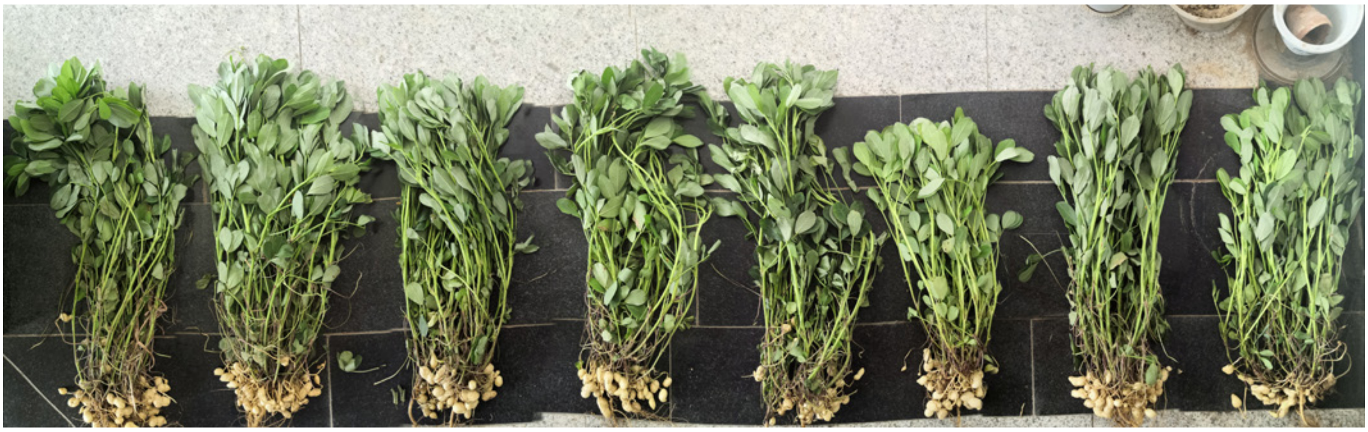


Photo 2. Peanut (*Arachis hypogaea* L.) samples taken at 67 days after emergence. Left to right: Treatment T3, T6, T7, T8, T4, T2, T5, and T1 (Control). See Table 1 for details. Photo by the authors.

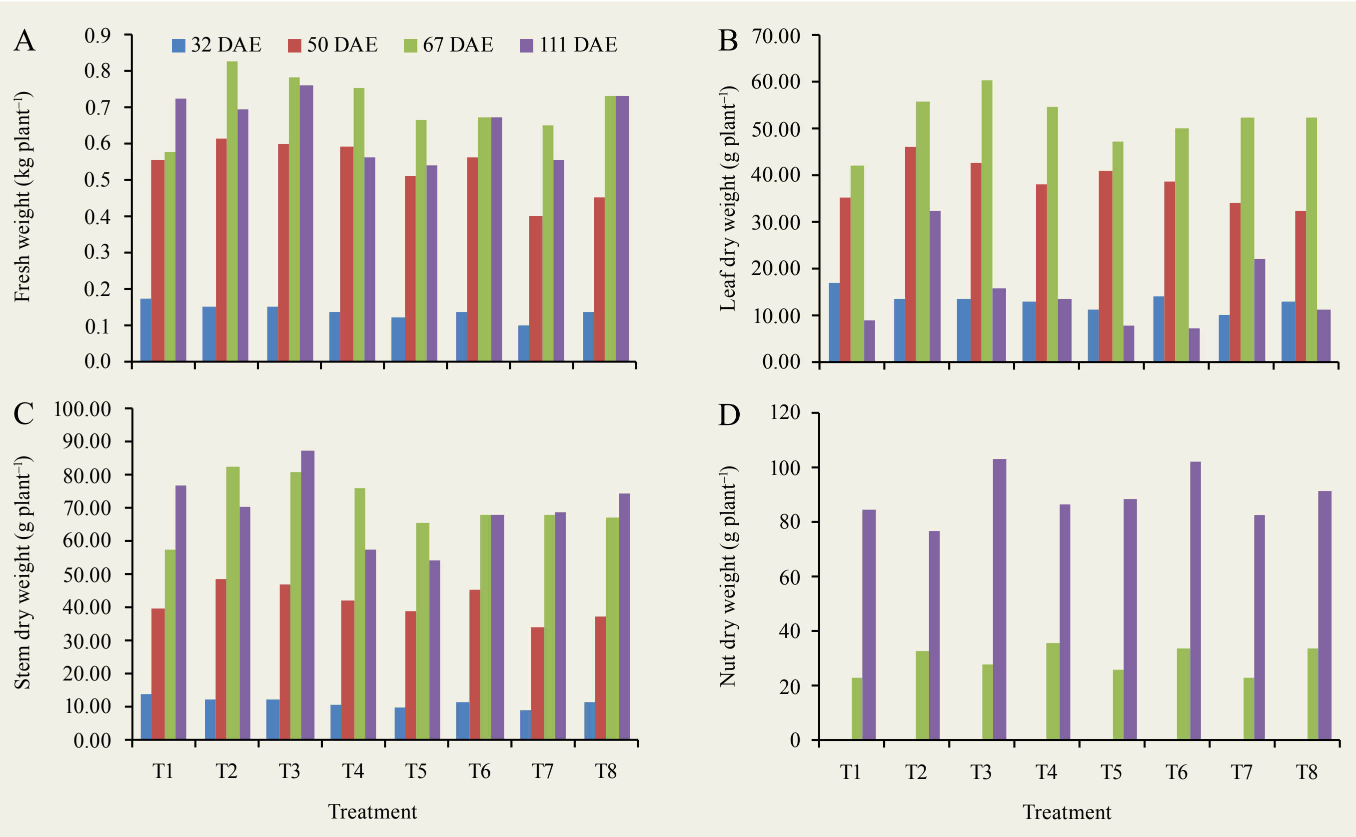


Fig. 1. Effects of fertilizer treatments on total fresh weight (A), leaf dry weight (B), stem dry weight (C) and nut dry weight (D) at four growth stages (32, 50, 67 and 111 DAE) of peanut in Henan, China in 2019. Refer to Table 1 for detailed description of the fertilizer treatments.

Results

The experiment soil was loamy in texture and alkaline in reaction with very high organic matter content, low available P and low alkali hydrolyzable nitrogen. The bulk density was low, indicating that it is not compacted and is suitable for plant growth (Table 3).

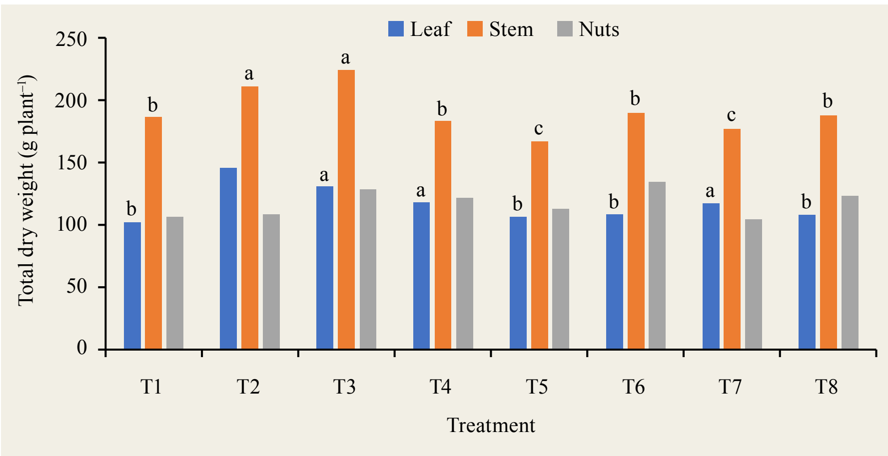


Fig. 2. Effects of combined application of NPK with polyhalite on total leaf dry weight, total stem dry weight and total nut dry weight summed from four peanut growth stages (32, 50, 67 and 111 DAE) in Henan, China in 2019. Refer to Table 1 for detailed description of the fertilizer treatments.

Combined application of NPK fertilizer with polyhalite affected the fresh and dry weight of peanut plant parts at different growth stages. The fresh weight of peanut showed an increasing trend up to 67 DAE and decreased afterwards in most of the treatments except the control where the fresh weight increased with increasing age (111 DAE). Treatment T2 gave the highest fresh weight at all stages of growth compared to other treatments, followed by T3, while the lowest was T7 (Fig. 1A). Peanuts' fresh biomass yield ranged from 0.54 to 0.76 kg plant^{-1} at 111 DAE. The highest yield was obtained from T3 and the lowest from T5. Combined application of NPK with polyhalite gave the highest yield, followed by NPK only. The effect of polyhalite reduced as the amount of NPK decreased.

Table 4. ANOVA table showing the effect of treatments on various yield and nutrient contents of nuts.

Treatments	Total dry weight			Nutrient contents in nuts at 111 DAE					
	Leaf	Stem	Nut	N	P	K	Ca	Mg	S
	----------------g plant^{-1}----------------			----------------g kg^{-1}----------------					
T1	103.00b	188.67bc	107.33	41.17bc	11.97b	5.50ab	1.00ab	1.70ab	1.40b
T2	147.00a	213.33ab	109.33	44.10a	11.20b	4.93b	0.93b	1.60b	1.27b
T3	132.00ab	226.33a	130.33	36.27de	12.23ab	5.67ab	1.10ab	1.90ab	1.40b
T4	119.00ab	185.33bc	122.67	36.23de	11.83b	5.20ab	1.03ab	1.73ab	1.33b
T5	107.33b	168.67c	114.00	42.13ab	16.47a	7.17a	1.10ab	2.33a	2.03a
T6	109.67b	192.00bc	136.00	33.27f	14.23ab	6.63ab	1.17a	2.10ab	1.77ab
T7	119.00ab	178.67c	105.33	33.87ef	13.37ab	6.27ab	1.10ab	2.03ab	1.60ab
T8	109.00b	189.33bc	124.33	38.43cd	11.73b	5.73ab	0.97b	1.80ab	1.43ab
Significance level	**	***	ns	***	ns	ns	ns	ns	ns
LSD	29.27	31.04	56.52	2.78	4.43	2.00	0.18	0.65	0.61
CV	8.76	5.69	16.85	4.17	19.87	19.66	9.72	19.69	22.97

Significance level: *** 0.001 and ** 0.01. ns = non-significant. Values with the same letter within each column are not significantly different from each other.

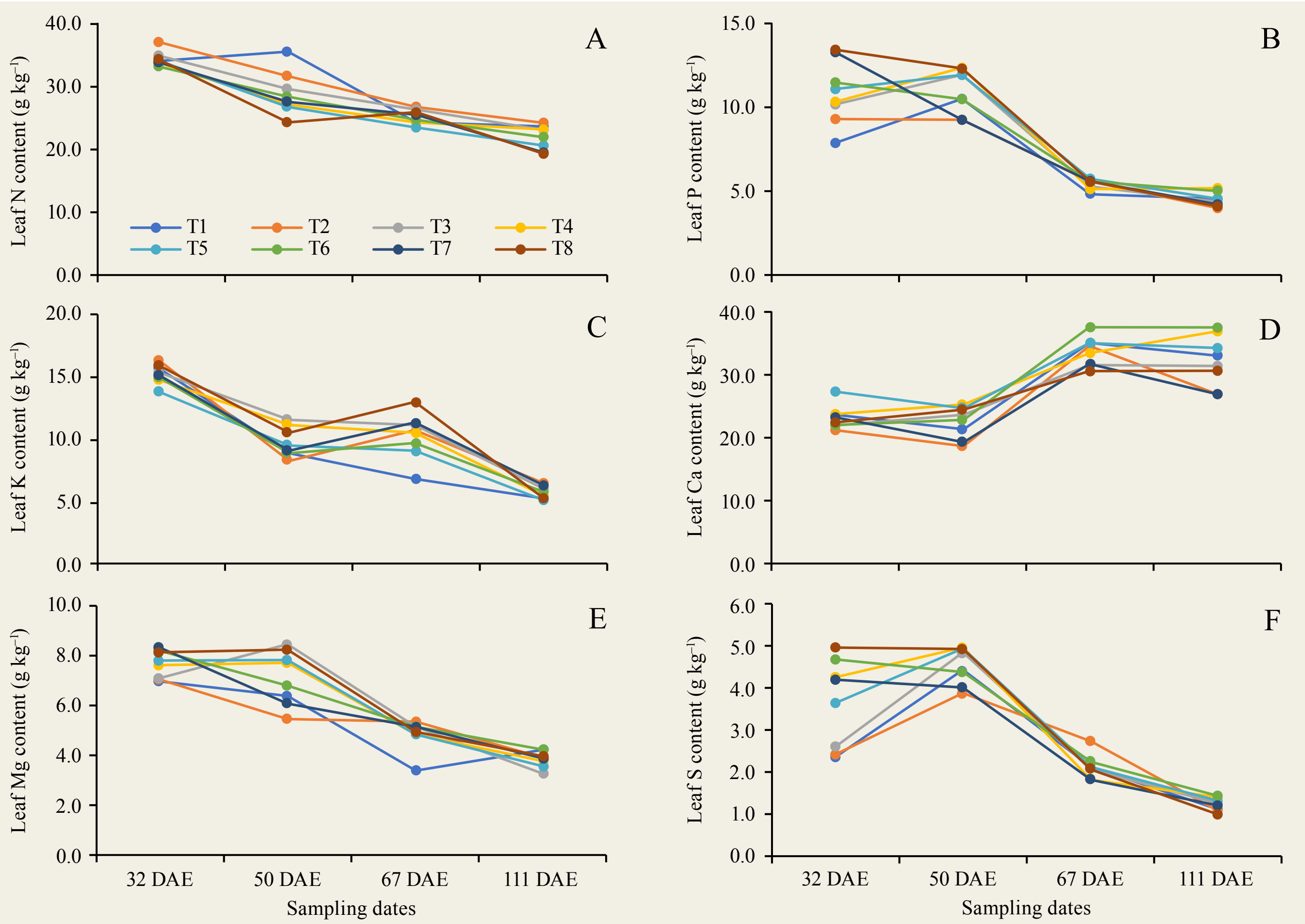


Fig. 3. Effects of NPK and polyhalite fertilizer combinations on N, P, K, Ca, Mg, and S concentrations in leaves at four growth stages in Henan, China.

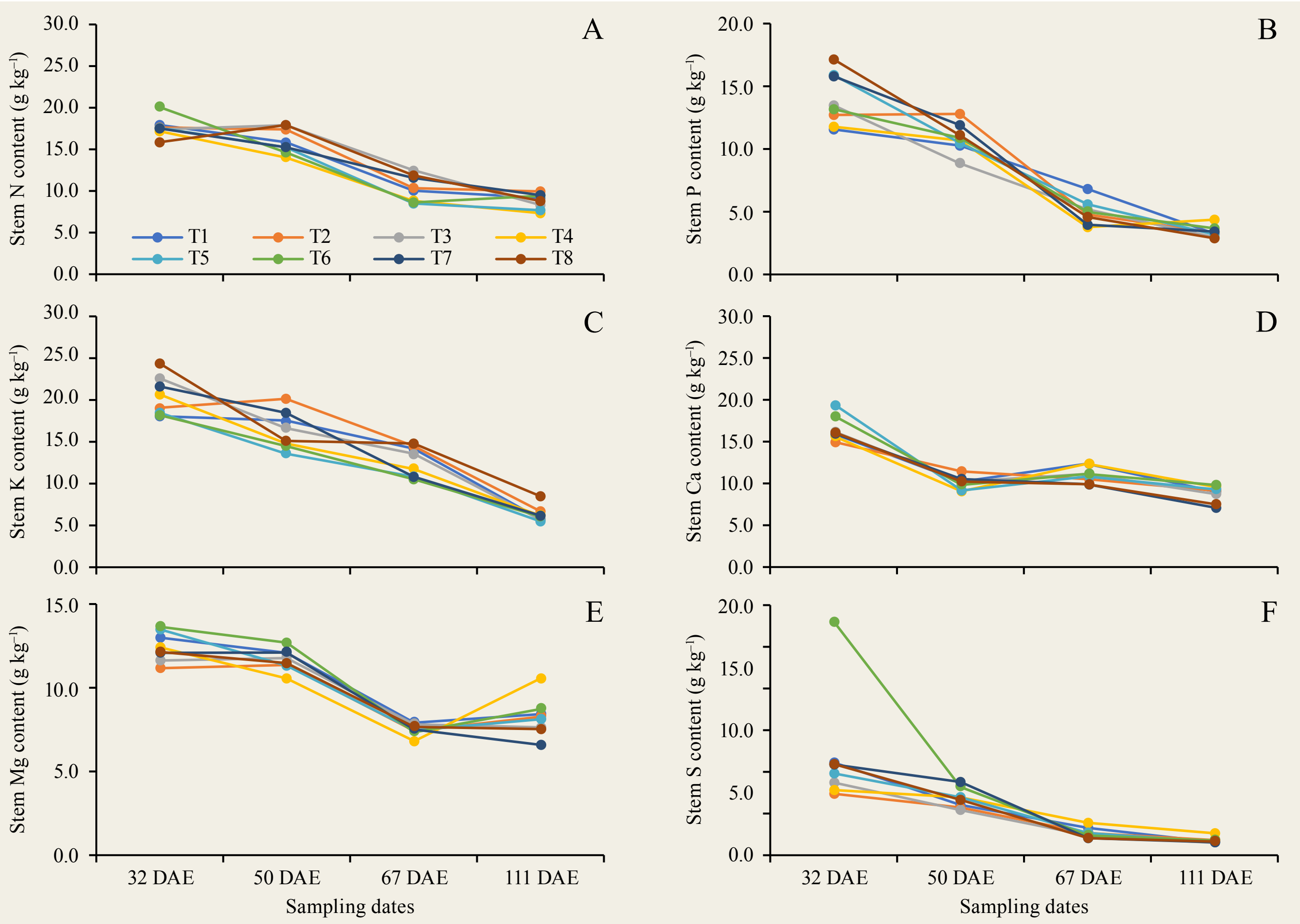


Fig. 4. Effects of NPK and polyhalite fertilizer combinations on N, P, K, Ca, Mg, and S concentrations in stems at four growth stages in Henan, China.

Similarly, leaf dry weight showed an increasing trend until 67 DAE and decreased at later stages in all treatments. On the contrary, stem dry weight and nut dry weight increased as the plant gets to maturity (111 DAE). The highest stem and nut dry weight were obtained from T2, and the lowest was from T7 (Fig. 1B, 1C, 1D). Highest leaf dry weight was obtained at 67 DAE from T2 and the lowest from the control at the same stage. Highest stem dry weight was obtained at 111 DAE in most treatments, except that of T2, T4 and T5 treatments where higher stem dry weight was obtained at 67 DAE. T3 gave the highest stem dry weight followed by the control at 111 DAE. Lowest stem dry weight was obtained from T5 followed by T7 where the lowest amount of NPK (70%) was applied with the same amount of polyhalite, indicating that optimum application of NPK is required to benefit from the additional nutrients supplied by polyhalite.

The effect of combined application of NPK with polyhalite fertilizers on total dry weight yields of leaf, stem, and nut collected at four different growth stages is presented in Fig. 2. Total leaf dry weight was the highest in T2 and lowest in T1, the increase being 43%. Stem weight was the highest in T3 and lowest in T5. T3 gave 37.8% more stem total dry weight yield over T5 and 20% more over the control (T1). Similarly total nut yield was highest in T6 and lowest in T7. T6 produced 28.9% more yield over T7 and 27% more yield over the control (T1).

Combined application of NPK with polyhalite also affected the concentration of plant nutrients in peanut plant parts at different growth stages. Accordingly, leaf concentrations of N, P, K, Mg and S decreased while leaf Ca increased with plant age. Stem N, P, K, Ca, Mg and S showed a decreasing trend with plant age. Nut N, P and S contents increased while K, Ca, Mg contents decreased with plant age (Fig. 3, 4, 5).

Leaf P content was highest at 50 DAE and decreased afterwards. The trend was similar for most treatments except T3 and T4 treatments where higher P was obtained from 32 DAE. Leaf K content was highest in early stage (32 DAE) followed by 67 DAE. The highest leaf K was obtained from T4 and the lowest from T1 (control), and

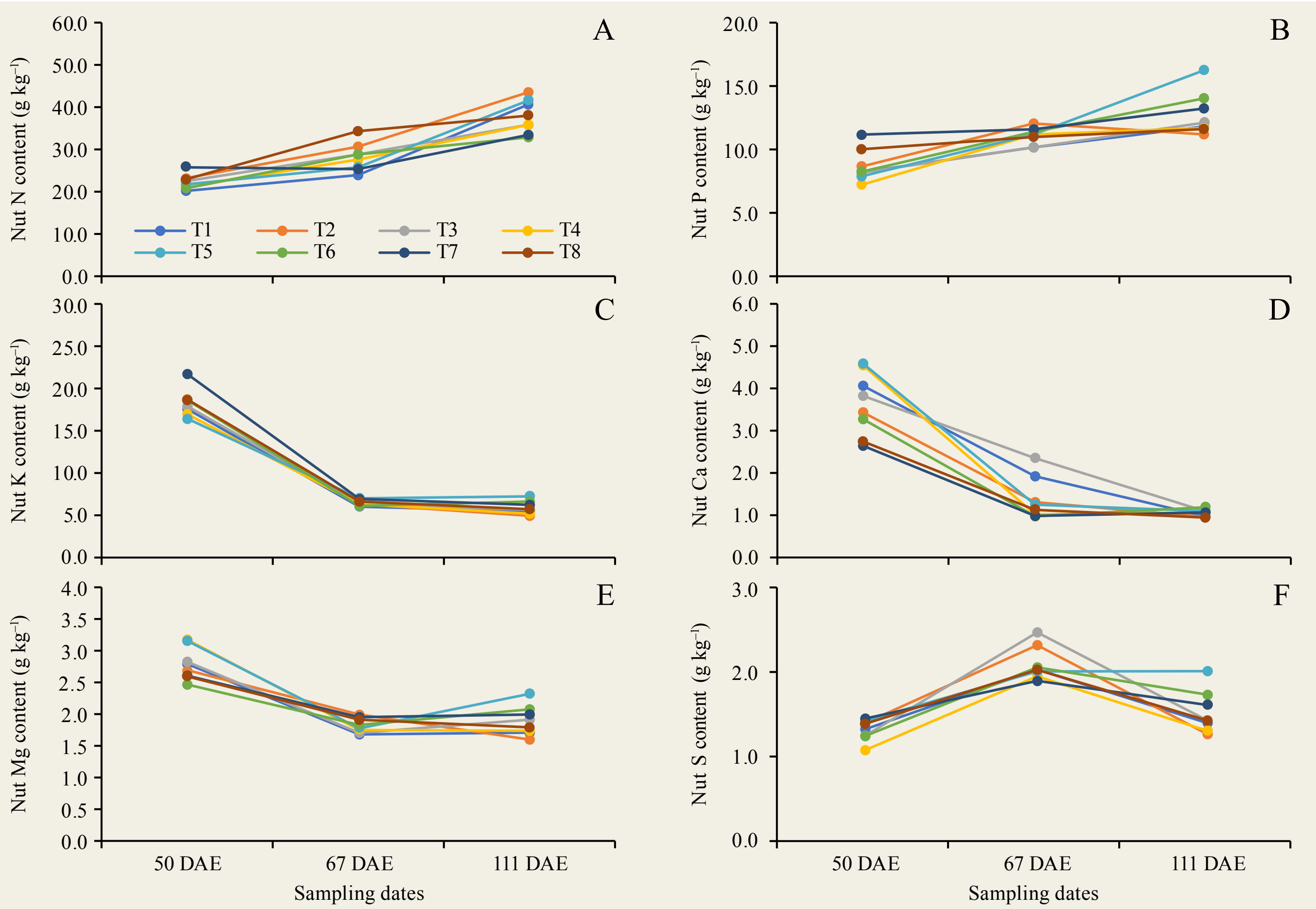


Fig. 5. Effects of NPK and polyhalite fertilizer combinations on N, P, K, Ca, Mg, and S concentrations in nuts at three growth stages in Henan, China.

there was significant difference between the two treatments. Leaf S content was highest at 50 DAE and decreased afterwards. The trend was similar for all treatments and there was no significant difference among treatments on leaf S content.

Nut N and P concentration showed an increasing trend with plant age; the highest N and P concentrations were at 111 DAE. Nut K, Ca and Mg content showed a general decrease with plant age. The nut S content was highest at 67 DAE followed by 111 DAE (Fig. 5). Nutrient contents of nuts do not vary greatly among treatments at 111 DAE, with the exception of N where a significant difference among treatments was observed (Table 4). All treatments resulted in a similar trend in nutrient concentrations in nuts, with no significant difference in nut nutrient content among treatments at all stages of growth.

Discussion

Appropriate crop nutrition management through balanced fertilization is crucial for sustainably achieving higher yield and quality of produce. Like other crops, peanut also requires a sufficient supply of essential nutrients other than N and P. In this experiment, application of polyhalite fertilizers in addition to the conventional NPK practice resulted in better yield and nutrient content in different parts of the peanut crop, and at different growth stages. This could be due to the effect of additional nutrients such as S, or Ca, and their interaction with other nutrients.

In line with this, previous studies indicated that exogenous calcium application had significant positive effects on absorption and accumulation of nitrogen, phosphorous, calcium and magnesium in different organs of peanut under salt stress (Xiao-long *et al.*, 2018; Yadav *et al.*, 2015). In their 2-year study, Abdel-Motagally *et al.* (2016) showed that sulfur application had a significant influence on yield and quality parameters in both seasons. Similarly, Patel and Zinzala (2018) have also reported that application of S and B improved yield and nutrient contents of peanut. Kabir *et al.* (2013) also reported that P, Ca and B application significantly increased plant height, number of branches plant^{-1}, and total dry weight of peanut.

In summary, basic NPK containing fertilizers are commonly used in China, however the result from this experiment is an indication that application of additional nutrients is required to improve crop performance. Besides yield and quality of peanut, understanding the effect of these fertilizers on soil properties after harvest and their role in nodulation needs further investigation. Dry matter yield and nutrient concentrations in different plant parts were affected differently. Application of NPK with 375 kg ha^{-1} polyhalite gave higher stem dry weight, which could be due to the addition of 72 kg ha^{-1} S and 43 kg ha^{-1} of K. On the other hand, application of 70% NPK with 375 kg ha^{-1} polyhalite gave the lowest dry matter yield indicating that optimum application of NPK is required to benefit from the applied nutrients from polyhalite. Potash and S responses will be visible when there are sufficient amounts of N and P, which are the most limiting elements. The results indicated that application of K and S contributed to improvements in yield and nutrient content. But adding higher contents of these two nutrients (beyond 161 kg ha^{-1} K_2O and 72 kg ha^{-1} S) do not continue improving yield and nutrient content in peanut. It is therefore recommended that determining the optimum rates of K and S under balanced application of other nutrients is required. Further multi-location and multi-year experiments are required to make optimum rate recommendations for S and K. Economic analysis of the fertilizer combinations is also required.

Acknowledgement

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The paper "Effects of Combined Application of NPK Compound Fertilizer with Polyhalite Fertilizers on Peanut Yield, Nutrient Content and Partitioning in Henan Province, China" also appears on the IPI website.