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Influence of nitrogen fertilizer application on maize yield and nitrogen use efficiency in China

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Abstract
Background*: Maize (Zea mays L.) production is influenced by several factors including Nitrogen (N) fertilizer use, planting density, and soil pH. Although N fertilizer has improved agriculture by improving crop produce However, the excessive application of N beyond crop requirements by farmers in China has led to reduced N use efficiency. ecological and health situations such as waterbody eutrophication, nutrient ooze, and volatilization.*
Materials and Methods*: A randomized block design (RBD) with four replicated treatments was used to conduct the experiment. Nitrogen treatment was set as (Control, N0, N60, and N200 kg/ha) with phosphorous (P) and potassium*
(K) at a constant rate of 75 kg/ha and 60 kg/ha, respectively, excluding control. Fertilizer was applied as a top dressing, and the sources of fertilizer used for the experiment were urea as N, single super phosphate (SSP) as phosphorus, and potassium chloride (KCL) as potassium. The size of each plot was 6m long and 3m wide (18 m^2). ***Results****: The result indicated that the application of 200 kg N/ha led to a higher yield of 5654,7685 kg/ha than control 5189, 6363 kg/ha in 2020 and 2021 respectively. Partial factor productivity of N was significantly higher when 60 kg N/ha was applied than 200 kg N/ha with a PFPN of 92, 28 kg/kg and 128, 33 kg/kg in 2020 and 2021 respectively. Also, agronomic use efficiency was higher with the application of 60 kg N/ha than 200 kg N/ha.*
Conclusion: *High application of nitrogen has been found to increase yield, however, the excessive application beyond crop requirement for maximum maize yield led to low partial factor productivity and agronomy use efficiency of N. Therefore, it is paramount to reduce N application rate as the application beyond optimal rate does not guarantee a steady increase in yield but rather causes a decline in N utilization of maize. Overall, the result indicates for China to sustain maize production and improve N use efficiency, application rate needs to be optimized.*
Key Word*: nitrogen application rate, partial factor productivity, agronomic use efficiency, yield, maize.*

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I. Introduction

One-third of China's grain production is from maize [1]. The common farming method practiced in the North China Plain is the wheat/maize system. Maize yield has increased significantly in recent decades in China and other mechanized parts of the world due to increased mineral fertilization, mechanization, and improvements in planting density[2]. The productiveness of any given plant is a feature of nutrient availability [3]. However, crops grown must efficiently utilize all or most of the nutrients applied [4], and as such, agricultural intensification for maximum food production necessitates holistic approaches in fertilizer management, particularly N [5].

Nitrogen is an essential nutrient that influences agricultural ecosystem productivity. It is mostly supplied through chemical fertilizers [6]. Maize productivity responds positively to N availability. In 2019, China's chemical N fertilizer consumption was (26 million metric tons), followed by India (18 MMT), the USA (11 MMT), and the Europe Union (9 MMT), making China the top agricultural consumer of total N in the world [7]. Application level, method, source of N, and climate affect corn production [8]. Increasing N application has been an important strategy in agricultural production for achieving high yields, yet there are no positive correlation between crop yield and N level [9]. Farmers in China apply N fertilizer >263 kg/ha, higher than the optimum rate practiced in the experimental field which leads to low NUE and AEN [10].

Nitrogen management has become a serious issue in China and other developed countries as the excessive application by farmers has led to the loss of profit, resources, and environmental issues such as leaching, volatilization, and eutrophication. Application level of 172 kg N/ha affected grain yield and NUE of maize and further increase of fertilizer led to yield decline, similar scenario was recorded in N use efficiency as application rate increased NUE reduced [11]. Regression analysis by Yang showed a linear decrease in PFPN AEN with an increase in N application rates [10].

A large portion of fertilizer N is not used effectively in agriculture, and 50 % of the N applied is recovered from soil and plant [12]. The average NUE is around 30 %, resulting from N loss [13]. Therefore, effective and improved N management practices are required to enhance maize productivity, agronomic efficiency, and N utilization. Good N management increases N use efficiency by applying agronomic rate, at the precise time and using the right method [14]. Optimum N management is reduction in N application combined with a mixture of slow-release and urea fertilizer, which leads to an increase of NUE and grain yield [15]. Deep placement of fertilizer with a combination of CRU and urea at a ratio of 2:1 can improve NUE and maize yield [16].

II. Material And Methods

The experiment was carried out from June 2020 to October 2021 at the China Agricultural University, Science and Technology Backyard (STB), Quzhou Experimental Station, Hebei Province, located on the North China Plain. Its geographical coordinates lie between 36°52´N and 115°01´E. The soil in this area is alkaline, and the cropping system practiced is the winter wheat/summer maize rotation. The study site has a warm-tempered monsoon zone with a mean yearly temperature of 14.4 °C and annual precipitation of 676 mm, of which 60 % occurs from July to September. The soil has a pH of 7.71, and the topsoil (0-20 cm) contains soil organic carbon of 17.1 g/kg, total N 1.22 g/kg, available P 103 mg/kg, and available K 144 mg/kg air-dried soil. Plant samples were dried and grounded to powder form for nutrient analysis. The material was dissolved in a mixture of concentrated H2SO4 and H2O2 before determining N, P, and K content. Nitrogen content was determined by the micro–Kjeldahl method (KDY-9810, KETUO Instrument Co. Ltd., Beijing, China); P content was determined by the vanadomolybdate method (UV757T, Shanghai Instrument Co. Ltd., Shanghai, China); K content was measured by flame photometry (FP640, Shanghai Instrument Co. Ltd., Shanghai, China) [17].

Study Design: Randomized Complete Design

Study Location: China Agricultural University, Science and Technology Backyard (STB), Quzhou Experimental Station, Hebei Province, located on the North China Plain.

Study Duration: June 2020 to October 2021.

Sample size: 16 plots.

Sample size calculation: The size of each plot was 6 m long and 3 m wide (18 m^2) each treatment replicated four times.

Subjects & selection method: A randomized block design (RBD) with four replicated treatments was used to conduct the experiment. Nitrogen treatment was set as (Control, N0, N200, and N60 kg/ha) with phosphorous (P) and potassium (K) at a constant rate of 75 kg/ha and 60 kg/ha, respectively, excluding control. Fertilizer was applied as a top dressing, and the sources of fertilizer used for the experiment were urea as N, single super phosphate (SSP) as phosphorus, and potassium chloride (KCL) as potassium.

Inclusion criteria:
1. Control (0kg/ha)
2. N 0, P 75kg/ha, K 60kg/ha
3. N 60kg/ha, P 75kg/ha, K 60kg/ha
4. N 200kg/ha, P 75kg/ha, K 60kg/ha

Procedure methodology

Denghai 605, a high-yield maize variety was sown on June 13, 2020, and May 25, 2021, using a planter and placing one seed per hole. The planting density was 66,666 plants/ha in 2020 and 2021, using a planting spacing of 25 cm and row spacing of 60 cm. The variety has an 88-90 % germination rate. Fertilizer application was applied after emergence, using the furrow application method at a depth of 10 cm and 5 cm from the maize plant. Imazapyr, a non- selective herbicide, was used to control weeds and *Bacillus thuringiensis* to control insects and pests.

Sampling and measurements

a) Basic soil fertility: Before planting, soil samples were taken from a depth of 0-20 cm before planting and 0-20 cm and 20-40 cm after harvest using an auger and were air-dried for 3 days after which was passed through a 2 mm sieve to remove debris. The soil samples were used to determine soil pH, organic carbon, total N, available N, phosphorus, and potassium content.

b) Determination of plant traits: Measurements were taken at tasseling (VT), and harvest stage using a carpenter tape, three plants from the middle row excluding the right and left border row of each plot were selected randomly using the destructive method to determine the plant height, ear height, leaf length, leaf width, and aboveground dry matter. The fresh leaf, stem, and cob were cut and bagged separately and oven-dried at 75ºC, and the final dry weight was recorded. Dried plant samples were blended and sent to the laboratory for nutrient analysis. Green leaf area (LA) was determined using a non-destructive method through the length-width coefficient method [17].

c) The relative content of chlorophyll: Chlorophyll content was reflected by SPAD value, which was determined using a chlorophyll meter (SPAD-502) at the tasseling stage on 3 plants selected randomly from the three middle rows of each plot, and the average was calculated.

Yield and its component: At physiological maturity, a harvested area of 5.4 m^2 that has not been tampered with was selected. Cobs were harvested from the three middle rows of each plot, excluding the first and last borderline due to the influence of environmental factors. Total ear harvested were weighed and oven-dried at 75 ˚C, after which dry weight was recorded, five (5) maize cob with the most common trait from each plot were selected from the total harvested ear and weighed, then oven-dried at 75 ˚C and dried weight was recorded. The five ear samples were used to measure ear length, ear diameter, bald tip using a measuring tape, number of rows in an ear, number of grains in a row, and 1000 grain weight (TGW). Nitrogen use efficiency was calculated as AEN, PFPN and NUE

Statistical analysis

Data were compiled in Excel 2019 and analyzed using R software version 4.0.2 with dataset and Origin pro-2021 to test a two-way ANOVA. At $p < 0.05$, the mean was compared using the least significant difference (LSD.

III. Result

Influence of nitrogen application level on growth parameter of maize.

The following growth characteristics (plant height, leaf number, leaf area, and SPAD of summer maize during the two years were analyzed and shown in (Table 1). The Table below shows no significant difference in plant height between treatment at tasseling stage and harvest in 2020, and no significant difference was recorded in the number of leaves, treatment N200 had the highest leaf area while CK had the lowest in 2020; however, had no significant difference was recorded between treatments. Statistically chlorophyll content that there was no significant difference among treatments. In 2021 at ($P < 0.05$), a significant difference was recorded in plant height at the tasseling stage between CK and N200 with control having a plant height of 255.2 cm and N200 with a plant height of 264.8 cm, no significant difference was recorded between N0 and N60. At harvest, no significant difference was recorded in plant height between treatments. Treatment had no significant effect on leaf number, leaf area, and SPAD, although, in terms of leaf area, control had a leaf area of 479.9 cm2 while N200 had a leaf area of 510.4 cm2. The lowest plant height, leaf area at tasseling, and harvest were recorded in CK in both years. Summary of analysis of variance (ANOVA) at ($P < 0.05$) shows that year had a significant effect on the following growth parameters plant height at tasseling stage, plant height at harvest, number of leaves, leaf area, and SPAD. However, treatment had no effect on the above-mentioned parameters, and the interaction between treatment and year did not affect plant height, leave numbers, leaf area, and chlorophyll content.

Table 1. Influence of nitrogen application level on growth parameter of maize in 2020-2021

Year	Treatment	Plant height at VT (cm)	Plant height at Harvest (cm)	Number of green leaves at VT	Leaf area (cm^2)	SPAD at VT
2020	Ck	209.8±2.8[a]	221.5±13.0[a]	12.2±0.8[a]	525.1±28.0[a]	60.3±3.0[a]
	N0	212.3±8.0[a]	227.7±9.0[a]	12.3±0.5[a]	530.2±37.3[a]	60.7±1.0[a]
	N60	212.1±12.5[a]	230.2±4.2[a]	12.5±0.3[a]	530.5±34.8[a]	60.7±2.1[a]
	N200	215.9±8.0[a]	234.7 ±13.1[a]	12.7±0.3[a]	542.2±19.4[a]	60.9±0.8[a]
2021	Ck	255.2±6.0[b]	236.7±1.9[a]	13.2±0.7[a]	479.9±9.6[a]	57.0±0.5[a]
	N0	261.5±6.4[ab]	240.0±16.8[a]	13.3±0.0[a]	502.0±40.2[a]	57.0±1.9[a]
	N60	262.6±4.5[ab]	240.8±5.9[a]	13.3±0.5[a]	505.6±21.2[a]	57.1±0.9[a]
	N200	264.8±4.8[a]	247.9±5.5[a]	13.7±0.5[a]	510.4±31.4[a]	58.3±2.1[a]
Year (Y)		0.001	0.001	0.001	0.004	0.001
Treatment(T)		ns	ns	ns	ns	ns

T×Y		ns	ns	ns	ns	ns

*NX: N represents nitrogen, X represents applied N rate. Values are means of four replicates of every treatment. Means followed by a common letter in a column are not significantly different at (P < 0.05) probability level.

Influence of nitrogen application rate on maize yield and yield components in 2020-2021

The result in (Table 2) shows the influence of different N rates on yield and its components during two growing seasons. The table shows that N application rate had no significant effect on ear height in both years although a higher ear height was recorded in 2021 than the previous year, with N200 producing the highest ear height of 98.8 cm and CK the lowest ear height of 95.7 cm. The response of N rate on cob length, cob diameter, and thousand-grain weight (TGW) was not significant. Kernel per ear had no significant effect among treatments in 2020. However, 2021 recorded a significant between (control and N 200) with a kernel number per ear of 581.8 and 656.3, respectively. No significant difference was recorded between treatment N0 and N60. In 2020 treatment N200 had a yield of 5654.7 kg/ha and N60 a yield of 5575.7 kg/ha, the lowest yield was recorded in CK 5189 kg/ha, an insignificant change was recorded between treatments. In 2021 the highest grain yield was recorded in treatment N200 with a 7685.1 kg/ha grain yield followed by N60 with a 6755.7 kg/ha grain yield. However, there was no significant difference between both treatments. Control had the least grain yield of 6363.2 kg/ha. Overall, statistical analyses of variance at (P < 0.05) showed that year significantly influenced yield, ear height, cob diameter, and thousand-grain weight. The interaction between treatment and year (T×Y) affected the number of kernels per ear cob.

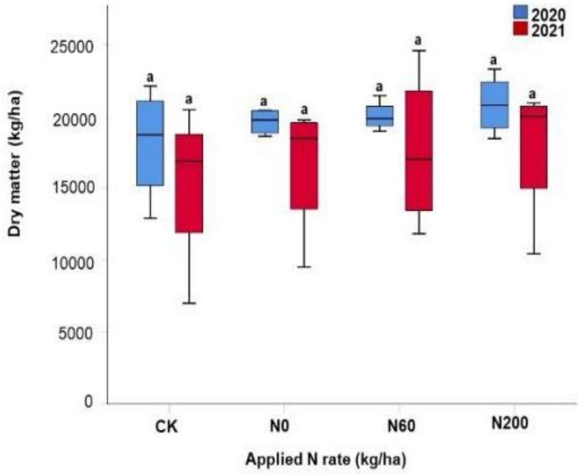
Table 2. Maize yield and its components as affected by N application in 2020-2021.

Year	Treatment	Ear height (cm)	Cob length (cm)	Cob diameter (cm)	Kernel per ear	1000 grain weight (g)	Yield (kg/ha)
2020	CK	83.3±7.1[a]	22.8±1.1[a]	5.7±0.1[a]	598.1±41.3[a]	352.0±13.1[a]	5189.9±567.3[a]
	N0	83.9±3.3[a]	22.8±1.4[a]	5.7±0.1[a]	611.7±56.2[a]	363.3±9.5[a]	5243.9±119.9[a]
	N60	85.4±3.7[a]	23.0±0.8[a]	5.7±0.4[a]	632.6±33.0[a]	368.0±11.0[a]	5575.7±38.5[a]
	N200	87.1±9.8[a]	23.3±0.7[a]	5.8±0.3[a]	641.7±28.0[a]	369.3±15.1[a]	5654.7±278.3[a]
2021	CK	95.7±2.4[a]	22.0±1.3[a]	5.1±0.3[a]	581.8±46.2[b]	339.3±17.3[a]	6363.9±619.1[a]
	N0	97.6±8.9[a]	23.0±1.3[a]	5.2±0.4[a]	654.3±36.0[a]	339.3±19.9[a]	6623.5±447.2[a]
	N60	98.5±7.1[a]	23.4±0.6[a]	5.2±0.4[a]	633.1±22.3[ab]	344.7±14.5[a]	6755.7±798.4[a]
	N200	98.8±8.8[a]	23.6±1.2[a]	5.2±0.3[a]	656.3±43.2[a]	352.3±24.5[a]	7685.1±383.8[a]
Year (Y)		0.001	ns	0.001	ns	0.001	0.001
Treatment (T)		ns	ns	ns	ns	ns	ns
T×Y		ns	ns	ns	0.04	ns	ns

*NX: N represents nitrogen, X represents applied N rate. Values are means of four replicates of every treatment. Means followed by a common letter in a column are not significantly different at (P < 0.05) probability level

Figure 1 showed that dry matter weight ranged from 15330 - 20820 kg/ha, with the lowest biomass associated with treatment CK (18130 kg/ha) and the highest N200 (20820 kg/ha) in 2020. In 2021 there was no significant difference between treatments, CK had the lowest biomass weight of 15330 kg/ha and N200 a high biomass of 17850 kg/ha. However, at (P > 0.05) treatment, year and the interaction between year and treatment did not affect dry matter weight.

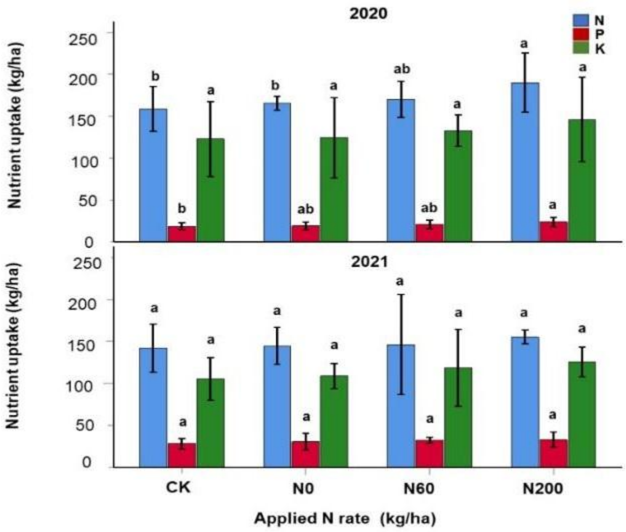
Figure 1 Effect of nitrogen rate on dry matter weight in 2020-2021 growing seasons.



Note: Values are means of four replicates of every treatment. Means followed by a common letter in a column are not significantly different at (P< 0.05) probability.

After harvest total nutrient uptake of NPK derived from stem, leaf, and grain were analyzed. As seen Fig (2) shows application rate affected N uptake in 2020 planting season. A significant difference was observed between treatments with N200 having the highest N uptake of 190.0 kg/ha and CK having an N uptake of 158.5 kg/ha. A significant difference was observed in P uptake between CK and N200. Treatment did not affect K uptake nutrient. In 2021 growing season N application rate did not affect the NPK nutrient of the plant. The highest NPK uptake was recorded in N200 and CK had the lowest nutrient uptake. Overall analysis shows that year had a significant effect on NPK uptake of maize, while treatment and the interaction between T×Y had no effect.

Fig 2 Influence of nitrogen application rate on Nutrient uptake of maize in 2020-2021



Note: Values are means of four replicates of every treatment. Means followed by a common letter in a column are not significantly different at (P< 0.05) probability

Effect of application rate on PFPN, AEN and NUE

This shows that PFPN increased significantly with decreasing N application rate in 2020 and 2021. Overall analysis shows years, treatment and T×Y interaction had a significant effect on PFPN. No significant difference was recorded between year, treatment, and the interaction between T×Y of AEN. Treatment N200 had the lowest N agronomic use efficiency. As N rate increased from 60 to 200 apparent utilization rate reduced in 2020 and 2021. Statistics shows that year, treatment, and the interaction between T×Y had no significant effect on NUE.

. **Table 1**: Effect of application rate on N agronomic efficiency (AEN), partial factor productivity of applied N (PFPN) and apparent utilization rate

Treatment	PFP (kg/kg)		AEN (kg/kg)		NUE (%)	
	2020	2021	2020	2021	2020	2021
CK	-	-	-	-	-	-
N0	-	-	-	-	-	-
N60	92.9±9.3a	128.1±12.8a	6.6±10.2a	6.5±3.8a	18.9±11.3a	10.2±29.7a
N200	28.3±0.4b	33.1±4.5b	2.3±1.4a	6.5±33a	15.6±5.6a	6.6±2.6a
Year (Y)	0.001		ns		ns	
Treatment (T)	0.001		ns		ns	
T×Y	0.001		ns		ns	

Note: The values are presented as the mean ± standard deviation. Different letters in the same columns represent significant differences at the level of P < 0.05.

Soil chemical properties as affected by nitrogen level in 2020 and 2021

After the harvesting of maize in 2020 and 2021, soil properties were tested and analyzed from a depth of 0-20 cm and 20-40 cm. The above table shows that N level did not affect available N at a depth of 0-20 cm and 20-40 cm in 2020. Application rate did not affect available P at (0-20 cm and 20-40 cm). It was observed that application rate had no effect on available K nutrient. In 2021 N rate had no effect on available N P and K at a depth of 0-20 and 20-40 cm.

Summary of analysis of variance shows that year had a significant effect on available N, P, and K at the depth of 20- 40 cm. In both planting seasons at a depth of 0-20 cm and 20-40 cm application rate did not affect soil pH. Summary of statical analysis shows that at a depth of 0-20 cm and 20-40 cm year, treatment, and interaction between T×Y had no impact on soil pH. Soil organic carbon shows that as depth increased soil organic carbon reduced across both seasons, however in 2021 treatment N0 and N60 had the lowest SOC at a depth of 0-20 cm, no significant difference was observed between treatments at a depth of 0-20 cm and 20-40 cm in both planting seasons. ANOVA shows that years had a significant effect on soil organic carbon at the depth of 0-20 cm and 20-40 cm, treatment and interaction did not affect SOC at both depths.

Year	Treatment	Available N (%)		Available P (mg/kg)		Available K (mg/kg)		pH 1:2.5		SOC (%)	
		0-20 cm	20-40 cm	0-20 cm	20-40 cm	0-20 cm	20-40 cm	0-20 cm	20-40 cm	0-20cm	20-40cm
2020	CK	0.11±0.1[a]	0.11±0.1[a]	12±0.7[a]	2±0.1[a]	136±2.8[a]	102±0.5 a	7.9±0.1 a	8.1±0.3[a]	1.6±0.1[a]	0.7±0.1[a]
	N0	0.11±0.1[a]	0.10±0.1[a]	10±0.3[a]	2±0.1[a]	143±2.3[a]	102±0.6 a	8.0±0.0 a	8.2±0.1[a]	1.7±0.2[a]	0.7±0.0[a]
	N60	0.11±0.1[a]	0.11±0.1[a]	8±0.4[a]	2±0.1[a]	131±1.6[a]	100±0.5 a	8.1±0.1 a	8.1±0.2[a]	1.6±0.2[a]	0.7±0.0[a]
	N200	0.11±0.1[a]	0.12±0.1[a]	8±0.2[a]	2±0.1[a]	142±1.4[a]	101±0.6 a	7.9±0.1 a	8.2±0.1[a]	1.6±0.1[a]	0.7±0.0[a]
2021	CK	0.11±0.1[a]	0.11±0.1[a]	9±0.4[a]	6±0.2[a]	141±1.9[a]	109±1.1 a	7.9±0.4 a	8.1±0.2[a]	1.5±0.1[a]	0.9±0.1[a]
	N0	0.10±0.1[a]	0.10±0.1[a]	9±0.5[a]	5±0.1[a]	143±1.8[a]	108±1.3 a	8.0±0.2 a	8.0±0.1[a]	1.3±0.3[a]	0.9±0.2[a]
	N60	0.11±0.1[a]	0.12±0.1[a]	10±0.3[a]	6±0.1[a]	151±1.7[a]	119±1.2 a	8.0±0.1 a	8.1±0.1[a]	1.5±0.2[a]	1.1±0.0[a]
	N200	0.10±0.1[a]	0.12±0.1[a]	9±0.4[a]	4±0.1[a]	149±2.2[a]	107±1.2 a	8.1±0.0 a	8.1±0.0[a]	1.4±0.3[a]	0.9±0.1[a]
Year (Y)		ns	0.001	ns	0.001	ns	0.001	ns	ns	0.027	0.001
Treatment (T)		ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
T×Y		ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

Note: The values are presented as the mean ± standard deviation. Different letters in the same columns represent significant differences at the level of $P < 0.05$.

IV. Discussion

Effect of nitrogen application on maize yield and biomass

The effect of applying N on maize grain yield and yield parameters varies depending on the rate applied and soil physiochemical conditions. Several researchers have mentioned the importance of other managerial factors such as planting density, source of N, and variety among others as they interact with N in affecting maize yield. The results from this study showed a higher grain yield when N200 was applied with a planting density of 66666 plants/ha. Maize grain yield increased with time, with 2021 producing the highest yield. The result is in line with other researchers who reported that maize yield is at a maximum stage when application is N200 and with a density of 66666 plants/ha [18]. Nitrogen application rate did not significantly influence maize yield, however, yield increased as N application increased. The average grain yield was higher in the application of N200 than N60 (6630, and 6139 kg/ha) respectively. The lowest average grain yield (5776 kg/ha) was recorded in CK treatment. The result thereby implied that soil residual availability of N meets or exceeds the crop's nutritional demand. This indicates that the application of N fertilizer beyond its optimum rate may reduce yield thereby causing loss of profit and resources [19]. A higher yield in cereal-based systems when no external fertilizer was used [20]. This was mostly attributed to the improvement of soil-related parameters, as the yield of long-term experiment control plots did not vary significantly. Similar findings were observed, where no N was applied, higher yields of 9894 kg/ha were realized than were N 350 kg/ha 9352 kg/ha [21]. This further proves that additional N supply in maize cropping systems should be minimized, and may bring several environmental benefits in continuous maize systems. In one study, grain yield was 13.366 kg/ha when 120 kg N/ha was applied, compared to 9859 kg/ha without N. Furthermore, a higher N rate of 240 kg/ha produced less grain yield than 120 kg/ha [22]. Meta-analytic studies in China review that maize yields can be increased by applying 146-180 kg N/ha, with soil pH less than 8 [23]. Researchers have reported that applying an average of 225 kg N/ha is positively linked with high yield driven by high radiation, water, and N use efficiency [24]. Identifying an optimum rate of N which facilitates high yields while reducing environmental repercussions remains a challenge in China.

However, overall analysis shows that time affected growth and yield parameters this could be as a result of environmental factors such as rainfall, and temperature [25,26] or management factors such as early planting. Early planting significantly increases yield which is reasonable as the maize was also planted at the right time [27]. Maize yields observed in this study were generally higher, even though they were affected by flooding in the second year of the experiment. Research has shown that grain yield increases with an increase in precipitation, up to a point where it starts declining [28]. However, this did not seem to have an effect on the yield among all treatments as high yield was observed even in the control. On average, maize grain yield was lower in 2020 than in 2021. The reason might be that besides different levels of N applied maize residue retention was carried out soon after harvesting. This affects N levels in the soil, as all the nutrients are retained in the soil and become available through mineralization to the next crop. Residue retention in China has become a common practice and has been reported to inhibit N leaching while increasing maize yields [29]. At the same time, strategies to increase fertilizer use efficiency while maintaining high grain yields and economic benefits should be encouraged, such as the use of control release urea [30]. Higher grain yields through conventional urea, with the right time of application and right amount, have been reported before as compared to conventional urea [31]. Achieving high yields with minimum N application as seen in this study could also be linked to the high genetic efficiency of the variety in N utilization. As such, future studies which focus on varieties that efficiently utilize residual nutrients and ensure minimum application of external fertilizers should be promoted [32]. Meanwhile, even though grain yields are high in China, there is still more work to be done to close the yield gap and achieve the zero-hunger goal by 2030. Hence, efficient and sustainable ways of applying N fertilizers require further scientific examination as this is important for policymakers, researchers, and farmers [33].

Effect of nitrogen application on nitrogen nutrient uptake of maize

Nutrient uptake of a crop depends on the concentration in the soil. Crop yield is affected by nutrient uptake [11]. Amounts of residual N from fertilizer that remain in the soil after harvest may be available to plants throughout successive growing seasons in the following ways: as mineral N; in roots; immobilized into microbial biomass [34], or integrated into other soil organic matter pools [35]. It was observed from this study that N uptake increased as application rate increased this is in line with researchers who recorded an increase in N uptake as the application rate increased with a decline with further N application [36,37]. This further indicates that the application of N fertilizer at an optimum rate is required for high crop uptake as excessive application leads to a decline [38]. Increased root branching has been linked to N fertilizer application, especially when applied close to the surface where P levels are highest [39]. The result from this study shows that as N increased P Uptake reduced. Additional application of N is been found to affect plant metabolism and root surface absorption of phosphorus. Residual effect due to excess application of N leads to change in P absorption by the plant [40]. The uptake of phosphorus is significantly affected by the application of N rate [41]. Research shows that the application of N increases P uptake in alkaline soil [42]. Further increase in N increases K uptake of grain and stover.

Effect of nitrogen application rate on N fertilizer use efficiency

A key indicator used in reflecting the productivity of N fertilizer is N partial factor productivity (PFPN). Research has shown that as N input increases PFPN reduces [43,44]. In support of this, Table 3.5 shows that as N rate input increased partial factor productivity of N (PFPN) reduced. In 2020 there was a significant and drastic difference between N200 and N 60 with an N fertilizer productivity of (28.3, and 92.9 kg/kg) respectively. The same result was recorded in 2021 as PFPN of N200 and N60 were (33.1, and 128.1 kg/kg) respectively. An increase in PFPN was recorded as N rate increased and declined when N exceeded the optimum rate[45–47]. This proves that an excessive N application rate (N200) certainly poses a reasonably high risk of N loss due to leaching, denitrification of nitrate N, and ammonia volatilization [48].

The AEN and NUE is an index of N use efficiency that shows the grain yield production potential to N applied [49]. In this study, the application rate of N had no significant effect on AEN and NUE between treatment and had no effect on year and the interaction between year and treatment. Treatment N200 had an AEN of 2.3 kg/kg and 6.5 kg/kg while N60 was 6.6 and 6.6 kg/kg in 2020 and 2021 respectively. Apparent utilization rate declined as N rate increased. A decline in AEN was recorded as N increased from 150 to 300 kg N/ha with an AEN of 3.9 - 2.1 kg/kg [46]. Treatment N60 had a higher AEN however, it was lower than the recommended value of 25-30 kg/kg for good management of AEN [50]. As N application rate reduced AEN and NUE increased. Therefore, the application rate was higher than the required rate indicating that a reduction of N application is necessary. With 20-40 % N fertilizer reduction, N utilization efficiency increases while soil N concentration is maintained [50]. Split application of 2 or 3 when the N requirement is ≥180 kg/ha was recommended for lower NUE [51].

Effect of different nitrogen applications on soil chemical properties

Soil pH in China is an area that has received a lot of attention in the past few decades due to soil degradation concerns. Previously around the 1980s to 2000 researchers found high soil acidification due to excessive N application [52]. However, more scientific experiments show that soil pH in many parts of the country has changed to more alkaline conditions [53]. In China maize production strives in neutral and alkaline soil, however, from the research it was observed that soil pH had no significant effect on treatment, year, and interaction. Furthermore, results across two years indicated that the overall levels of available N, P, K, and soil organic carbon increased in the 20-40 cm soil depth. Having larger values of residual soil nutrients might be an area that China needs to explore by incorporating heavy crop feeding species. In maize cropping systems, alternating maize with legumes or other cereals that maximizes the use of residual fertilizer may lead to reduced fertilizer application, and limit excessive fertilizer application

V. Conclusion

In this study, four treatments were used to access the effect of N application rate on maize yield and N use efficiency. Results from the research show that China is faced with a problem of over-application of N fertilizer by smallholder farmers which does not necessarily translate to further yield increase. The application of N60 resulted in higher AEN, PFPN and NUE in both seasons than in N200. Therefore, to increase use efficiency China needs to reduce N application. The average yield of N200 (6630 kg/ha) was higher than N60 (6139 kg/ha) compared to CK with an average yield of (5776 kg/ha). This further implies that maize grain yield and N use efficiency are not increased with high N application.

Therefore, it is suggested that an optimized application rate be used to reduce wastage of fertilizer and increase N use efficiency as the soil in China has a great residual nutrient content after harvesting. In conclusion, good integrated agronomic practices such as right timing, right application rate, right source of N, method of N application, tillage practices such as residue retention should be practiced in China.

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