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RESEARCH

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Assessment of the nitrogen fertilizer split-application on maize grain yield and profitability on Nitisols of South-Kivu, Eastern D.R. Congo

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Abstract

Soil depletion constitutes a major challenge for agriculture and food security in highlands of eastern Democratic Republic of Congo (DRC). This study aimed to assess the effectiveness of the split-application of nitrogen fertilizer on grain yield and profitability of maize on Nitisols in eastern DRC. The urea fertilizer (100 kg ha^{-1}) was applied in single, two, and three split-applications on three maize varieties for two cropping seasons. Results showed that maize growth and yield parameters varied significantly with N splitting strategy, varieties, and cropping season ($p < 0.01$). The single N application at the 45th day after sowing presented the highest grain yield (5.5 t ha^{-1}) compared to split-applications for both cropping seasons. The variety 'ZM 627' had the highest grain yield in both seasons (5.4 and 5.8 t ha^{-1} for 2017 and 2018 cropping seasons, respectively). The benefit–cost ratio analysis showed that single application was more profitable, *i.e.* 1.63 USD kg^{-1} of fertilizer compared to two (0.6 USD kg^{-1}) and three splits (0.22 USD kg^{-1} of fertilizer), though dependent on used varieties. The trend was the same for agronomic efficiency (AE); the single application yielded 11 kg kg^{-1} of maize grains. In addition, the split applications resulted in additional labor costs. Results from this study do not, therefore, recommend the N splitting strategy for maize on South-Kivu Nitisols.

Keywords Nitrogen splitting strategy, Fertilization, Nitisols, Yield, Zea mays, Kabare

Introduction

Land degradation is one of the major constraints for agricultural production in Sub-Saharan African (SSA) countries where the majority of populations heavily depend on farming for food and income (Chianu et al. 2012; Dimkpa et al. 2023). One of the most land degraded regions in SSA is the Great Lakes region, particularly the highland regions of the South-Kivu province in eastern Democratic Republic of Congo (DRC, Chuma et al. 2022a). Soils in the highlands of South-Kivu are the most nutrient-depleted in eastern DRC, a major constraint on agricultural productivity that limits the growth and yield of more demanding crops such as maize, one of

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the region's staple foods (Bagula et al. 2014; Chuma et al. 2022a). According to many studies in the region, almost 100 kg ha^{-1} $year^{-1}$ of soil nutrients are lost from agricultural lands (Bagula et al. 2014). In South-Kivu highlands, crop yield is mainly associated with poor soil content in organic matter and the low use of inorganic fertilizers in predominantly smallholder farms (Bashagaluke et al. 2015; Gurmessa 2020).

The main cause of nutrient depletion is runoff loss due to soil erosion, a widespread phenomenon in the region (Chuma et al. 2022b; Falconnier et al. 2023). The highland region of South-Kivu province has extremely steep relief, making it highly susceptible to soil erosion by water (Karume et al. 2022; Chuma et al. 2022b). In addition, the continuous depletion of nutrients by crops without adequate renewal measures and the low use of mineral fertilizers contribute to the problem (Zamukulu et al. 2018). This situation is exacerbated by low nutrient retention capacity of degraded soils, especially Ferralsols and Nitisols, leading to significant mineral losses (Zamukulu et al. 2023).

However, in South-Kivu agro-ecological zones (AEZs), maize is grown on a range of soils with a predominance of Ferralsols, Cambisols, and Nitisols according to the World Reference Base (WRB) classification (Malembaka et al. 2021). These soils are generally characterized by complete mineral weathering, clay texture (40–70% clay surface), and micro aggregation, fragile structure under cultivation, poor base exchange complex, high acidity (pH < 5), and Manganese (Mn) and Aluminum (Al) toxicity (Ngongo et al. 2009; IUSS Working Group WRB 2022; Zamukulu et al. 2023), characteristics that threaten maize production (Bizimana 2017). These characteristics also explain the low fertilizers' response observed in these soils. Nitrogen is the nutrient that is lost the most through these processes. It is lost through drainage, leaching, volatilization, and other mechanisms (Falconnier et al. 2023). This inefficiency in fertilizer use also discourages small-scale farmers from making investments in terms of farm inputs (Chuma et al. 2020; Falconnier et al. 2023).

In addition to the problems of soil depletion, fertility in this region is highly heterogeneous, with great variability among farms, both locally and regionally, which can lead to different responses to fertilizer (Gram et al. 2020; Agegnehu et al. 2023). Therefore, the proper application of mineral fertilizers, especially nitrogen based fertilizers such as urea, remains the best practice for maintaining soil fertility in the South-Kivu highlands as soils of this region lack sufficient quality organic matter (Pypers et al. 2011; Laub et al. 2023). One of the strategies to improve the response of maize to nitrogen fertilizer and reduce losses is to split its application over time (Belete et al. 2018). Split application of nitrogen based fertilizers is regarded as a promising practice for improving crop growth, yield, and nutrient use efficiency (Liu et al. 2019; Zhang et al. 2021).

In addition, split application of nitrogen in the form of urea at the right time has shown that this approach could be an alternative means of minimizing nitrogen losses, thereby improving maize yields and increasing farmers' incomes (Joshi et al. 2014; Iago et al. 2017; Ogunboye et al. 2020). Similar results were reported for other cereals such as the pearl millet (Ajeigbe et al. 2020) and wheat (Xinpeng et al. 2021). No study has examined the effect of split application of nitrogen fertilizers on maize yield and profitability in conditions of heterogeneous eastern DRC soils, especially degraded Nitisols. Thus, the present study was conducted with the following objectives: (i) determining the optimum urea nitrogen splitting rate that would improve maize grain yield and profitability, and (ii) determining whether response to split application is variety-specific under South-Kivu Nitisols.

Materials and methods

Study area

Trials were established at the Mulungu station of the National Institute for Agronomic Study and Research (INERA) (02° 19′ 09.2"S, 028° 47′ 06.9"E, and at 1752 m above the sea level), in Kabare territory, eastern DRC. The soil of the study area belongs to the Nitisols class under the FAO-UNESCO classification (Zamukulu et al. 2023). This soil is developed on volcanic ash and characterized by a high clay activity and organic matter (OM) content, a large mineral reserve and is moderately acidic (Table 1).

According to weather conditions, Mulungu station has a humid tropical climate of the *Aw3* type based on the Koppen-Geiger classification. It is characterized by two alternating seasons: the rainy season (September to May) and the dry season (June to August) (Chuma et al. 2022a, b; Zamukulu et al. 2023). Data from the INERA-Mulungu meteorological station showed an average annual rainfall of 1355.3 mm and an average temperature of 25.3 °C during 2017 and 2018 (Fig. 1).

Plant material

The main characteristics of maize varieties used in the study are described in Table 2.

Experimental design and trial management

The experiment was conducted in a split-plot design during two cropping seasons (Short rainy season 2017 and Long rainy season 2018). Two factors were studied, nitrogen split-application (primary factor) and variety (secondary factor). Four N split applications were tested

Table 1 Soil characteristics of the study site

Soil depth (cm)	0–10	10–20	20–30	> 30	Average	Fertility level	References
pH H_20	5.20	5.20	4.70	4.70	4.95	Strongly acidic	Gurmessa (2020)
N (%)	0.37	0.27	0.34	0.27	0.31	Low	Ejigu et al. (2021)
C (%)	2.36	1.89	0.90	0.48	1.41	Medium	Ejigu et al. (2021)
Ca (Cmol/kg)	5.90	6.13	5.73	5.66	5.90	Medium	Enang et al. (2016)
Mg (Cmol/kg)	2.40	2.73	2.15	2.20	2.37	High	Ejigu et al. (2021)
K (Cmol/kg)	0.20	0.14	0.10	0.11	1.14	Medium	Ejigu et al. (2021)
CEC (meq/100 g)	21	17	15	12	16.25	High	Adzemi et al. (2017)
Total P (mg kg^{-1})	35	30	22	22	27.25	Very high	Kefas et al. (2020)
Sand (%)	14	8	8	6	9	–	–
Clay (%)	62	64	70	80	69	–	–
Silt (%)	24	27	22	14	21.75	–	–
Textural class	Clayey	Clayey	Clayey	Clayey	Clayey	–	–

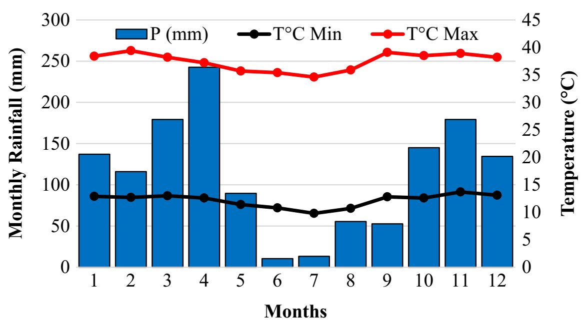

Fig. 1 Rainfall and temperature distributions (2017 and 2018) at the study site

according to the recommendations of some studies to determine the proper timing for optimum soil nutrients' uptake (Joshi et al. 2014; Iago et al. 2017; Ogunboye et al. 2020). Study factors are described in Table 3.

Three replicates (blocks) with 12 plots each were established in this study. The blocks were spaced by 1.5 m while plots within blocks were 1 m apart. A plot consisted of 24 m^2 (4.8 m × 5 m) with six planting rows. The plants were spaced by 80 cm between rows and 50 cm within rows, giving a density of 25 000 plants ha^{-1}. Soil preparation consisted of flat plowing by a wheel tractor to a depth of about 20 cm. Harrowing was carried out to loosen and homogenize the soil. The NPK (17-17-17) fertilizer was applied at planting to all plots at a rate of 150 kg ha^{-1}. Urea (46–0-0) was applied as a top-dressing fertilizer at a rate of 100 kg ha^{-1} (i.e. 46 kg ha^{-1} of nitrogen). No phytosanitary treatment was carried out. Weeding was carried out 30 and 60 days after sowing.

Data collection and analysis

Growth and yield parameters collected during the experiment are presented in Table 4.

Agronomic efficiency and economic profitability of applied fertilizers

The agronomic efficiency (AE) was calculated using the following equation:

$$\mathrm{AE}\left(\mathrm{kg\ kg^{-1}}\right) = (\mathrm{Y_{FI}} - \mathrm{Y_{F0}})/(\mathrm{F_i} - \mathrm{F_0}) \quad (1)$$

With Y_{Fi} the yield obtained with fertilizer (i ranging from 1 to 3) and F_0 the splitting level (per ha).

The economic profitability was calculated to estimate the net income and benefit–cost ratio for all nitrogen splits under different varieties taking into account the expenses incurred during the experiment and the price of a kg of maize at the local market (Nyembo et al. 2013;

Table 2 Agronomic characteristics of maize varieties used in the experiment

Variety	Origin	Yield potential (t ha^{-1})	Optimal altitude (m)	Cycle (days)	References
SAM4VITA	CIAT-HarvestPlus	3.5–5.5	900–1800	120–150	(Mugisho et al. 2019)
PVA SYN 18 (F2)	CIAT-HarvestPlus	3.5–4.5	900–1800	120–150	
ZM 627	INERA-Mulungu	3.8–4.0	–	125–130	

Table 3 Description of the study factors

Factors	Modalities	Description
Split-application	F0	No urea application
	F1 (100 kg ha^{-1})	All urea dose was applied once at 45th day after sowing
	F2 (40 kg ha^{-1} + 60 kg ha^{-1})	Two splits of the urea dose, i.e. or 40 kg ha^{-1} of N, and 60 kg ha^{-1} of N at the 30th and 45th days after sowing (DAS), respectively
	F3 (20 kg ha^{-1} + 40 kg ha^{-1} + 40 kg ha^{-1})	Three urea splits. All urea dose, i.e. 20 kg ha^{-1} of N at the 15th DAS, 40 kg ha^{-1} of N at the 30th, and the 45th DAS, respectively
Variety	SAM4VITA	See Table 2
	PVA SYN 18 (F2)	
	ZM 627	

Table 4 Summary of data collection procedures

Parameters	Data collection methods
Germination rate (%)	$GR = (NGG/NGS) \times 100$ at the 15th day after sowing
Stem diameter (cm)	Measured at the collar using a calliper
Plant height (cm)	Measured from the collar to the tip of the central leaf on a sample of five plants using a tape measure and the mean was calculated
Number of ears per plant	Hand count from a sample of five plants
Weight of the cob (g)	Cobs from a plot were weighed using a balance
Weight of 1000 grains (g)	1000 grains were sampled for each plot and weighed by a precision scale
Grain yield (t ha^{-1})	Grains of a plot was weighed and then extrapolated to the ha

GR germination rate, *NGG* number of germinated grains, *NGS* number of grains sown

Ajeigbe et al. 2020). The economic analyses were performed to compare the profitability of producing maize varieties under different N application split treatments based on the standard agronomic practices. The average maize prices at the main local markets were surveyed at harvest in the study area. The maize grain value was determined based on the average price in the study area and extrapolated to the ha based on their respective yield per ha, assuming there was no cost borne from weed control. Urea quantity (UQ) is the quantity of urea applied in each plot and the Unit Cost (UC) is the monetary value of urea at the local market. Application cost (AC) is the monetary value of labor for urea application in the soil and Total Cost (TC) involved the urea cost at the market and the application cost (labor). Yield increase (YI) is the difference between yields from treatment with N split and those with no N split. Yield increase Value (YIV) in USD is the ratio of the monetary value of yield increase in kg ha^{-1} at the market by maize grain prices during the experimental period. Best cost Revenue (BCR) was calculated by dividing Yield increase value by Total cost (BCR = YIV/TC). A day's work cost 2000 Congolese francs (CF), i.e. 1.11 USD (1 USD = 1800 CF at the study period), at a rate of 125 man-days per hectare. The price of maize at the local market was 700 CF. A 50-kg bag of urea was purchased for 75 USD and the cost of N application was 146.25 USD, which was paid fairly to all the labor. In addition, the profitability of N split-application per season was calculated by the same method.

Data analysis

All data collected (Table 4) were subjected to the analysis of variance (ANOVA) using R studio software (4.0 version). Season, N splitting strategy, and variety were considered as factors to determine their effects and the effects of their interactions on different variables. The treatment means that were significantly different at 5% *p*-value threshold were compared using the Tukey's HSD test.

Results

Effect of nitrogen splitting strategy, variety, and season on growth and yield parameters of maize

Results in Table 5 showed that plant height at flowering ($p < 0.001$) and maturity ($p = 0.0056$) varied significantly with cropping seasons. The highest plant height at flowering was obtained in season A 2018 (114.3 cm) compared to season B 2017 (98.0 cm). At maturity, the

Table 5 Effect of cropping season on maize yield and growth parameters

Season	Growth parameters				
	DCF (cm)	DCM (cm)	PHF (cm)	PHM (cm)	EIH (cm)
2017B	1.3 ± 0.2[a]	1.9 ± 0.3[a]	98.0 ± 2.5[b]	194.0 ± 11.2[b]	86.0 ± 15.2[a]
2018A	1.5 ± 0.3[a]	2.0 ± 0.3[a]	114.3 ± 20.4[a]	205.8 ± 21.6[a]	83.6 ± 6.6[a]
P-value	*0.087*	*0.139*	*< 0.001*	*0.0056*	*0.399*
	Yield parameters				
	NEP	WEP (g)	W1000G (g)	Yield (t ha^{-1})	
2017B	1.2 ± 0.2[a]	277.5 ± 30.3[b]	464.8 ± 76.2[a]	5.0 ± 0.5[b]	
2018A	1.3 ± 0.2[a]	294.1 ± 37.8[a]	453.7 ± 75.7[a]	5.7 ± 0.6[a]	
P-value	*0.069*	*0.045*	*0.533*	*< 0.001*	

DCF diameter of the stem collar at flowering; *DCM* diameter of the stem collar at maturity; *PHF* plant height at flowering; *PHM* plant height at maturity; *EIH* height at the ear insertion; *NEP* number of ears per plant; *WEP* weight of ears per plant; *W1000G* Weight of 1000 grains; [a], [b]: The average of the same column and the same factor followed by the same letters are not statistically different at a probability level of 5% according to LSD test (Least Significant Difference)

highest height was obtained in season A 2018 (205.8 cm) and the lowest in season B 2017 (194.0 cm). Furthermore, the spike weight per plant ($p = 0.04$) and grain yield ($p < 0.001$) varied significantly with cropping seasons. The highest number of spikes was obtained in the 2018 A season, 1.3 spike per plant compared to the 2017 B season, 1.2 spike per plant. The highest grain yield was obtained in season A 2018 (5.7 t ha^{-1}) compared to season B 2017 (5.0 t ha^{-1}). Other parameters such as stem diameter, height at the ear insertion, number of ears per plant, and 1000 seed weight were not influenced by the cropping season.

Effects of the study factors on maize growth parameters

The results of the effects of varieties and N splitting strategy on maize growth parameters for two cropping seasons are presented in Table 6. Stem diameter at flowering varied significantly with season ($p < 0.01$), variety ($p < 0.001$), nitrogen splitting ($p < 0.001$), and season × nitrogen splitting strategy interaction ($p < 0.05$). It was 4 and 1.7 cm large for seasons B 2017 and A 2018, respectively. The single split (F1) had the highest collar diameter at flowering, 1.5 and 1.8 cm, in seasons B 2017 and A 2017, respectively, while F0 with no fertilizer had the lowest collar diameter at flowering, 1.1 cm in both seasons. The stem collar diameter at maturity varied significantly with season ($p < 0.05$), variety ($p < 0.001$), N splitting strategy ($p < 0.001$), and variety × nitrogen splitting strategy interaction ($p < 0.05$). The highest stem diameter at maturity was obtained with the variety 'ZM 627' in both cropping seasons, i.e. 2.0 cm and 2.3 cm, in seasons B 2017 and A 2018, respectively, while the variety 'PVA SYN18 (F2)' with 1.8 cm and 1.9 cm, respectively, in season B 2017 and A 2018. F1 had the highest collar diameter at maturity in both cropping seasons at 2.2 cm and 2.3 cm, respectively in seasons B 2017 and A 2018 compared to F0 with 1.8 cm and 1.7, respectively, in seasons B 2017 and A 2018.

The highest plant height at flowering was obtained by variety 'ZM 627' in both cropping seasons, 99.5 cm and 127.6 cm for seasons B 2017 and A 2018, respectively, compared to variety 'PVA SYNGA' with 96.7 cm and 104.6 cm, respectively, for seasons B 2017 and A 2018. F1 had the highest plant height at the flowering of 99.6 cm and 128.8 cm in seasons B 2017 and A 2018, respectively compared to F0 with 96.6 cm in season B 2017 and 97.3 cm in season A 2018.

The highest plant height at maturity was obtained with the variety 'ZM 627' with 199.7 cm for the season B 2017 and 205.2 cm for the season A 2018, respectively, compared to the variety 'PVA SYNGA' with 190.3 cm for the season B 2017 and 191.5 cm for the season A 2018. F1 had the highest plant height at maturity in both cropping seasons, 204.6 cm and 221.8 cm in seasons B 2017 and A 2017, respectively compared to F0 with 189.9 cm in season B 2017 and 178.6 cm in season A 2018. The highest ear insertion height was obtained with the variety 'ZM 627' with 103.6 cm in season B 2017 and 85.8 cm with the variety 'PVA SYNGA' in season A 2018.

Effects of varieties and nitrogen splitting strategy on yield parameters for two cropping seasons

The effects of varieties and nitrogen splitting strategy on yield parameters for two cropping seasons are presented in Table 7. The number of spikes per plant varied significantly with season ($p < 0.01$), variety ($p < 0.01$), nitrogen splitting strategy ($p < 0.01$), and season × nitrogen splitting strategy interaction ($p < 0.05$). The highest number of ears per plant was obtained with variety 'ZM 627' in both cropping seasons, i.e. 1.3 and 1.4 ears per plant, respectively, for seasons B 2017 and A 2018 while the lowest was on variety 'PVA SYN18 (F2)' with 1.1 and 1.2 ears per

Table 6 Effects of varieties and fertilizer splitting strategy on maize growth parameters for two growing seasons

Factors		DCF (cm)	DCM (cm)	HF (cm)	HM (cm)	HIE (cm)
SRS 2017						
Variety	SAM4VITA	1.3 ± 0.2[a]	1.9 ± 0.1[a]	97.9 ± 2.2[ab]	191.9 ± 14.4[ab]	78.2 ± 12.0[b]
	PVA SYN 18 (F2)	1.3 ± 0.2[a]	1.8 ± 0.2[a]	96.7 ± 2.6[b]	190.3 ± 7.8[b]	76.1 ± 6.4[b]
	ZM 627	1.4 ± 0.1[a]	2.0 ± 0.4[a]	99.5 ± 2.2[a]	199.7 ± 8.7[a]	103.6 ± 6.7[a]
Splitting	F0	1.1 ± 0.2[b]	1.8 ± 0.1[b]	96.6 ± 2.8[b]	189.9 ± 11.1[b]	82.0 ± 18.8[a]
	F1	1.5 ± 0.1[a]	2.2 ± 0.3[a]	99.6 ± 3.2[a]	204.6 ± 10.9[a]	87.45 ± 15.9[a]
	F2	1.4 ± 0.2[a]	1.9 ± 0.1[b]	98.1 ± 1.9[ab]	189.8 ± 7.2[b]	86.9 ± 12.7[a]
	F3	1.4 ± 0.1[a]	1.8 ± 0.3[b]	97.8 ± 1.4[ab]	191.6 ± 9.1[b]	87.5 ± 15.0[a]
LRS2018						
Variety	SAM4VITA	1.4 ± 0.2[b]	1.9 ± 0.2[b]	110.8 ± 13.2[b]	205.2 ± 18.7[a]	82.8 ± 7.2[a]
	PVA SYN 18 (F2)	1.3 ± 0.2[b]	1.9 ± 0.2[b]	104.6 ± 9.6[b]	191.5 ± 17.8[c]	85.8 ± 5.9[a]
	ZM 627	1.7 ± 0.3[a]	2.3 ± 0.3[a]	127.6 ± 27.4[a]	220.6 ± 18.9[a]	82.1 ± 6.7[a]
Splitting	F0	1.1 ± 0.1[c]	1.7 ± 0.1[b]	97.3 ± 7.6[b]	178.6 ± 11.7[b]	84.4 ± 7.0[a]
	F1	1.8 ± 0.2[a]	2.3 ± 0.3[a]	128.8 ± 28.8[a]	221.8 ± 14.9[a]	79.7 ± 8.0[a]
	F2	1.5 ± 0.2[b]	2.1 ± 0.2[ab]	117.1 ± 17.3[a]	215.3 ± 14.2[a]	86.4 ± 4.9[a]
	F3	1.4 ± 0.2[b]	2.1 ± 0.2[a]	114.0 ± 8.5[a]	207.4 ± 16.0[a]	83.8 ± 5.2[a]
p-value season (S)		< 0.05*	< 0.05*	< 0.001***	< 0.001***	*> 0.05[ns]*
p-value variety (V)		< 0.001***	< 0.001***	< 0.001***	< 0.001***	< 0.001***
p-value splitting (F)		< 0.001***	< 0.001***	< 0.001***	< 0.001***	*> 0.05[ns]*
p-value S × V		*> 0.05[ns]*	*> 0.05[ns]*	< 0.001***	< 0.001***	< 0.001***
p-value S × F		< 0.05*	*> 0.05[ns]*	< 0.001***	< 0.001***	*> 0.05[ns]*
p-value V × F		*> 0.05[ns]*	< 0.05*	< 0.001***	< 0.05*	*> 0.05[ns]*
p-value S × V × F		*> 0.05[ns]*	*> 0.05[ns]*	*0.01***	*> 0.05[ns]*	*> 0.05[ns]*

SRS Short rainy season; *LRS* Long rainy season; *DCF* Diameter of the stem collar at flowering (cm); *DCM* Diameter of the stem collar at maturity (cm); *HF* Height at flowering (cm); *HM* Height at maturity (cm); *HIE* Height at ear insertion (cm); [a], [b], [c]: The average of the same column and the same factor followed by the same letters are not statistically different at a probability level of 5% according to LSD test (Least Significant Difference)

* significant

** very significant

*** very highly significant, *ns* not significant

plant for seasons B 2017 and A 2018, respectively. The single urea application (F1) yielded the highest number of cobs per plant, 1.5 cobs per plant across both seasons while the control (F0) and three splits (F3) had lowest number of cobs per plant, 1.0 and 1.1 cobs per plant for seasons B 2017 and A 2018, respectively.

The ear weight per plant varied significantly with season ($p < 0.01$), variety ($p < 0.\ 01$), nitrogen splitting strategy ($p < 0.01$), and season × variety interaction ($p < 0.01$). The highest ear weight was obtained with the variety 'ZM 627', 288.8 g per ear and 326.4 g per ear, respectively for seasons B 2017 and A 2018, compared to the variety 'PVA SYN18 (F2)' with the lowest ear weight, 266.2 g per ear and 264.4 g per ear for seasons B 2017 and A 2018. The first fraction (F0) had the highest ear weight of 315.4 g per ear and 319.5 g per ear compared to the control without any N splitting (F0), with the lowest ear weights of 243.7 and 265.8 g per ear for seasons B 2017 and A 2018.

The 1000 grain weight varied significantly by variety ($p < 0.01$), splitting ($p < 0.01$), season × variety interaction ($p < 0.05$), season × splitting interaction ($p < 0.01$), and season × variety × nitrogen splitting strategy interaction ($p < 0.05$). The highest 1000 grain weight was obtained with variety 'ZM 627', 483.2 and 507.0 g, respectively, for seasons B 2017 and B 2018 compared to variety 'PVA SYNGA' with the least 1000 grain weight in both seasons, 443.5 and 417.1 g, respectively, for seasons B 2017 and A 2018. F1 had the highest 1000 grain weight of 559.3 and 491.7 g in seasons B 2017 and B 2018, respectively, compared to F0 which had the lowest 1000 grain weight of 365.6 and 377.2 g in seasons B 2017 and A 2018, respectively.

Grain yield varied significantly with season ($p < 0.01$), variety ($p < 0.01$), and nitrogen splitting strategy ($p < 0.01$). The highest grain yield was obtained with the variety 'ZM 627' in both cropping seasons, i.e. 5.4 and 5.8 t ha^{-1}, respectively, for seasons B 2017 and A 2018 compared with the lowest yielding variety 'PVA SYN18 (F2)', i.e. 4.6 and 5.5 t ha^{-1}, respectively, for seasons B 2017 and A 2018. Single N application (F1) had the highest grain yield of 5.5 and 6.4 t ha^{-1} in seasons B 2017 and A 2018, respectively,

Table 7 Effects of the study factors on maize yield parameters

Factors modalities		Number of ears/plant	Weight of ear (g)	W1000G (g)	Yield (t ha^{-1})
SRS 2017					
Variety	SAM4VITA	1.2 ± 0.2^{ab}	277.5 ± 30.8^{ab}	467.7 ± 76.3^{ab}	5.0 ± 0.3^{b}
	PVA SYN18 (F2)	1.1 ± 0.1^{b}	266.2 ± 31.6^{b}	443.5 ± 80.3^{b}	4.6 ± 0.4^{c}
	ZM 627	1.3 ± 0.3^{a}	288.8 ± 26.2^{a}	483.2 ± 73.1^{a}	5.4 ± 0.4^{a}
Splitting	F0	1.0 ± 0.1^{b}	243.7 ± 22.9^{c}	365.6 ± 21.9^{c}	4.5 ± 0.3^{c}
	F1	1.5 ± 0.2^{a}	315.4 ± 10.6^{a}	559.3 ± 32.5^{a}	5.5 ± 0.3^{a}
	F2	1.3 ± 0.1^{ab}	282.5 ± 14.8^{b}	485.2 ± 33.6^{b}	5.1 ± 0.4^{b}
	F3	1.0 ± 0.0^{b}	268.4 ± 11.7^{bc}	449.2 ± 30.4^{b}	4.8 ± 0.3^{bc}
LRS 2018					
Variety	SAM4VITA	1.3 ± 0.1^{ab}	291.6 ± 35.0^{b}	436.3 ± 54.8^{b}	5.7 ± 0.4^{a}
	PVA SYN18 (F2)	1.2 ± 0.1^{b}	264.4 ± 24.5^{C}	417.1 ± 58.7^{b}	5.5 ± 0.6^{b}
	ZM 627	1.4 ± 0.2^{a}	326.4 ± 24.7^{a}	507.0 ± 83.1^{a}	5.8 ± 0.6^{a}
Splitting	F0	1.1 ± 0.8^{b}	265.8 ± 39.5^{b}	377.2 ± 22.0^{c}	5.1 ± 0.3^{b}
	F1	1.5 ± 0.2^{a}	319.5 ± 41.7^{a}	491.7 ± 100.2^{a}	6.4 ± 0.3^{a}
	F2	1.3 ± 0.1^{ab}	300.3 ± 28.6^{ab}	479.5 ± 44.8^{b}	5.8 ± 0.4^{ab}
	F3	1.3 ± 0.2^{ab}	290.9 ± 21.6^{ab}	465.0 ± 59.6^{b}	5.4 ± 0.3^{b}
p-value season (S)		*< 0.01***	*< 0.001****	*0.174*^{ns}	*< 0.001****
p-value variety (V)		*< 0.001****	*< 0.001****	*< 0.001****	*< 0.001****
p-value N splitting (F)		*< 0.001****	*< 0.001****	*< 0.001****	*< 0.001****
p-value S×V		*> 0.05*^{ns}	*< 0.01***	*< 0.05**	*> 0.05*^{ns}
p-value S×F		*< 0.05**	*> 0.05*^{ns}	*< 0.01***	*> 0.05*^{ns}
p-value V×F		*> 0.05*^{ns}	*> 0.05*^{ns}	*> 0.05*^{ns}	*> 0.05*^{ns}
p-value S×V×F		*> 0.05*^{ns}	*> 0.05*^{ns}	*< 0.05**	*> 0.05*^{ns}

SRS Short rainy season; *LRS* Long rainy season; [a], [b], [c]: The average of the same column and the same factor followed by the same letters are not statistically different at a probability level of 5% according to LSD test (Least Significant Difference)

* significant

** highly significant

*** very highly significant; ns: not significant; P1000G: 1000 grain weight

compared to F0 which had the highest grain yield in both cropping seasons of 4.8 and 5.4 t ha^{-1} in seasons B 2017 and A 2018, respectively.

Agronomic efficiency (AE) of nitrogen splitting strategy

The results of the agronomic efficiency (AE) of N used on three maize varieties are presented in Table 8. The agronomic efficiency results showed that single nitrogen application on the variety SAM4VITA generated 8 kg of maize grain per kg of applied nitrogen compared to two and three splits, which generated 5 kg of maize grains. One kg of N for single split on PVASYN18 (F2) generated 12 kg of maize kernels compared to three splits that generated only 4 kg of maize kernels per kg of N. On the variety ZM627, the single N application generated 13 kg of maize kernels per kg of N compared to three splits that had lowest maize kernels (3 kg kg^{-1}). On average, 1 kg of nitrogen applied once yielded 11 kg of maize grain compared to three splits (3 kg of maize grain kg^{-1}).

Table 8 Agronomic efficiency (AE) of nitrogen split-application strategy

Variety	Urea splitting	AE (kg kg^{-1})
SAM4VITA	F1	8
	F2	5
	F3	5
PVA SYN**18 (F2)**	F1	12
	F2	6
	F3	4
ZM627	F1	13
	F2	8
	F3	3
Mean EA	F1	11
	F2	6
	F3	3

F1: 100 kg ha^{-1} in single N application; F2: 100 kg ha^{-1} in two splits; F3: 100 kg ha^{-1} in three splits

Estimation of the economic profitability of nitrogen splitting strategy

Results of the economic profitability of the nitrogen splitting strategy on the three maize varieties are presented in Table 9. The results of the estimation of the economic return on N showed that the single application (F1) was more profitable, i.e. 1.19 USD per kg of N for the SAM-4VITA variety, compared to three splits (F3) which was less profitable, i.e. 0.15 USD per kg of N. The single application was more profitable on the PVASYN18 (F2) variety at 1.78 USD per kg of N compared to three split applications which was less profitable, at 0.3 USD per kg of N. The single application was more cost-effective on ZM627 at 1.93 USD per kg of N compared to three splits, which was less cost-effective with 0.22 USD per kg of N. In conclusion, applying the nitrogen in single dose at the 45th day after sowing is cost-effective. For each kilogram of fertilizer applied at the 45th day after sowing, USD 1.63 was gained.

Estimation of the economic profitability of N splitting strategy for the two cropping seasons

Results of the estimation of the economic profitability of N splitting strategy for the two cropping seasons are presented in Fig. 2. The profitability of N splitting strategy by season showed that single application for the 2017 short rainy season (B 2017) obtained 1.48 USD as BCR compared three splits in B 2017 which was least profitable (0.22 USD). Single application for A2018 obtained 1.93 USD as BCR compared to three N splits (0.22 USD). In conclusion, N splitting strategy did not improve maize profitability.

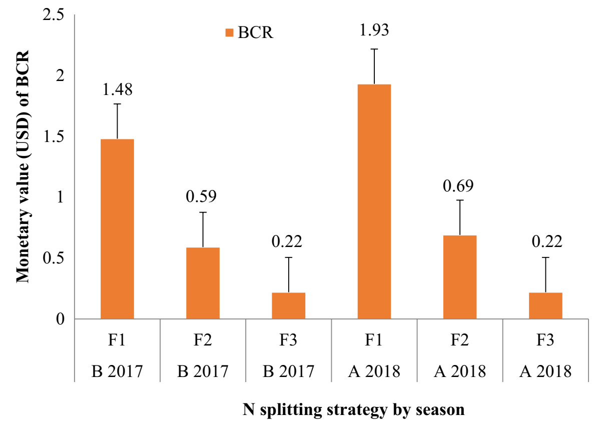

Fig. 2 Estimation of the economic profitability of N splitting strategy across growing seasons

Discussion

Effect of varieties on maize yield and its components in both cropping seasons

Our results showed that maize grain yield and its components varied significantly by variety in both cropping seasons. The highest maize grain yield was obtained from the variety 'ZM627' compared to the other varieties which

Table 9 Estimation of the economic profitability of urea nitrogen split-application

Variety	Split	Urea quantity (kg ha^{-1})	Urea cost (USD)	Application cost (USD)	Total cost (USD)	Yield (t ha^{-1})	Yield increase (t ha^{-1})	Yield value increase (USD)	BCR
SAM4VITA	F0	0	–	–	–	5.0	–	–	–
	F1	100	150	146.25	296.25	5.8	0.8	352	1.19
	F2	100	150	292.50	442.50	5.5	0.5	220	0.50
	F3	100	150	438.75	588.75	5.2	0.2	88	0.15
PVA SYN18 (F2)	F0	0	–	–	–	4.5	–	–	–
	F1	100	150	146.25	296.25	5.7	1.2	528	1.78
	F2	100	150	292.50	442.50	5.1	0.6	264	0.60
	F3	100	150	438.75	588.75	4.9	0.4	176	0.30
ZM627	F0	0	–	–	–	5.0	–	–	–
	F1	100	150	146.25	296.25	6.3	1.3	572	1.93
	F2	100	150	292.50	442.50	5.8	0.8	352	0.80
	F3	100	150	438.75	588.75	5.3	0.3	132	0.22
Split	F0	0	–	–	–	4.8	–	–	–
	F1	100	150	146.25	296.25	5.9	1.1	484	1.63
	F2	100	150	292.50	442.50	5.4	0.6	264	0.60
	F3	100	150	438.75	588.75	5.1	0.3	132	0.22

USD US dollar; *BCR* benefit-to-cost ratio. At the time of the research, 1 *USD* was equivalent to 1800 Congolese francs and 1 kg of unprocessed maize cost was 800 Congolese francs gave almost similar yields (Table 8) in both cropping seasons. Results of Ilunga et al. (2018); (Nyembo et al. 2012, 2013) have shown that maize grain yield varies significantly with the biological materials used, which justifies the genetic performance of each material. The results of Mugisho et al. (2019) showed that the significant differences in grain yields among varieties in this study would be linked to resistance to the most common diseases such as *Helminthosporiosis* in the eastern part of DRC and that their results showed that varieties SAM4VITA and PVS SYN18 (F2) are most resistant to this disease, hence the grain yield close to yield potential as reported in their descriptors. Grain yields varied significantly according to the varieties used in both cropping seasons (Table 6). The results of Nyembo et al. (2014) showed that varietal performance is a function of parameters such as disease and pest resistance, but lodging resistance influenced by plant height is one of the parameters that play a significant role in maize production.

Effect of nitrogen splitting strategy on maize yield and its components

Grain yield of maize and its components varied significantly with urea nitrogen splitting in both cropping seasons. Our results are similar to those of Nyembo et al. (2013). These results show that the frequency of urea splitting significantly influences maize grain yield, but argued that in Ferralsols, increasing the frequency of urea splitting beyond two no longer increases maize yield. Our results showed that plots receiving 240 g of urea per plot in single application (F1) and those receiving the same dose in two splits had high grain yields compared to control plots and those receiving the same dose in three fractions.

Application of the full dose of urea 45 days after sowing increased maize grain yield in the 2018 long rainy season than in 2017 short rainy season (Table 8). Our results are similar to those obtained under similar conditions by Ilunga et al. (2018) in Lubumbashi area demonstrating that the application of inorganic fertilizers at 30 days after sowing or more increases maize grain yields during the drought period on Ferralsols, as these soils are hard and the lower water deficiency reduces nutrient use efficiency. According to Hassan et al. (2010), the response of maize to N splitting can be explained by the fact that the plant benefits from the supply of nutrients at the right timing, which increases the weight of its ears and the average weight of 1000 grains.

Our results showed that the N split-application contributes to the improvement of production in the long rainy season (season A) than in the short rainy season (season B), especially when the application is made in one or two splits (Table 8). In fact, Gagnon et al. (2012) showed that maize still responds significantly to the application of mineral fertilizers such as urea, but this response is a function of the cropping season, as their results showed a higher yield in the wet season than in the dry season and a significant improvement in the nutrient use efficiency. Not only does urea split application increase grain yields of cereal crops such as maize, but it also influences the productivity of vegetable crops such as tomatoes according to the results obtained by Mensah et al. (2019).

N splitting strategy had improved maize grain yield in our experiments. The results of Joshi et al. (2014) being similar to ours had shown that N application on maize after emergence improves significantly maize yield and its components. Moreover, Trierweiler and Omar (1983) had reported that above 200 kg of N per ha, splitting is required to reduce N loss and improve yield and N use efficiency. According to Sitthaphanit et al. (2010), yield influence due to N splitting could be explained by the fact that splitting is one of the good strategies of N management which is efficient in the environments receiving approximately 1350 mm of rain and where N splitting was applied in the period from 30 to 60 days after sowing as it was the case in our experiment under the Mulungu conditions (Fig. 1).

Agronomic efficiency of nitrogen splitting strategy

Our results on the agronomic efficiency of urea N splitting strategy on the maize crop showed a disproportionate variation in agronomic efficiency values, with the highest value on F1 compared to the other splitting strategies (Table 9). Similar observations were made by Mushagalusa et al. (2016) and Zamukulu et al. (2018) showing that the agronomic efficiency of fertilizers is a function of the dose applied and soil types. On the other hand, Abebe and Feyisa (2017) had no variation in agronomic efficiency due to the timing of nitrogen application. They showed that variation in water regime is a key element influencing soil moisture with a strong potential to improve nutrient movement in soils. Results by Vanlauwe et al. (2014) showed that the application of lime before sowing is one of the strategies to be promoted to improve the agronomic efficiency of mineral fertilizers in acid soils such as Ferralsols or Acrisols that not only limit agricultural production but also limit the movement of certain essential nutrients into the soil (Bora et al. 2021). Results of Iago et al. (2017) reported that N split applications improve the utilization of N and increase grain yield in several crops like maize and other cereals.

Profitability of nitrogen splitting strategy on maize

Our results showed variations in economic profitability depending on the N splitting strategy. The application of the full dose to a fraction generates more income

(Table 9). The results of Nyembo et al. (2013) showed a variation in economic profitability depending on the urea nitrogen splitting. The application of fertilizer in single dose generated more benefits (Table 9). Results of Xu et al. (2009) showed that only yield increase through chemical fertilizer application influences economic profitability, but factors such as input prices, proximity to roads and markets were identified as determinants of the economic profitability of fertilizer application in Zambian farming communities. The findings of Everaarts et al. (2017) have shown that despite the increase in yield due to fertilizer application, the instability of agricultural commodity prices also influences the economic profitability of chemical fertilizers. Results of Watkins et al. (1998) indicated that the N split-application has significant economic and environmental benefits, particularly in areas with low soil fertility such as the acidic soils of the Bushi highlands. Furthermore, the conclusion of Olfati et al. (2015) showed that split application of nitrogen fertilizers can play an important role in soil nutrient management as it increases crop yields, is cost-effective and contributes significantly to rational soil nitrogen management.

Conclusions

Results from our experiment showed that maize grain yield on Nitisols from Kabare is influenced by season, variety, and urea nitrogen split-application. Besides, 1000 grain weight was also influenced by variety (V), N splitting and their interactions. The ear weight was influenced by season (S), variety (V), and the S×V interaction. The number of ears per plant was significantly influenced by season, variety, N splitting as well as S×N split-application interaction. The 2018 long rainy season had highest grain yield (5.7 t ha^{-1}) compared to 2017 short rainy season (5 t ha^{-1}). The application of 100 kg ha^{-1} of urea as top-dressing fertilizer at the 45th DAS has highest yield (5.9 t ha^{-1}) compared to the control with no N application that had the lowest grain yield (4.8 t ha^{-1}). Best cost revenue was not influenced by N split-application. The agronomic efficiency of fertilizer application was affected by N splitting strategy, with 11 kg, 6 kg, and 3 kg of maize grains for single, two, and three N splitting applications, respectively. It could be much interesting to test other N sources, varieties, fertilizer rates, and timing of N split-application for better recommendations to smallholder maize farmers in eastern DRC.

Abbreviations

AE	Agronomic Efficiency
BCR	Best-cost Revenue
CEC	Cation Exchange Capacity
CIAT	International Centre for Tropical Agriculture
DAS	Days after Sowing
DRC	Democratic Republic of Congo
INER	Institut National pour l'Etude et la Recherche Agricole
UEA	Université Evangélique en Afrique
USD	United State Dollar
WRB	World Reference Base for Soil Resources

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Author contributions
PZ and EMB conceived and designed the experiment; collected data; analyzed and interpreted the data, and wrote the original manuscript; JMM, GBC, YM, CBM, and ELC analyzed and interpreted the data and participated in the paper revision; GMB and SM participated in collecting field data. AKL and GNM supervised the study and participated in the paper revision. All the authors read and approved the final manuscript.
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The data that support the findings of this study are available from the corresponding author upon reasonable request.

Declarations

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