Open Access Library Journal
2022, Volume 9, e9100
ISSN Online: 2333-9721
ISSN Print: 2333-9705

Response of Quality Protein Maize to the Synchronization of Application and Needs for NPK Fertilizer in Acid Soils of the South-West of the DR Congo

Jean Pierre Kabongo Tshiabukole[1,2,3*], Gertrude Pongi Khonde[1,2,3], André Matondo Phongo[1], Nlandu Ngoma[1], Roger Kizungu Vumilia[2,3,4], Amand Mbuya Kankolongo[1,2,3], Antoine Mumba Djamba[1,2], Jean Claude Lukombo Lukeba[1,2], Rebecca Mitshiabu Mudiayi[2]

[1]Université Pédagogique Nationale (UPN), Kinshasa, Democratic Republic of the Congo
[2]Institut National pour l'Etude et la Recherche Agronomiques (INERA), Mvuazi, Democratic Republic of the Congo
[3]ASARECA Climate Smart Agriculture Alliance, Entebbe, Uganda
[4]Université de Kinshasa (UNIKIN), Gandajika, Democratic Republic of the Congo
Email: *jpkabon2005@gmail.com

How to cite this paper: Tshiabukole, J.P.K., Khonde, G.P., Phongo, A.M., Ngoma, N., Vumilia, R.K., Kankolongo, A.M., Djamba, A.M., Lukeba, J.C.L. and Mudiayi, R.M. (2022) Response of Quality Protein Maize to the Synchronization of Application and Needs for NPK Fertilizer in Acid Soils of the South-West of the DR Congo. *Open Access Library Journal*, **9**: e9100.
https://doi.org/10.4236/oalib.1109100

Received: July 13, 2022
Accepted: September 4, 2022
Published: September 7, 2022

Abstract

To understand the response of quality protein maize to the different dates of NKP basal fertilizer application in the acid soils of the southwest of the DRC, an experiment was carried out during two cropping seasons (2019-2021) following a factorial design. The first factor was the season (two levels), the second was the period of fertilizer application (three levels) and the third was the variety (four levels). The experiment was repeated three times. Two varieties of quality protein maize were compared to two varieties of normal maize. Quality Protein Maize outperformed normal maize in growth and production parameters. The effects of season and date of fertilizer application strongly influenced ($p < 0.0001$) the growth parameters. The local and normal varieties had a longer cycle than the other varieties, with anthesis and silking interval of more than 8 days. Fertilizer application at sowing time proved to be more advantageous for having positively influenced yield. The two Quality Protein Maize varieties Mudishi-1 and Mudishi-3 recorded yields of 8 t/ha and 7.9 t/ha respectively when fertilizer was applied at sowing time during the main cropping season. However, the local variety was very sensitive (1.5 t/ha) when fertilizer application was delayed up to 30 days of growth during the short season (season B). In conclusion, the application of NPK basal fertilizers at the time of sowing resulted in a high rate of harvested plants which therefore decreases with the delayed fertilizer application. Losses are very significant when fertilizers are applied after 30 days from the start of the cycle in

the short cropping season.

Subject Areas

Agricultural Science

Keywords

Quality Protein Maize, Climate Smart Agriculture, Acid Soils, Basal Fertilizers, NPK

1. Introduction

Maize is one of the important cereal crops grown in the DRC and spreads out from the forest to the savannah. Its production in the savannah of southwestern DRC has moved from a minor crop to a major and commercial cereal crop in competition with cassava and rice crops in the country's economy [1].

The released Quality Protein maize (QPM) varieties have a high grain yield potential. They are friendly processed, easy to digest and of low cost compared with other cereals. Its versatility makes it a widespread crop adapted to a wide range of agro-ecological zones. Maize, as a typical cereal, responds favorably to the application of fertilizers, especially in the savannah, where the soils are generally not very fertile [2] [3]. It has a strong depleting effect on the soil and it is generally observed that it does not produce a good grain yield in the plots without fertilizer application [4]. According to Useni *et al.* (2013) [5], inadequate plant nutrition management and low soil fertility are the main factors responsible for lower yields.

In most experiments, the response of maize to nitrogen (N) is very significant [6]. In a continuous farming system, nitrogen fertilizer is the most important nutrient for maize production. Savanna soils are also deficient in native phosphorus (P) [6] [7]. The appropriate use of inorganic fertilizers (NPK) on crops led to increased yield where there was substantial nutrient depletion [6] [8] [9] [10].

Compared with normal maize, QPM has higher nutritional quality as it contains double the amount of lysine and tryptophan and no changes in other amino acids except a lower level of leucine [11]. Since this maize was recently introduced into the country, it has been the subject of several agronomic studies [12] [13] [14] [15] including fertilization in the acid soils of southwestern DRC [6].

Experiments on planting density and basal fertilization rate have been carried out [6] and [13]. However, accurate data on the appropriate period of the basal fertilizer application have not been made available so far. Several options for basal fertilizer application can be used: 1) before sowing, 2) at sowing and 3) after emergence. The period of inorganic fertilizer (NPK) application is then the most important factor influencing the growth, development and yield of maize crops. The aim of this experiment was to find out the right time of basal fertilizer application for QPM enhanced production in acid savannah soils in southwestern of DRC.

2. Materials and Method

2.1. Experimental Site

The trial was conducted on acid soil at the INERA Mvuazi Research Center during two cropping seasons: A (October 2019 to February 2020) and B (mid-March 2021 to mid-May 2021). Mvuazi is located at 14˚54' East longitude and 5˚21' South latitude, at an altitude of 470 m. The soil of Mvuazi belongs to the Sudano-Guinean climatic zone of type Aw4 [16]. This soil is characterized by low organic matter content and low water holding capacity, resulting in low nitrogen availability [1] [17] and Orthic feral soil type [18] (**Table 1**).

2.2. Climate Data

Figure 1 presents the evolution of climate data during the two experimental seasons (2019-2021).

2.3. Materials

The factorial design with three replicates and three factors was used. The first factor included three dates of NPK application. The second factor included four maize varieties including two of quality protein maize (Mudishi-1 and Mudishi-3) and two of normal maize (Samaru and unimproved Local variety). The third factor comprised of two seasons. Plot sizes were 5 m × 1.5 m, made up of two central rows with spacings of 0.75 m × 0.50 m.

Fertilization with mineral fertilizers was done on the basis of mineral fertilizer NPK 12-24-12 at sowing, *i.e.*, zero-day after sowing (0 DAS), fifteen days after sowing (15 DAS) and thirty days after sowing (30 DAS). Urea (46%) was applied using the microdosing method. The microdosing consisted of a localized application of NPK fertilizer (3 g/hill) or 160 kg/ha and Urea (1.125 g/hill) or 60 kg/ha [6]. Urea was applied in two halves respectively at 15 DAS and 30 DAS.

Table 1. General physico-chemical properties of Mvuazi soil.

Parameters (unit)	***Sol pH***	***P1 (ppm)***	***K (ppm)***	***Ca (ppm)***	***Mg (ppm)***	***Mn (ppm)***	***S (ppm)***	***Cu (ppm)***	***B (ppm)***
Results	**5.76**	14	105	1505	229	55	23	12.30	0.21
Low Guid	6.00	30	268	1651	165	100	20	2.00	1.00
High Guid	7.00	100	537	2064	264	250	200	10.00	2.00
Parameters (unit)	***Zn (ppm)***	***Na (ppm)***	***Fe (ppm)***	***CEC (meq/100g)***	***OC (meq/100g)***	***Silt (%)***	***Sand (%)***	***Clay (%)***	***N (%)***
Results	7.98	47	194	13.76	4.07	13	49	39	0.21
Low Guid	4.00	0	150	15.00		30	30	20	0.20
High Guid	20.00	158	350	30.00		50	55	55	0.50

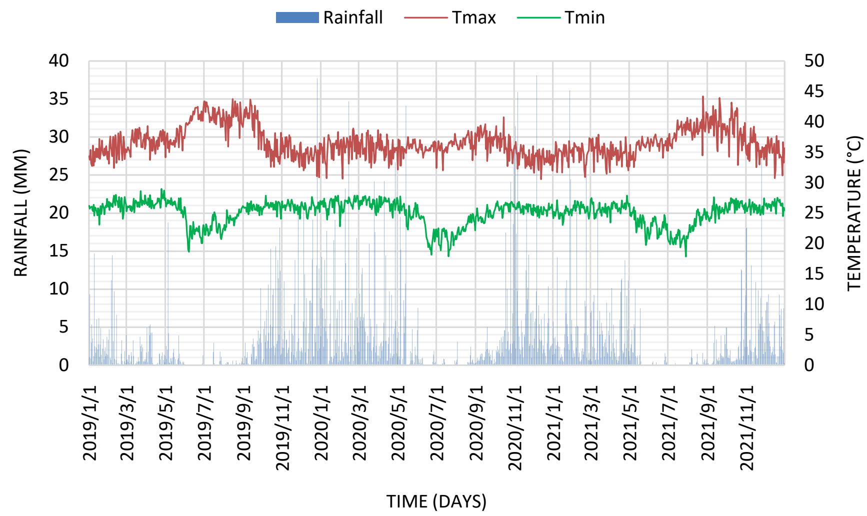

Figure 1. Evolution of climatic parameters (rainfall, maximum temperature and minimum temperature).

2.4. Method

Sowing with three seeds per hill was done after mechanical ploughing, harrowing and cleaning of rubbles, followed by thinning at emergence, leaving two plants per hill for a density of 53,333 plants per hectare [13] [19] [20].

Data were gathered on the growth parameters: plant height (Ph), ear height (Eh), percentage of stem lodging (Sl), percentage of root lodging (Rl), plants aspect (Pasp), phenological parameters: days at 50% male flowering (Poll), days at 50% female flowering (Silk) and Anthesis and silking interval (ASI), disease parameters: ear rot (Erot) and production parameters: ear aspect (Easp) and grain yield (Yld) [21] [22].

2.5. Statistical Analyzes

Data collected were processed and submitted to the analysis of variance according to the general linear model (aov(y~fact1*fact2*fact3)) of the agricolae package of the statistical software R 3.6.3. The separation of the means at the threshold of 0.05 was made by the test of the least significant difference (LSD) of the same package. The principal component analysis (PCA) carried out using the Factominer and foctoextra package of the R 3.6.3 software made it possible to establish correlations between response variables and group individuals into groups of similarities.

3. Results and Discussion

3.1. Analysis of Variance

The analysis of variance was carried out on the data and measurements collected on the growth and production variables. Corresponding results are presented in **Table 2** and **Table 3**. Results analysis showed that there were highly significant effects of the season ($p < 0.0001$), the date of application ($p < 0.0001$), and the variety (p < 0.0001) on male and female flowering. The height of the plants as well as that of the ear was influenced by the season. With regard to the production variables, highly significant differences were observed for yield according to the seasons and dates of fertilizer application (p < 0.0001). However, a significant difference was observed in the interaction between season and variety.

Table 2. Effects of factors studied on growth parameters.

Season	Day after planting	Variety	Poll (days)	Silk (days)	ASI (days)	Ph (cm)	Eh (cm)	Rl (%)
Season A	0 day after planting	local	64.33 ± 3.21ab	69.33 ± 4.04ab	5.00 ± 2.00bcd	213.53 ± 32.55cdefgh	143.40 ± 20.44abc	36.39 ± 2.82abcd
		Mudishi-1	56.00 ± 1.73fg	59.33 ± 2.08de	3.33 ± 1.52de	212.86 ± 41.88cdefgh	113.53 ± 27.78cdef	14.46 ± 5.75defgh
		Mudishi-3	55.00 ± 2.00fgh	58.33 ± 1.52def	3.33 ± 0.57de	218.00 ± 30.65bcdefg	**121.86 ± 28.17abcdef**	29.83 ± 26.88bcdef
		Samaru	55.33 ± 2.51fgh	58.66 ± 1.15def	3.33 ± 3.51de	185.73 ± 10.03ghi	103.13 ± 5.20def	43.45 ± 32.26abc
	15 days after planting	local	**66.00 ± 3.46a**	70.66 ± 3.21a	4.66 ± 0.57cd	192.03 ± 36.34fghji	**85.60 ± 29.61f**	39.79 ± 15.14abc
		Mudishi-1	57.00 ± 0.00efg	59.00 ± 1.00de	2.00 ± 1.00e	210.46 ± 29.88defgh	118.40 ± 30.61bcdef	53.20 ± 34.02ab
		Mudishi-3	58.00 ± 0.00def	59.33 ± 1.15de	**1.33 ± 1.15e**	195.13 ± 16.59efghi	100.60 ± 12.45def	**55.00 ± 29.99a**
		Samaru	61.33 ± 4.04bc	64.66 ± 4.16c	3.33 ± 0.57de	174.20 ± 12.40hi	89.60 ± 11.65ef	39.96 ± 13.24abc
	30 days afyer plantig	local	**66.00 ± 5.29a**	**72.00 ± 5.19a**	6.00 ± 1.00abc	167.73 ± 38.99i	99.40 ± 26.85def	32.58 ± 9.84abcdef
		Mudishi-1	57.00 ± 1.7efg	59.66 ± 1.52d	2.66 ± 0.57de	194.86 ± 24.31efghi	98.33 ± 24.19def	26.52 ± 17.83cdefg
		Mudishi-3	57.00 ± 0.00efg	59.00 ± 1.73de	2.00 ± 1.73e	184.00 ± 21.18ghi	102.26 ± 21.74def	30.81 ± 16.92abcdef
		Samaru	60.66 ± 4.04cd	65.33 ± 4.50b	4.66 ± 0.57cd	**171.83 ± 15.58hi**	91.13 ± 12.92ef	36.14 ± 8.92abcde
Season B	0 day after planting	local	58.00 ± 2.00def	64.66 ± 2.30c	6.66 ± 1.15abc	253.73 ± 13.08abc	158.73 ± 0.46a	10.10 ± 1.54fgh
		Mudishi-1	51.33 ± 2.30ij	57.33 ± 1.15defgh	6.00 ± 2.00abc	206.86 ± 72.63defghi	159.76 ± 68.74a	4.50 ± 4.78gh
		Mudishi-3	49.3 ± 1.15jk	54.00 ± 3.46hij	4.66 ± 2.30cd	234.00 ± 7.81abcdef	121.60 ± 14.08abcdef	2.90 ± 5.02gh
		Samaru	48.00 ± 0.00k	51.33 ± 2.30j	3.33 ± 2.30de	238.73 ± 8.43abcd	131.33 ± 9.86abcd	**0.00 ± 0.00h**
	15 days after planting	local	58.00 ± 2.00def	66.33 ± 0.57bc	**8.33 ± 1.52a**	**262.73 ± 19.07a**	**161.40 ± 19.70a**	11.87 ± 10.78efgh
		Mudishi-1	51.33 ± 2.30ij	57.33 ± 1.15defgh	6.00 ± 2.00abc	240.33 ± 20.15abcd	158.06 ± 58.13ab	1.11 ± 1.92h
		Mudishi-3	51.33 ± 2.30ij	56.00 ± 2.00efghi	4.66 ± 1.15cd	239.80 ± 6.52abcd	128.80 ± 6.23abcde	0.68 ± 1.17h
		Samaru	48.66 ± 1.15jk	**53.33 ± 3.05ij**	4.66 ± 2.30cd	235.53 ± 18.66abcde	128.00 ± 9.89abcde	**0.00 ± 0.00h**
	30 days after plantig	local	59.33 ± 1.15cde	66.66 ± 0.57bc	7.33 ± 0.57a	257.20 ± 13.34ab	153.86 ± 12.45ab	4.34 ± 7.52gh
		Mudishi-1	52.66 ± 2.30hi	55.33 ± 1.15fghi	2.66 ± 1.15de	225.13 ± 15.13abcdefg	128.06 ± 20.45	2.20 ± 0.24gh
		Mudishi-3	54.66 ± 1.15gh	58.00 ± 0.00defg	3.33 ± 1.15de	229.13 ± 4.98abcdef	131.46 ± 12.00abcd	0.81 ± 1.40h
		Samaru	**48.00 ± 0.00k**	54.66 ± 1.15ghij	6.66 ± 1.15abc	229.53 ± 11.49abcdef	128.40 ± 8.16abcde	2.90 ± 5.02gh
CV (0.05)			3.594	3.563196	36.175	11.88835	19.86	74.50705
LSD (0.05)			3.306748	3.536899	2.624402	42.0911	40.19738	24.45686
Effect Season			<2e-16***	4.33e-13***	7.97e-06***	2.46e-09***	1.9e-07***	2.12e-12***
Effect Date			0.000776***	0.002285**	0.9838	0.1714	0.1038	0.119
Effect Variety			<2e-16***	<2e-16***	2.96e-06***	0.2042	0.0372*	0.74
Effect Season*Date			0.137981	0.818854	0.0887.	0.102	0.2597	0.114
Effect Season *Variety			8.98e-05***	1.93e-05***	0.6887	0.0281*	0.3474	0.573
Effect Date *Variety			0.486374	0.085109.	0.0371*	0.8845	0.621	0.757
Effect Season*Date*Variety			0.288646	0.436919	0.6216	0.9659	0.6976	0.541

Table 3. Effects of the factors studied on the production parameters.

Season	Days after planting	Variety	Sl (%)	Pasp (1-5)	Pharv (%)	Easp (1-5)	Erot (1-5)	Yld (kg/plant)
Season A	0 day after planting	local	36.39 ± 13.89a	2.33 ± 0.57b	53.70 ± 25.20de	3.66 ± 0.57a	3.00 ± 1.73abcde	3.0 ± 1.0ghij
		Mudishi-1	14.67 ± 7.91bcd	1.00 ± 0.00e	91.97 ± 10.56a	1.33 ± 0.57cd	3.33 ± 2.08abcd	**7.9 ± 0.4a**
		Mudishi-3	**38.04 ± 31.91a**	1.00 ± 0.00e	96.08 ± 6.78a	1.33 ± 0.57cd	2.00 ± 1.00bcde	**8.0 ± 0.4a**
		Samaru	21.17 ± 7.62abcd	1.33 ± 0.57de	94.07 ± 0.65a	1.00 ± 0.00d	1.66 ± 1.15cde	7.0 ± 0.3ab
	15 days after planting	local	23.07 ± 19.59abc	**3.00 ± 0.00a**	47.59 ± 24.74e	**4.00 ± 0.00a**	2.33 ± 1.15abcde	3.7 ± 0.35efghi
		Mudishi-1	13.47 ± 8.81bcd	1.00 ± 0.00e	97.77 ± 3.85a	1.00 ± 0.00d	3.33 ± 2.08abcd	5.6 ± 0.8bc
		Mudishi-3	18.99 ± 18.34abcd	1.00 ± 0.00e	98.59 ± 1.21a	1.00 ± 0.00d	4.00 ± 1.00ab	5.2 ± 1.1cde
		Samaru	19.41 ± 12.37abcd	1.00 ± 0.00e	98.33 ± 2.88a	1.00 ± 0.00d	4.00 ± 1.00ab	4.6 ± 1.0cdefg
	30 days	local	24.80 ± 10.02ab	2.33 ± 0.57b	**40.14 ± 26.37e**	**4.00 ± 0.00a**	2.66 ± 1.52abcde	1.0 ± 0.05k
		Mudishi-1	14.07 ± 4.01bcd	1.00 ± 0.00e	95.42 ± 7.92a	1.33 ± 0.57cd	**4.33 ± 0.57a**	4.2 ± 0.6cdefg
		Mudishi-3	13.38 ± 7.37bcd	1.00 ± 0.00e	**97.77 ± 3.85a**	1.33 ± 0.57cd	3.66 ± 3.05abc	3.7 ± 0.7defghi
		Samaru	14.49 ± 15.58bcd	1.00 ± 0.00e	88.59 ± 19.75ab	1.00 ± 0.00d	1.66 ± 1.15cde	3.1 ± 0.4ghij
Season B	0 day	local	6.40 ± 4.11bcd	1.33 ± 0.57de	58.78 ± 5.57cde	2.00 ± 1.00bc	2.33 ± 0.57abcde	3.1 ± 0.5ghij
		Mudishi-1	2.79 ± 3.02d	2.00 ± 0.00bc	60.82 ± 14.57bcde	1.66 ± 0.57cd	2.00 ± 1.00bcde	4.7 ± 0.3cdef
		Mudishi-3	**1.42 ± 2.45d**	1.33 ± 0.57de	91.03 ± 50.13a	1.66 ± 1.15cd	1.00 ± 0.00e	5.3 ± 0.9cd
		Samaru	3.01 ± 2.86cd	1.33 ± 0.57de	88.89 ± 19.24ab	1.00 ± 0.00d	2.66 ± 1.15abcde	4.4 ± 0.2cdefg
	15 days	local	8.76 ± 6.86bcd	1.66 ± 0.57cd	**47.94 ± 7.64e**	1.66 ± 0.57cd	2.00 ± 1.00bcde	2.2 ± 0.5ijk
		Mudishi-1	5.61 ± 6.90bcd	1.00 ± 0.00e	83.70 ± 16.67abc	1.33 ± 0.57cd	1.00 ± 0.00e	4.2 ± 0.3cdefg
		Mudishi-3	12.08 ± 5.54bcd	1.33 ± 0.57de	85.18 ± 13.40abc	1.00 ± 0.00d	1.00 ± 0.00e	3.9 ± 0.6defgh
		Samaru	2.63 ± 4.55d	1.66 ± 0.57cd	**92.98 ± 12.15a**	1.33 ± 0.57cd	1.33 ± 0.57de	3.7 ± 0.6efghi
	30 days	local	23.12 ± 9.14abc	1.66 ± 0.57cd	50.05 ± 14.49e	2.66 ± 0.57b	3.00 ± 1.00abcde	**1.5 ± 0.5jk**
		Mudishi-1	4.34 ± 2.14cd	1.33 ± 0.57de	85.11 ± 16.29abc	1.00 ± 0.00d	1.00 ± 0.00e	2.6 ± 0.2hijk
		Mudishi-3	5.87 ± 3.11bcd	1.00 ± 0.00e	79.20 ± 5.58abcd	1.33 ± 0.57cd	1.00 ± 0.00e	3.2 ± 0.3fghi
		Samaru	3.20 ± 2.81cd	1.00 ± 0.00e	84.21 ± 27.34abc	1.00 ± 0.00d	1.33 ± 0.57de	3.6 ± 0.0efghi
CV (0.05)			89.013	28.118698	22.14885	29.24296	53.23849	23.11174
LSD (0.05)			20.17995	0.6479035	28.92298	0.7938932	2.028318	0.1586004
Effect Season			9.29e-06***	0.766	0.0706.	0.00268**	2.49e-05***	2.59e-06***
Effect Date			0.7137	0.25	0.7406	0.39355	0.938	4.43e-11***
Effect Variety			0.0377*	4.17e-09***	2.2e-09***	< 2e-16***	0.563	3.71E-10
Effect Season*Date			0.0595.	0.702	0.948	0.78928	0.091.	0.0083
Effect Season *Variety			0.8287	4.01e-06***	0.2269	1.14e-07***	0.025*	0.0501.
Effect Date *Variety			0.8122	0.123	0.6297	0.25543	0.393	0.2234
Effect Season*Date*Variety			0.6666	0.15	0.937	0.46816	0.389	0.3042

3.2. Growth Parameters

Male flowering at 50% (poll): the highest number of days at 50% male flowering was observed in the local variety on the 15th day after sowing and this difference was significant ($p < 0.0001$) for the effects of seasons, date of application, varieties and season*variety interaction with the variety Samaru which recorded 48 days to reach 50% male flowering when NPK is applied on the 30^{th} day after sowing. The number of days to 50% male flowering decreased with delay in fertilizer application beyond 15 days after sowing.

Female flowering at 50% (Silk): Samaru variety reached 50% of female flowering at 53.3 days after sowing, which was earlier than the local variety with 50% female flowering at 72 days when NPK application was done 30 days after sowing. As for male flowering, the number of days to 50% female flowering decreased with increasing NPK fertilizer application time beyond 15 days after sowing, but the difference was highly significant ($p < 0.0001$) for the interaction effects between seasons and varieties.

Anthesis and silking Interval (ASI): the higher number of days of interval between male and female flowering was observed in the local variety with 8.33 days at 15 days after sowing compared with the Mudishi-3 variety which recorded an ASI of 1.33 days when the application of fertilizers is done at 15 days after sowing. The difference was highly significant ($p < 0.0001$) for season and variety effects.

Plant height (Ph): plant height was greater in the local variety (262.73 cm) under the application of NPK fertilizer 15 days after sowing in season B and the lowest value was observed in the Samaru variety (225.13 cm) for the same season. As for season A, the greatest plant height was recorded in the Mudishi-3 variety (218 cm) when NPK fertilizer was applied at sowing, compared with the Samaru variety (172.83 cm) for the NPK fertilizer application 30 DAS in season A. The difference was highly significant ($p < 0.0001$) for season effects and significant ($p < 0.05$) for date*variety effects.

Ear height (Eh): the highest value for ear height was observed in the local variety (161.40 cm) for the application of NPK fertilizer at 30 days after sowing, in contrast to the variety Mudishi-3 (121.60 cm) for NPK supply at 15 DAS in Season B. The Mudishi-3 (121.86 cm) variety recorded the highest value of Eh when NPK fertilizer was applied at sowing in Season B. A, against the local variety (85.60 cm) when NPK fertilizer was applied at 15 DAS. These results show that there was a highly significant difference ($p < 0.0001$) for the seasonal effects and a significant difference ($p < 0.05$) for the various effects (Table 2).

3.3. Production Parameters

Plant aspect (Pasp): performance on plant aspect was excellent (score 1) for most treatments. However, this aspect of the plants was less good (score 3) for the local variety when the fertilizer application was applied 15 days after sowing in season A. There was a highly significant difference ($p < 0.0001$) for the effects of variety and season*variety interaction (Table 3).

Harvested plant rate (Pharv): a significantly high harvested plant rate (97.77%) was found in Mudishi-3 variety during season A under the application of NPK fertilizers at 30 DAS, compared with the local variety which recorded a low rate (40.14%) of plants harvested for the same treatment. On the other hand, in season B, this rate was higher for Samaru variety (92.98%) and lowered in the local variety (47.94%) for the application of NPK fertilizer at 15 DAS. The effects of variety strongly ($p < 0.00001$) influenced the results for the rate of plants harvested (Table 3).

Ears aspect (Easp): the best aspects (score 1) of the ears were observed in all the varieties under different application periods of the NPK fertilizers except the local variety (score 4) when the NPK fertilizer was applied at 15 and 30 days after sowing in season A. The variety and season factors significantly ($p < 0.0001$) influenced the aspect of ears (Table 3).

Ear rot score (Erot): the ear rot score was high (score 4.33) in the Mudishi-1 variety under the application of fertilizers at 30 days after sowing in season A. The difference between the averages was highly significant ($p < 0.0001$) under the effect of the season. However, the interaction effects of season and variety significantly influenced ($p < 0.05$) the rating of rot. This rating decreased with the variety and in season B (Table 3).

Grain yield (Yld): average grain yield was high in Mudishi-1 (7.90 t/ha) and Mudishi-3 (8.0 t/ha) varieties when fertilizer was applied at sowing time in season A while the local variety recorded an average of 3 t/ha for the same treatment. In general, yield decreased with late application of fertilizer after sowing and in season B; season B was shorter than season A. The difference was highly significant ($p < 0.0001$) with respect to the effects of season, fertilizer supply date and variety (Table 3).

3.4. Principal Component Analysis (PCA)

The principal component analysis showed that only the first two dimensions had an eigenvalue greater than one. These two dimensions alone produced 74.82% of the variations. The first dimension is characterized by growth variables (male flowering and female flowering) and the appearance of plants and ears. As for the second dimension, it is characterized by the height of the plants and the insertion of the ear as opposed to the yield and the rate of plants harvested. The high values of the athesis and siliking interval (ASI) are opposed to the production parameters (Pharv and Yld) (Figure 2).

Figure 3 shows a grouping of varieties around treatments (date of fertilizer application and seasons). Figure 3 showed that the local variety, being unimproved, deviated from the remainder of the average parameters studied for this variety and joined the large values of ASI, Pasp, Easp, silk and poll in all seasons.

The high values of the production parameters are recorded in season A, mainly for the application of fertilizers at sowing time.

4. Discussion

In general, the application of NPK as basal fertilizers promotes plant growth and increases the grain yield of maize varieties in acid soils [6] [9] [23]. In this study, the average growth variables as well as those of production were mostly influenced by the season, the date of fertilizer application and the varieties. The improved varieties exhibited better performance in terms of plant quality and grain yield.

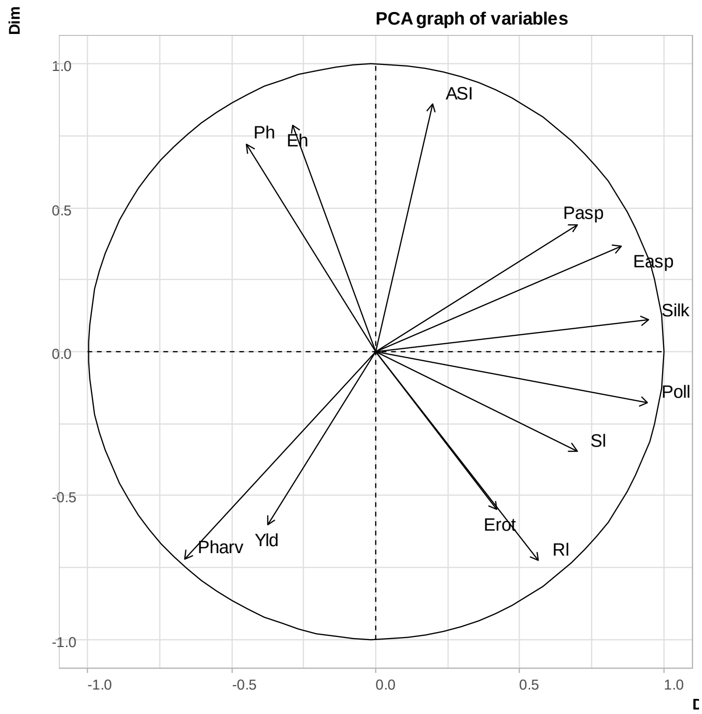

Figure 2. Map of the variables studied.

Figure 3. Variables, individuals and factors studied map.

The date of basal fertilizer application has previously been studied by [9] and [24]. They concluded that the NPK application at sowing is very advantageous if it is not followed by a dry period. Otherwise, applying the NPK within 10 days after emergence is suitable and any delay in the application is detrimental to production. These results are similar to those found in this study, which shows that NPK applied 15 days after sowing significantly reduce growth performance and negatively affects grain yield.

Mudishi-3 variety has appeared to tolerate late application of basal fertilizers and got an acceptable average production in season A. These hypotheses were verified by [25], showing that this variety had a very low-stress sensitivity index (SSI) and as a result, its yield remained stable under the drought conditions occurring in the middle of the growing season.

The low values of the production variables recorded in season B can be due to corresponding rainfall and thermal episodes recorded during the experiment (**Figure 1**). The short periods of intense rainfall causing vicious droughts at the end of the main cropping season disrupting maize productivity, have been reported by [26]. This phenomenon, combined with the delay in the application of basal fertilizers, may explain the weak performance of maize in the short rainy season. This situation was reported by [27].

According to Useni *et al*. (2013) [5], inadequate plant nutrition management and low soil fertility are the main factors responsible for lower yields. This opinion is in accordance with the fact that a maize crop that does not receive nutrients during its phase of growth and organ development ends up with a significant productivity decrease [1] because the absorption of certain major elements such as P and K is done continuously starting the first days of the maize cycle [28] [29] [30].

5. Conclusion

The objective of the present study was to determine the best date of basal fertilizer application for the production of QPM in the acid soils of the savannah in the southwestern zone of DRC. Two varieties of QPM were compared to two varieties of normal maize in a factorial design replicated three times during two seasons. The results obtained showed that the application of NPK basic fertilizers leads to maize plants high-performance with a high grain yield. In addition, the application of fertilizers at sowing time favors a faster maturing for the improved varieties of QPM compared with the unimproved local variety. The application of NPK basal fertilizers at the time of sowing promotes a high rate of harvested plants which therefore decreases with the delayed nutrient supply. The reductions in yield are very significant when the inputs are applied after 30 days from the start of the cycle in a short growing season.

Acknowledgements

We would like to thank the entire team of scientists and technicians who authored this article. They gave their precious time to contribute to the implementation of this study despite their numerous duties. We appreciate the truthful and sincere collaboration which exists between the three research institutions (INERA) and universities (UPN and UNIKIN) which made this experiment successful under the ASARECA Climate Smart Agriculture Alliance (ACSAA).

Conflicts of Interest

The authors declare no conflicts of interest.

References

[1] Tshiabukole, J.P.K. (2018) Evaluation de la sensibilité aux stress hydriques du maïs (*Zea mays* L.) cultive dans la savane du Sud-Ouest de la RD Congo, cas de Mvuazi. These de Doctorat, Faculte des Sciences Agronomiques, Departement de Phytotechnie, Universite Pedagogique Nationale, Kinshasa, 162.

[2] Nyembo, K.L., Banza, M.J., Salima, B.S.N., Tshipama, T.D., Kiluba, K.M., Mpoyo, M.G. and Muteba, K.M. (2015) Les faibles doses d'engrais azotés ne permettront pas d'optimiser le rendement des nouvelles variétés de maïs dans la région de Lubumbashi (RD Congo). *International Journal of Innovation and Applied Studies*, **12**, 176-182.

[3] Jaliya, M.M., Falaki, A.M., Mahmud, M. and Sani, Y.A. (2008) Effect of Sowing Date and Npk Fertilizer Rate on Yield and Yield Components of Quality Protein Maize (*Zea Mays* L.). *ARPN Journal of Agricultural and Biological Science*, **3**, 23-29.

[4] Kumar, R., Kumawat, N., Kimar, S., Kumar Singh, A. and Bohra, J.S. (2017) Effect of NPKSAND Zn Fertilizationon, Growth, Yield and Quality of Baby Corn—A Review. *International Journal of Current Microbiology and Applied Sciences*, **6**, 1392-1428. https://doi.org/10.20546/ijcmas.2017.603.161

[5] Yannick, U.S., Minerve, C.K., John, T.K., Emmanuel, M.M., Prisca, K.K., François, N.N., Patrick, K.A.K., Kalilo, K., Louis, B.L., Luciens, N.K. and Michel, M.M. (2013) Utilisation des déchets humains recyclés pour l'augmentation de la production du maïs (*Zea mays* L.) sur un ferralsol du Sud-Est de la RD Congo. *Journal of Applied Biosciences*, **66**, 5070-5081. https://doi.org/10.4314/jab.v66i0.95005

[6] Tshiabukole, J.P.K., Khonde, G.P., Phongo, A.M., Ngoma, N., Vumilia, R.K. and Kankolongo, A.M. (2022) Liming and Mineral Fertilization of Acid Soils in Maize Crop within the Savannah of Southwestern of Democratic Republic of Congo. *Open Access Library Journal*, **9**, Article ID: e8412. https://doi.org/10.4236/oalib.1108412

[7] Bache, B.W. and Rogers, N.E. (1970) Soil Phosphate in Relation to Phosphate Supply to Plants from Some Nigerian Soils. *The Journal of Agricultural Science*, **74**, 383-390. https://doi.org/10.1017/S0021859600023029

[8] Banjoko, V.A. and Adediran, J.A. (2003) Effect of Source, Rate and Method of Notrogenfertilizer Application on Maize Yield in the Savanna Zone of South Western Nigeria. *Moor Journal of Agricultural Research*, **4**, 19-25. https://doi.org/10.4314/mjar.v4i1.31748

[9] Tabu Hugues, I., Mukalay John, B., Mukoka Lucky, L., Kimonge Ismael, M., L'kisaten, M.H., Lububo Antoine, K. and Kimuni Luciens, N. (2018) Influence du moment d'application du NPK sur la croissance et le rendement du maïs (*Zea mays* L.) installé sur un ferra sol. *Journal of Applied Biosciences*, **127**, 12794-12803. https://doi.org/10.4314/jab.v127i1.4

[10] Luciens, N.K., Yannick, U.S., Michel, M.M., David, B.M., Emery, K.L. and Louis, B.L. (2012) Effets des apports des doses variées de fertilisants inorganiques sur de

Zea mays. *Journal of Applied Biosciences*, **59**, 4286-4296.

[11] Mbuya, K., Nkongolo, K.K., Narendrula, R., Kalonji-Mbuyi, A. and Kizungu, R.V. (2010) Participatory Selection and Characterization of Quality Protein Maize (QPM) Varieties in Savanna Agroecological Region of DR-Congo. *Journal of Plant Breeding and Crop Science*, **2**, 325-332.

[12] Mbuya, K., Kabongo, J.P.T., Pongi, G.K., Mundondo, A.E., Anageanatiga, O.E. and Ekuke, L.W. (2014). Effet du mais à forte teneur en protéine sur l'élevage des poulets de chair dans la province du Bas-Congo et l'impact sur sa production en république démocratique du congo. *African Crop Science Journal*, **22**, 969-977.

[13] Mbuya, A.K., Kabongo, J.P.T., Pongi, G.K., Matondo, A.P., Nlandu, N., Kombozi, G.B., Tshimbombo, C.J., Mulumba, G.B., Kaboko, J.K., Masengu, T.T., Nkongolo, J.M. and Kizungu, R.V. (2020) Effect of Double Planting Density and Smaller Fertilization Rates on Grain Yield of Quality Protein Maize in a Clay-Sandysoil in Mvuazi. *Open Access Library Journal*, **7**, Article ID: e6632. https://doi.org/10.4236/oalib.1106632

[14] Tshiabukole, J.P.K., Khonde, G.P., Phongo, A.M., Ngoma, N., Kankolongo, A.M., Vumilia, R.K. and Djamba, A.M. (2021) Simulation of Fall Armyworm (*Spodoptera frugiperda*) Attacks and the Compensative Response of Quality Protein Maize (*Zea mays*, var. Mudishi-1 and Mudishi-3) in Southwestern DR Congo. *Open Access Library Journal*, **8**, Article No. e7217. https://doi.org/10.4236/oalib.1107217

[15] Khonde, P., Tshiabukole, K., Kankolongo, M., Hauser, S., Djamba, M., Vumilia, K. and Nkongolo, K. (2018) Evaluation of Yield and Competition Indices for Intercropped Eight Maize Varieties, Soybean and Cowpea in the Zone of Savanna of South-West RD Congo. *Open Access Library Journal*, **5**, Article No. e3746. https://doi.org/10.4236/oalib.1103746

[16] Köppe, W. (1936) Das geographische System der Klimate. In: Köppe, W. and Geiger, H., Eds., *Handbuch der Klimatologie*, Gebrüder Borntraeger, Berlin, 1-44.

[17] Fakorede, M.A.B., Badu-Apraku, B., Kamara, A.Y., Menkir, A. and Ajala. S.O. (2003) Maize Revolution in West and Central Africa: An Overview. *Proceedings of a Regional Maize Workshop*, IITA-Cotonou, Republic of Benin, 29-41.

[18] SOTERCAF (2015) Carte des sols de la RDC, carence en oligo-éléments, juin 2015.

[19] Kabongo, T., Pongi, K., Mumba, D., Kizungu, V., Mbuya, K. and Nkongolo, K. (2016) Evaluation of Maize Sensitivity to Drought in Southwestern Savannah Area of DR. Congo. *African Journal of Agricultural Science and Technology*, **4**, 812-817.

[20] Yannick, U.S., Alain, M.L., Luhanga, M., Mbar Mukaz Dieudonné, C. and Luciens, N.K. (2014) L'apport des faibles doses d'engrais minéraux permet-il d'accroitre le rendement du maïs cultivé à forte densité? Un exemple avec deux variétés de maïs à Lubumbashi. *Journal of Applied Biosciences*, **74**, 6131-6140.
https://doi.org/10.4314/jab.v74i1.4
http://www.m.elewa.org

[21] Bello, O.B., Ganiyu, O.T., Wahab, M.K.A., Azeez, M.A., Abdulmaliq, S.Y., Ige, S.A., Mahmood, J., Oluleye, F. and Afolabi, M.S. (2012) Yield and Disease Reactions of Quality Protein Maize Varieties in the Southern Guinea Savanna Agro-Ecology of Nigeria. *International Journal of Agriculture and Forestry*, **2**, 203-209.

[22] Tshiabukole, K., Khonde, P., Kankolongo, M., Jadika, T., Kasongo, K., Badibanga, M., Kasongo, T. and Vumilia, K. (2017) Suitable Hybrids and Synthetics Provitamin a Maize Selected for Release in the Democratic Republic of Congo. *Open Access Library Journal*, **4**, Article No. e3446. https://doi.org/10.4236/oalib.1103446

[23] Law-Ogbomo, K.E. and Law-Ogbomo, J.E. (2009) The Performance of *Zea mays* as

Influenced by NPK Fertilizer Application. *Notulae Scientia Biologicae*, **1**, 59-62. https://doi.org/10.15835/nsb113459 http://www.notulaebiologicae.ro

[24] Amali, P.E. and Namo, O.A.T. (2015) Effect of Time of Fertilizer Application on Growth and Yield of Maize (*Zea mays* L.) in Jos—Plateau Environment. *Global Journal of Agricultural Sciences*, **14**, 1-9. https://doi.org/10.4314/gjass.v14i1.1

[25] Tshiabukole, J.P.K., Kankolongo, A.M., Khonde, G.P., Mumba Djamba, A., Kizungu Vumilia, R. and Nkongolo Kabwe, C. (2016) Stress Tolerance Indexes of Maize (*Zea mays* L.) Grown in the Southwestern Savannah in the Democratic Republic of Congo. *International Journal of Innovation and Scientific Research*, **26**, 355-360. http://www.ijisr.issr-journals.org/

[26] Tshiabukole, K., Khonde, P., Muku, M., Vumilia, K., Lunekua, K. and Kankolongo, M. (2016) Influence of Climate Variability on Seasonal Rainfall Patterns in South-Western DR Congo. *Open Access Library Journal*, **3**, Article No. e2952. https://doi.org/10.4236/oalib.1102952

[27] Claasen, M.M. and Shaw, R.H. (1979) Water Deficit Effects on Corn. I. Vegetative Component. *Agronomy Journal*, **62**, 649-652. https://docplayer.fr/23919429-Lafertilisation-en-culture-de-mais-c-i-p-f-jfr-oost.html

[28] Bot, A. and Benites, J. (2005) The Importance of Soil Organic Matter: Key to Drought-Resistant Soil and Sustained Food Production (No. 80). Food & Agriculture Organization of the United Nations, Rome, 95 p.

[29] La fertilité en culture de maïs C.I.P.F. (JFr. Oost) (2005) 9 p. https://docplayer.fr/23919429-Lafertilisation-en-culture-de-mais-c-i-p-f-jfr-oost.html

[30] Lambergt, J., Tremblay, N. and Hamel, C. (1994) Nutrition minérale des plantes. In: Hassani, T.A.E. and Persoons, E., Eds., *Agronomie moderne*: *Bases physiologies et agronomiques de la production végétale*. *Bases physiologiques de l'élaboration du rendement*, Hatier-Aupelt-Uref, Universités Francophones, Paris, 269-292.