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Response Durum Wheat to Fertility Levels under Tropical Semiarid Climatic Conditions of Southern Côte d'Ivoire

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Authors' contributions

This work was carried out in collaboration between all authors. Authors TMJ and BK designed the study, performed the statistical analysis, wrote the protocol and the first draft of the manuscript. Authors NKJC and KKF managed the analyses of the study. Authors KRN, ZF, DE and YKA managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Aims: To determine the effect of NPK-fertilizer on wheat agronomic parameters and identify the couple of maximum yield and rate of fertilizer according to a response curve.
Study Design: A pot (277.75 cm^2) trial was conducted in randomized complete block design composed of three replications.
Place and Duration of the Study: The study was carried out in the botanic center of Felix Houphouet-Boigny University, in Abidjan city located in south Côte d'Ivoire, during three successive cropping cycles of wheat in 2015.

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Methodology: In 18 pots containing 5 kg of soil as substact, six NPK-fertilizer (15-22-22) rates (100 kgha^{-1}, 200 kgha^{-1}, 300 kgha^{-1}, 400 kgha^{-1}, 500 kgha^{-1} and 600 kgha^{-1}) was applied as basal fertilizer. At tillering and boosting stages, 35 kgha^{-1} of urea ($CO(NH_2)2$; 46%N) was applied for each pot respective.
Results: Wheat response was highly significant ($p< 0.0001$) for both linear and quadratic trends of wheat grain yield (GY) as well as for the total dry matter (TDM). The rates of 400 kgha^{-1} and 425 kgha^{-1} were relevant to the highest grain yields and total dry matter (11.02 and 40.35 g/pot) though, more pronounced trend was accounting significantly for 300 kgha^{-1} across the successive trials.
Conclusion: Consequently, the rate of 400 kgha^{-1} of NPK (15-22-22) should be the optimum recommended for durum wheat production in the forest zone of south Côte d'Ivoire. Therefore, an investigation of wheat response to K-fertilizer is still required for the improvement of plant vigor.

Keywords: Wheat; response curve; fertilization; basal fertilizer; Côte d'Ivoire.

1. INTRODUCTION

Africa wheat cultivation is longer limited to the North Africa because of the required drier climate, preferentially with worm days alternating with cool nights [1]. In fact, wheat cultivation requires a range of temperatures between 10℃ and 30℃, and a rainfall (<1000 mm) lower than that of the tropical zone of Africa [2]. Yet recently, Côte d'Ivoire is submitted to spacious-temporal climatic variability since 70 decade like the whole West Africa countries with more persisting rainfall deficieny. Particularly, in the southern coastal zone characterized by four seasons with more variation of rainfall in a global reduction trend [3]. There is change in rainfall pattern, including rainfall reduction and air temperatures fluctuating in new ranges [4]. However, the forest zone of south country is still more suitable for rainfed agriculture as new geographic cropping zone opportunity for marginal adopted food crops in there [5]. In this line, productivity test of wheat was successfully conducted by [6] in some extend emphasizing the requirement of N, P and K as optimum composition of fertilizer: combining cations as Ca, Mg and/or Zn has negatively affected the grain yield though, some positive effects were observed during the vegetative growth. Moreover, the simple rate of NPK as applied needs to be confirmed in order to determine the required optimum rate. This approach should meet the concept of site specific fertilizer management [7].

In fact, the forest agro-ecology of south Cote d'Ivoire is characterized by a rising air temperature coupled with high sun light intensity [4,6,8] contrasting with temperate zones as traditional cropping zone of wheat [1]. In such ecology, ethylene and reactive oxygen syntheses can reduce carbon metabolism impairing plant mineral nutrition with consecutive reduction of biomass production [9,10]. Hence, the need of identification of NPK-fertilizer optimum rate in a given ecology for grain production.

Therefore, the current study is initiated for exploring the response of wheat to different rates of NPK (15%, 22%, 22%) in the south Côte d'Ivoire. The aim was: i) to determine the effect of NPK-fertilizer on wheat agronomic parameters and, ii) to identify the match of maximum yield and rate of fertilizer according to a response curve. Overall, the study should emphasize the requirement of N, P and K for wheat production in a marginal cropping zone as the forest ecology of West Africa.

2. MATERIALS AND METHODS

2.1 Site and Study Design

The study was carried out in the botanic center of Felix Houphouet-Boigny University (05°20'50.2''N; 03°59'10.6''W; 52 m asl) in the distric of Cocody, in Abidjan city located in south Cote d'Ivoire. The extreme values of air temperature were ranging between 28.2℃ and 23.9℃ coupled with an annual average rainfall of 2008.8mm.

During June 01-high rainfall season), August (02-dry season) and November (03-low rainfall season) 2015, five kilogram (5 kg) of soil were sampled using hand hoe respectively for being decanted into eighteen (18) plastic pots of 4 liters capacity further characterized by an upper surface of 277.75 cm^2, 18 cm depth and 20 cm of inner diameter. Soil was sampled in 0 – 20 cm depth under canopy. A randomized complete block design was laid with three replications for the experiment with 6 treatments in respective pot. A fertilizer NPK-15-22-22 (15% N, 22% P, 22% K) was applied at increasing rates of 100 kgha^{-1}, 200 kgha^{-1}, 300 kgha^{-1}, 400 kgha^{-1}, 500 kgha^{-1} and 600 kgha^{-1} as basal fertilizer before sowing two seeds of Simeto durum wheat cultivar (*Triticum durum*, *desf*.) originated from Italy. Simeto is a modern cultivars with *Rht-B1* genes (1974–2000) coming from Capeiti 8 and Valnova crossing since 1988 [11,12]. At tillering and boosting stages, a rate of 70 kgha^{-1} of urea ($CO(NH_2)_2$; 46%N) was applied respectively in all the pots. Water supply was done during dry period applying 555 cc of water corresponding to 20 mm while weeding was manual if necessary.

2.2 Data Collection

On 7 and 17th days after seeding (DAS), the germination rate was determined per treatment per pot. The leaves number per seedling and per treatment per pot was also counted on 10 and 17th DAS as well as plant height and circumference measurement at different physiological stages for the determination of vigor index. The stages of tillering, boosting, flowering and maturity were further determined in addition to the numbers of tillers and panicles per pot. At the maturity stage, the plant height and circumference were determined per pot in addition to the harvest. After drying and threshing, wheat straw and grain were weighed separately and the straw yield (SY) were determined per pot.

After sieving, the grain yield (GY) was weighed before drying in oven during 24 hours at constant temperature of were determined per pot.

Moreover, the model of [13] was applied for GY estimation as the potential (SGY) of the soil on the basis of soil content of Ca and Mg:

$$\text{SGY (g/pot)} = 458 + 368\times \text{Ca (g kg}^{-1}) + 144 \times \text{Mg (g kg}^{-1}) \quad (1)$$

Using the SY and GY, the Total Dry Matter (TDM) was calculated as bellow:

$$\text{TDM (g/pot)} = \text{GY} + \text{SY} \quad (2)$$

$$\text{HI (\%)} = (\text{GY/SY}) \times 100 \quad (3)$$

Beside these yield parameters, the index of plant vigor (IV) was also determined using the method of [14]:

$$\text{IV} = \text{Log } [\text{C}^2 \times \text{H})/4\pi)] \quad (4)$$

C: circumference of the total tillers; H: Plant height

2.3 Sampling and Soil Analyze

After keeping soil in the pots, another sample was taken in 0 – 20 cm depth in the proximity area using hand auger. This sample was prepared for laboratory analysis concerning the determination of soil particle size, the pH (water), the contents of organic carbon-C, total nitrogen-N, available phosphorus-P, potassium-K, zinc-Zn and magnesium-Mg. Robinson pipette method was used for particle size determination as described by [15]. Soil contents of C, N-total and P were determined by [16], Kjeldhal and colorimetry after perchloric acid digestion [17] respectively. Soil exchangeable cation concentrations were determined by flame emission and atomic absorption of spectrometry for K and Mg respectively after acetic ammonium extraction as done for Zn before EDTA dosage [18]. Glass electrode was used for pH measurement in soil/water ratio of 1/2.5.

2.4 Statistic Analysis

The randomization of NPK treatments for the experiment design was done by GenStat Discovery 3 for each of the three replications. The mean values of GY, SY, HI, IV, plant height (H), tiller (T) and panicle (P) numbers were determined by analyze of variance (ANOVA) for identification of optimum rate of fertilizer. Mean values classification was done by least significant difference.

Pearson correlation analyses were performed for exploring the relation between soil parameters and wheat yield for a given rate of fertilizer. Moreover, surface curve response analysis of NPK rates was done to emphasize the yield trend according to the fertilizer rates in order to identify the optimum rate. SAS package was used for statistic analysis according α value of 0.05.

3. RESULTS

3.1 Soil Characteristics and Site Climate

Results of soil tests are recorded in the Table 1 emphasizing sandy-clayed soil (sand 79.1%; clay 16%). About 20 g kg^{-1} of soil C content is noticed as twice lower than the threshold level of 40 g kg^{-1} in addition to a sufficient (> 1 g kg^{-1}) N content

Table 1. Soil physic-chemical characteristics in 0 – 20 cm depth

Particulars	Value	Methods
pH (1 : 2.5:: Soil : Water)	5.9	Glass Electrode pH Meter [1]
pH(1:2.5::soil :KCl)	5.2	
Clay (%)	16	Pipette Method [2]
Coarse silt (%)	2.3	
Fine silt (%)	2.6	
Coarse sand (%)	63.6	
Fine sand (%)	15.5	
C-organic (%)	2	Wakley and Black Method [3]
N (gkg^{-1})	1.3	Modified Kjeldahl Method [4]
P-available (ppm)-Olsen	25	colorimetry after perchloric acid digestion Method [5]
K ($cmolkg^{-1}$)	0.097	flame emission of spectrometry Method [6]
Ca ($cmolkg^{-1}$)	1.731	atomic absorption of spectrometry Method [7]
Mg ($cmolkg^{-1}$)	0.451	
Zn ($mgkg^{-1}$)	19.32	acetic ammonium extraction before EDTA dosage Method [8]
Mg:K	4.65	
Ca:Mg	3.84	
CEC ($cmolkg^{-1}$)	6.72	
K: CEC	0.014	

(1.3 g kg^{-1}) contrasting with the recorded high (>10:1) ratio of 15.38:1. Soil contents of Ca, Mg and K) are 1.73 cmol kg^{-1} (< 2 cmol kg^{-1}), 0.45 cmol kg^{-1} (> 0.45 cmol kg^{-1}) and 0.09 cmol kg^{-1} (< 0.10 cmol kg^{-1}) underlining deficiencies of Ca and K resulting low value of ECC (6.72 cmol kg^{-1}) below the threshold level (< 20 cmol kg^{-1}). Moreover, low ratios of Ca:Mg (3.48< 10) and K:ECC (0.001< 0.05) are illustrating cations unbalance and K deficiency. However, Mg:K ratio is high (> 2). The low value of pH (5.9) is coupled with sufficient contents of available phosphorus (> 10 mg kg^{-1}) and zinc (>1 mg kg^{-1}) ranging about 25 mg kg^{-1} and 19.32 mg kg^{-1} respectively.

Fig. 1 exposes the recorded air temperature and rainfall during the experiment period showing annual average temperature of 26.35℃. The months of February, March, April and May are the warmest (27.5℃). The lowest temperatures are often observed during August. The highest rainfall amount (685 mm) is noticed for June while the lowest (6.1 mm) is for September. The annual rainfall recorded during the experiment is 2008 mm (Table 2).

3.2 Effects of Different Rates of NPK on Agromorphological Parameters

The mean values of the rate of grain germination are kept in Table 3 for 7 and 17 days after seeding (DAS) according to the different rates of NPK-fertilizer. Full germination (100%) was observed indifferently to fertilizer rates at 17 DAS while, lowest rate of germination was observed for the lowest rate (100 kg ha^{-1}) of NPK at 7 DAS. Within 10 days, a significant difference of germination rate is observed except for the fertilizer rates of 300, 500 and 600 $kgha^{-1}$ although; Treatment effect is not significant (P > 0.05) at 7 DAS.

The mean values of leaves at 7 and 17 DAS during the cropping are presented in Table 4. There is increasing number of leaves along the time though, this trend is not statistically significant (P = 0.40; P = 0.06).

The mean values of tiller numbers at 22, 44 and 44 DAS are presented in Table 5. There is a significant effect of NPK fertilizer at 44 DAS (P = 0.002) and 66 DAS (P = 0.001) contrasting with the observation done at 22 DAS (P = 0.61). Moreover, no significant difference is observed between the mean values at 22 DAS while, the number of tillers is lowest for the rate of 100 kg ha^{-1} (2/pot) likewise at 66 DAS contrasting with the highest value (4/pot) observed for 300 kg ha^{-1} and 600 kg ha^{-1} respectively.

Excluding the NPK rate of 100 $kgha^{-1}$, increasing trend of tiller numbers is observed from 22 to 66 DAS for all the treatments with a maximum value early observed at 44 DAS for 600 $kgha^{-1}$. Three weeks were required for the effect of fertilizer rate on tiller number though; not exceeding 2/pot until 22 DAS.

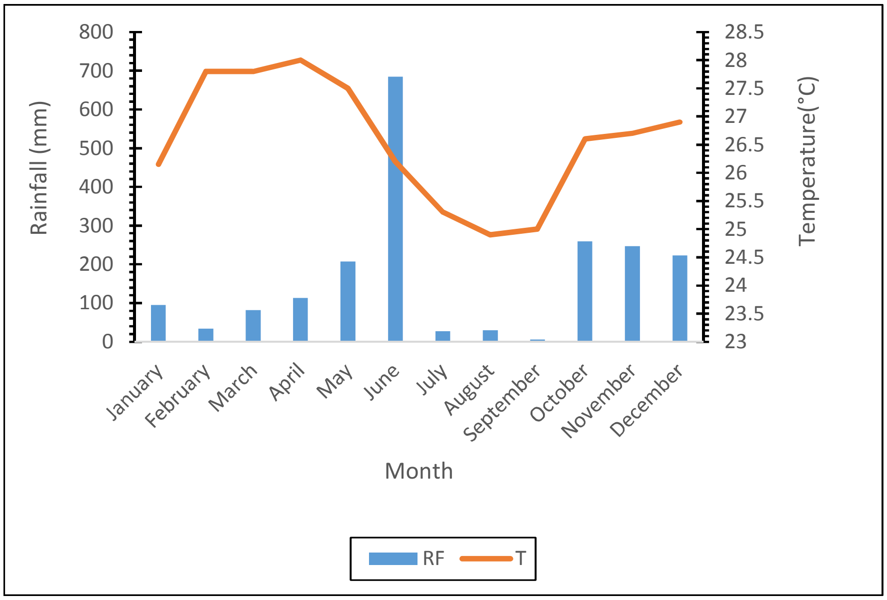

Fig. 1. Variations of air temperature (T) and rainfall (RF) during the trial period

Table 2. Values of air temperature (T°C), rainfall (RF (mm)) and air humidity (H) during the physiological stages of wheat during the trials

	Trial 1			Trial 2			Trial 3		
	T°C	RF (mm)	H (%)	T°C	RF (mm)	H (%)	T°C	RF (mm)	H (%)
Germination	26.2	685	80.5	24.9	28.9	73.5	26.9	223	87.5
Tillage	25.3	27.7	86	25	6.1	85.5	26.5	95	96.1
Boosting	24.3	29.8	75.5	26.6	259	90.3	27.8	33.5	95.9
Maturity	24.3	29.8	73.6	26.6	259	90.3	27.8	33.5	95.9
Minimum	24.9	6.1	57.6	24.9	6.1	57.6	24.9	6.1	57.6
Maximum	28	685	90.6	28	685	90.6	28	685	90.6
Mean	26.5	153.8	90.41	26.5	153.8	90.41	26.5	153.8	90.41

Table 3. Germination rate at 7 and 17 DAS according to different rates of NPK

NPK rate (kgha^{-1})	Germination rate (%)	
	7 DAS	17 DAS
100	66.67 bB	100 Aa
200	83.33 aB	100 aA
300	100 aA	100 aA
400	83.33 aB	100 aA
500	83.33 aA	100 aA
600	100 aA	100 aA
P > F	0.54	0
CV (%)	27.37	0
G.M (%)	86.11	100
ppds $_{0.05}$	41.93	0

Values with the same letters statistically similar for α = 0.05. Uppercase fonts are for comparison in column and lower cases are for lines

Table 4. Leave numbers at 10 and 17 DAS according to different rates of NPK fertilizer

NPK rate ($kgha^{-1}$)	Leave number	
	10 DAS	17 DAS
100	2 aA	3 Aa
200	2 aA	3 aA
300	2 aA	3 aA
400	2 aA	3 aA
500	2 aA	3 aA
600	2 aA	3 aA
P > F	0.40	0.06
CV (%)	19.81	6.07
G.M	2.27	2.96
$ppds_{0.05}$	0.42	0.17

Values with the same letters are simillar statistically for α = 0.05. Uppercase fonts are for comparison in column and lowercases for the lines

Plant growth in height was statistically not significant indifferently to the date of observation. Moreover, the values remain statistically similar from 22 DAS to the maturity stage across and along fertilizer rates. Nevertheless, great values of plant height at maturity are observed for the rates of 600 $kgha^{-1}$, 300 $kgha^{-1}$ and 200 $kgha^{-1}$ thereby resulting a grand mean (GM) value in the range of 25 to 49 cm (Table 6).

3.3 Effect of Treatment on Yield Parameters

The heading rate at 60 and 68 DAS and flowering rate at 68 and 76 DAS are recorded according to the different rates of NPK fertilizer in Table 7. There is significant effect of fertilizer rate on each of the studied parameters at the date of observation respectively. Furthermore, significant difference of mean values is observed indifferently to the parameters and observation date. The rate of 200 $kgha^{-1}$ of NPK induced significantly ($P < 0.004$) the highest heading rate and flowering at 60 and 68 DAS. Yet, the NPK rate of 400 $kgha^{-1}$ induced significantly ($P < 0.0002$) the highest rate of flowering at 76 DAS. Lowest values are always observed for the NPK rate of 100 $kgha^{-1}$ for each of the studied parameters. However, the rates of 200 $kgha^{-1}$ and 300 $kgha^{-1}$ often showed highest rates likewise for 400 $kgha^{-1}$ and 600 $kgha^{-1}$ in some extend.

The highest grain yields (13.42 g/pot and 9.71 g/pot) are recorded for the fertilizer rates of 300 $kgha^{-1}$ and 600 $kgha^{-1}$ with more pronouncing trend significantly for 300 $kgha^{-1}$ over the three cropping seasons (Fig. 2). The mean values recorded for the fertilizer rates of 200 $kgha^{-1}$ and 100 $kgha^{-1}$ are among the lowest (8.05 g/pot and 4.84 g/pot). Roughly, the yields increased from single to three under increasing rate of NPK fertilizer.

On the other hand, the best straws yield and dry matters are recorded with 400 $kgha^{-1}$, 600 $kgha^{-1}$ and 300 $kgha^{-1}$ rates as well as 500 $kgha^{-1}$ rate to a certain extent (Fig. 3).

The mean values of harvest index (HI) and plant vigor index (VI) according to the different rates of NPK fertilizer per pot are kept in Table 8. Only HI shows significant effect of the treatment ($P < 0.005$). The highest index are recorded for 300 $kgha^{-1}$ and 600 $kgha^{-1}$ as NPK fertilizer rates corresponding to 31.20% and 26.32% respectively. The lowest mean value of HI is induced by the NPK rate of 100 $kgha^{-1}$.

The relations between GY and HI as well as the VI are presented in Table 9 by correlation coefficients according to different rates of NPK fertilizer. Significant ($P < 0.05$) positive correlation value accounts for HI and VI under the effect of 300 $kgha^{-1}$ of NPK. There is no more significant relation between GY and HI likewise for GY and VI.

3.4 Response Curve to NPK Fertilizer Rate

Wheat responses to NPK fertilizer rates by the grain yield (GY) and total dry matter (TDM) are presented in Figs. 4 and 5 respectively. Both linear ($P < 0.001$) and quadratic ($P < 0.0001$) trend are characterizing the response of GY respectively as well as for TDM ($P < 0.001$; $P < 0.002$) according to Table 10.

There is linear increasing effect of NPK up to a maximum yield (11.02 g/pot) for 400 $kgha^{-1}$ as NPK rate. Yield decreasing is observed beyond this rate. Similarly, a linear increasing of TDM is observed up to a maximum of 40.35 g/pot for NPK fertilizer rate of 425 $kgha^{-1}$. Further applying NPK induces a decreasing trend. The intercepts of these trends are highly significant for a significant model (Table 10).

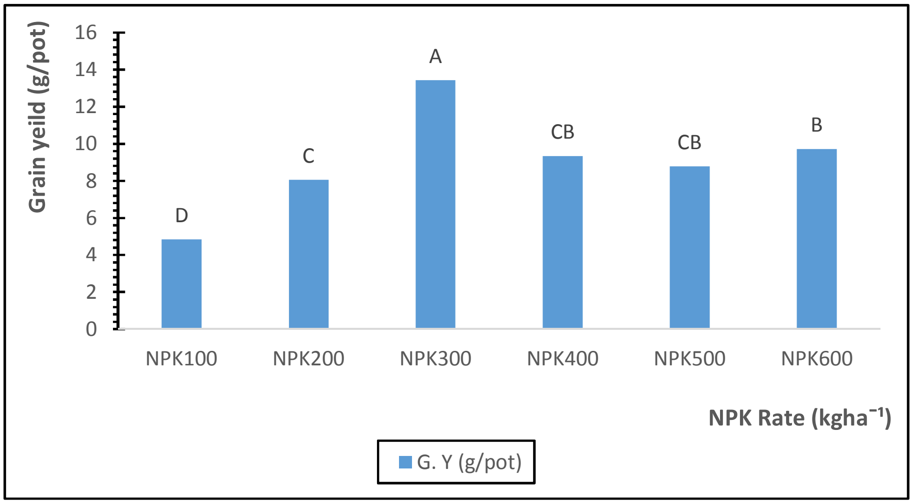

Fig. 2. Mean values of wheat grain yield over the three cropping according to the different rates of NPK fertilizer (*P* = 0.0001)

Table 5. Mean values of tiller numbers at 22, 44 and 66 DAS according to different rates of NPK

NPK rates (kgha^{-1})	Number of tillers		
	22 DAS	**44 DAS**	**66 DAS**
100	2 aA	2 cC	2baBA
200	2 aA	3bcBC	2baBA
300	2 aA	4 aA	4aA
400	2 aA	3 bcBC	4aA
500	2 aA	3bcBC	4 aA
600	2 aA	4 aA	4aA
P > F	0.61	0.002	0.001
C.V. (%)	21.29	28.26	27.97
G.M	1.94	3.14	3.57
ppds $_{0.05}$	0. 39	0.84	0.94

Values with the same letters are simillar statistically for α = 0.05. Uppercase fonts are for comparison in column and lowercases for the lines

Table 6. Mean values of plant height at 22, 44, 66 and maturity stage according to different rates of NPK fertilizer

NPK rate (kgha^{-1})	Height (cm)			
	22 DAS	**44 DAS**	**66 DAS**	**Maturity**
100	24.88 aA	30.88 aA	41.88 aA	49.38 aA
200	24.70 aA	31.38 aA	41.44 aA	48.66 aA
300	22.88 aA	29.38 aA	40.38 aA	47.88 aA
400	22.88 aA	29.11 aA	39.66 aA	47.16 aA
500	26.27 aA	32.27 aA	39.66 aA	47.33 aA
600	28.22 aA	34.72 aA	45.72 aA	53.22 aA
P > F	0.63	0.65	0.73	0.74
C.V. (%)	30.25	24.23	22.24	18.81
G. M (cm)	24.82	31.29	41.46	48.94
ppds $_{0.05}$	7.11	7.18	8.74	8.72

Values with the same letters are simillar statistically for α = 0.05. Uppercase fonts are for comparison in column and lowercases for the lines

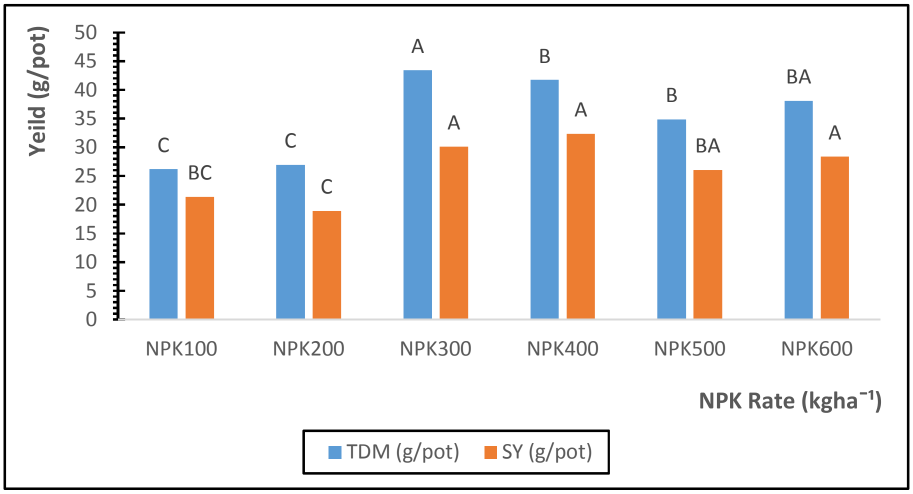

Fig. 3. Mean values of straw yield (SY) and total dry matter (TDM) according to the different rates of NPK fertilizer (*P* = 0.0008 and *P* = 0.0001)

Table 7. Heading rates at 60 and 68 DAS as well as that of the flowering at 68 and 76 DAS according to the different rates of NPK fertilizer

NPK rate ($kgha^{-1}$)	Heading (%)		Flowering (%)	
	60 DAS	68 DAS	68 DAS	76 DAS
100	4.17 bC	51.16 cA	4.17 bC	34.44 cB
200	45.56 aB	84.99 aA	40.50 bB	74.99 baA
300	22.82 baB	77.18 baA	23.81 baB	70.63 baA
400	32.60 aB	70.38 baBA	34.68 bB	82.18 aA
500	29.50 aB	72.58 baA	30.55 aB	66.47 baBA
600	34.92 aB	80.08 baA	27.29 aB	74.64 baBA
P > F	0.05	0.0046	0.049	0.0002
C.V. (%)	72.28	19.70	69.55	23.12
M.G. (%)	28.51	71.70	26.34	66.67
ppds $_{0.05}$	24.15	16.07	21.48	18.07

Values with the same letters are simillar statistically for α = 0.05. Uppercase fonts are for comparison in column and lowercases for the lines

Table 8. Mean values of harvest index (HI) and vigor index (VI) according to the fertilizer rates/pot

NPK rate ($kgha^{-1}$)	HI (%)	VI
100	18.50c	1.32a
200	20.44a	1.45a
300	31.20a	1.62a
400	22.99bc	1.66a
500	25.49bac	1.65a
600	26.32ba	1.90a
P > F	0.005	0.38
C.V. (%)	32.16	17.89
GM	26.27	1.69
ppds $_{0.05}$	8.01	0.28

Values with the same letters are simillar statistically for α = 0.05

4. DISCUSSION

The soil used as substract for the experimentation was roughly low in chemical fertility although sampled from under wood and yet, enriched in organic matter with high ratio of C/N about 15.2 underlining slow rate of mineralization. The base saturation rate was 31.6% characterizing high level of soil leaching. These results are in concordance with [19] statement when asserting that the soil of southern forest zone of Côte d'Ivoire recording more than 1500 mm of rainfall are dystric belonging to Ferralsol class. Of analyze of our results, this situation may have affected soil contents of K and Ca. Yet, there is synergism between Ca and N in one hand [20] and K and N in other hand in addition to that occurring between K and P [21]. Therefore, soil deficiencies in N, K and Ca as observed may have affected the efficiency of applied NPK fertilizer, hence, disturbing the plant physiology. In fact, N/K ratio is conditioning change in physiological stage, especially from vegetative to flowering or fructification (generative) hence, enhancing the effect of photoperiodism [22]. According to the threshold values in soil and wheat leaf [23], this ratio should stand about 25/1 against 1/1 respectively when, decreasing yield is observed for over 34:1 as N:Ca ratio in soil [24]. Thereby, we have contrast between N requirements of N which should have limited availability to fit the optimum ratios. Moreover, N efficiency looks like low when referring to N/K ratio (0.34) though, it should contributed in increase P uptake, especially, for NH_4^+ which may induce rhyzosphere acidification, promoting solubility of some insoluble phosphorus compounds [22,25]. Adoption [13] model of yield according to soil inherent fertility revealed the value of 2.1tha^{-1} meanwhile, harvested yields were higher than 2.1tha^{-1} for the successive cropping cycles respectively. These analyses underlined a good response of wheat to the agro-systemic condition of the current study. In fact, this model should fixe the maximum yield as the potential of the studied soil in the basis of the contents of calcium and magnesium. In contrast, this calculated yield was low than the yield recorded with the effect of NPK fertilizer although, a lowest yield was observed for the rate of 100 kg ha^{-1}.

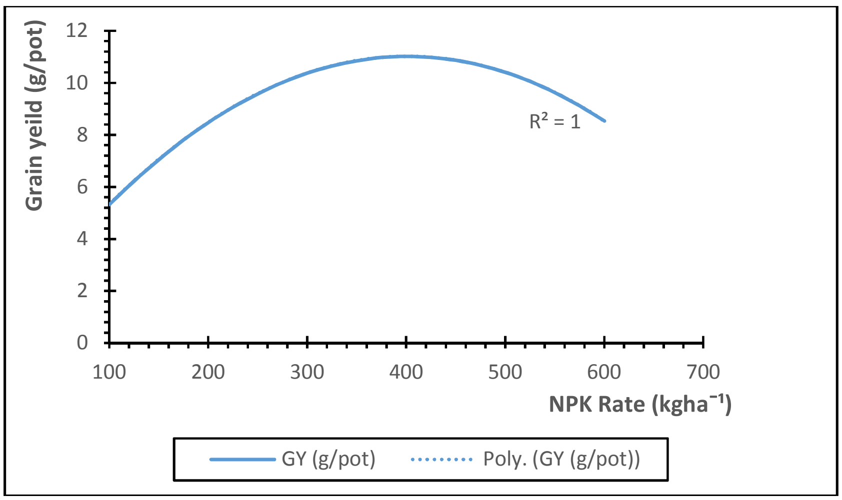

Fig. 4. Response curve of wheat grain yield to the rates of NPK fertilizer

Table 9. Correlation (R) and its probability (P) between GY and HI as well as GY and VI according to different rates of NPK

NPK rate (kgha^{-1})	Parameters	GY	
		R	***P* > F**
100	HI	0.70	0.09
	VI	0.26	0.49
200	HI.	0.28	0.45
	VI.	-0.62	0.07
300	HI.	0.87	0.002
	VI.	0.06	0.02
400	HI.	0.14	0.71
	VI.	0.91	0.49
500	HI.	0.55	0.12
	VI.	0.04	0.47
600	HI.	0.65	0.06
	VI.	0.09	0.62

Table 10. Wheat response curve characteristics to the rates of NPK fertilizer

NPK rate (kgha^{-1})	Response		Standard Error	
	GY (g/pot)	TDM (g/pot)	GY (g/pot)	TDM (g/pot)
100	5.33	24.57	0.69	2.55
125	6.32	26.87	0.58	2.14
150	7.06	28.99	0.50	1.83
175	7.81	30.93	0.45	1.64
200	8.48	32.68	0.42	1.55
225	9.07	34.26	0.42	1.55
250	9.58	35.65	0.43	1.59
275	10.02	36.87	0.45	1.65
300	10.38	37.90	0.46	1.71
325	10.65	38.75	0.47	1.75
350	10.85	39.42	0.48	1.76
375	10.98	39.91	0.47	1.75
400	**11.02**	40.22	0.48	1.71
425	10.98	**40.35**	0.45	1.65
450	10.87	40.30	0.43	1.59
475	10.68	40.06	0.42	1.55
500	10.41	39.65	0.42	1.64
525	10.06	39.05	0.45	1.83
550	9.63	38.28	0.50	2.14
575	9.12	37.32	0.58	2.55
600	8.54	36.318	0.69	2.57
	GY		**TDM**	
	Pr > |t|	**DDL**	**Pr > |t|**	**DDL**
Intercept	0.0001	1	0.0001	1
Linear	0.0011	1	0.001	1
Quadratic	0.0001	1	0.002	1
Model	0.0001	1	0.0001	1
Dose	0.0001	1	0.0001	1

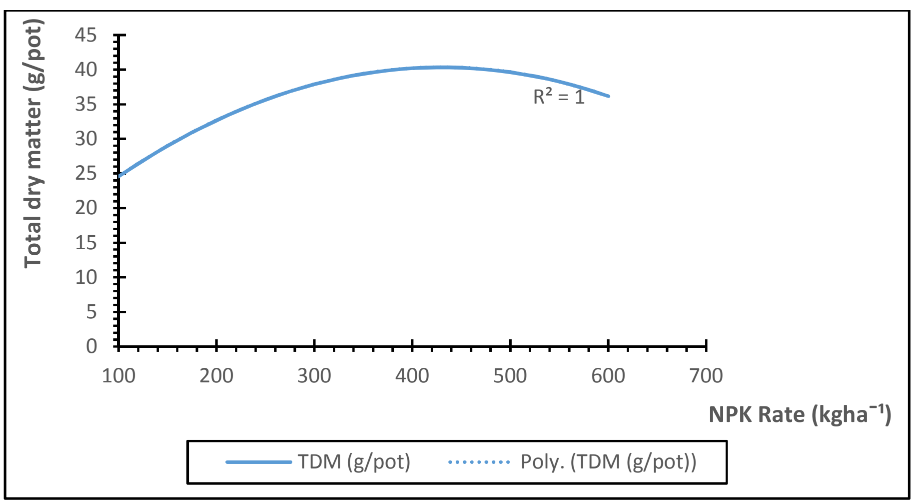

Fig. 5. Response curve of wheat total dry matter to the rates of NPK fertilizer

According to [26], the photosynthesis of the C3 plants decreases beyond 22℃ affecting the growth and the development of the plant. Therefore, the range of air temperature of 25 - 28℃ may account for the low values of plant height (25 – 50 cm) as observed during the experiment in 2015. However, this context has not impaired the emergence (germination), the growth and wheat grain production in the agro-ecology of southern forest zone of Côte d'Ivoire though, air humidity of about 90% could altered the quality of grain replenishment, its nutritional quality and its germination power.

In turn, no significant difference ($P > 0.05$) of grain germination rate was observed between the different rates of NPK fertilizer. These data revealed the inopportunity of fertilizer of wheat grain germination. In fact, [27] asserted that grain germination is corresponding to the tegument leaky by primary root. It is mainly depending to soil moisture and oxygen availabilities as well as air temperature. Therefore, the average air temperature of 26℃ and monthly mean rainfall fluctuating between 153 and 173 mm during the experiment was suitable for wheat grain germination. Moreover, there was no significant difference for the leaf number of plant up to 17 DAS according to NPK fertilizer rates emphasizing the use of grain reserve by seed line of 3 leave stage [28] instead of the applied NPK fertilizer. From these analyses, there is a prove of suitability of the studied pedo climatic conditions for wheat grain germination and growth of the cropped cultivar.

Except for the germination rate and the number of plant leave, the different rates of NPK fertilizer have significant effects on studied parameters. In fact, the tiller number was significantly stimulated by minimum NPK rate of 300 $kgha^{-1}$ and over (Table 5). Thereby, highly significant straw yield and total dry matter productions were observed (Figure 3). However, highest tiller numbers and highest straw yield and total dry matter were accounting for the NPK rates ranging between 300 and 500 $kgha^{-1}$. Yet, the growth consists in irreversible increasing of dimension and weigh of plant organs, hence referring to a quantitative concept [29]. Rational applications of N, P and K may stimulate the phosynthesis process increasing sun light transformation for biomass production. Therefore, promoting the vigor of the plants during the vegetative stages [28,30]. Nevertheless, the mean value of plant vigor index was 1.69 as low value while the leaves were long and heavy for the stand. This aspect of wheat vigor in the South of Côte d'Ivoire underlines the requirement of potassium in addition to phosphorus for rooting and tillering improvement [28] under synergism effect with nitrogen. The highest grain yield as observed for the NPK fertilizer rate greater than 300 $kgha^{-1}$ is relevant not only to the limiting factor concept [31] by also to integrated management of nutrients [32].

The highest grain yield (11.02 g/pot) and total dry matter (40.35 g/pot) obtained with the rate of 400 $kgha^{-1}$ and 425 $kgha^{-1}$ of NPK respectively showed that, nitrogen is important in determining the final grain yield of wheat during the rapid phase of crop development. In fact, nitrogen is required for higher rates of increasing grains and for biomass formation [33].The highest grain yield of any crop is the result of positive relationships of most yield components due to nitrogen fertilizer application. [34] found similar result with pot experiment in southeastern Ethiopia. The air temperature average of 26℃, there is stimulation of emergence and tillering which is requiring an optimum greater than 20°C [35]. But, this temperature deemed high for wheat may impaired grain replenishment because water use for cooling different organs of plant instead of grain filling [36,37,38]. Nevertheless, 11.02 g/pot was recorded as wheat grain yield for 400 kg ha^{-1} of the ternary fertilizer NPK. These analyses underline one more time, the requirement of NPK for wheat mineral nutrition in the climatic conditions of South Côte d'Ivoire. The positive correlation observed between GY and the VI for 400 $kgha^{-1}$ of NPK in table 10 was a consequence of this synergism [21].

5. CONCLUSION

The results of current study emphasized the opportunity of Durum wheat production in climatic conditions of South Côte d'Ivoire. For these conditions, the suitable fertilizer is NPK inducing a maximum yield of 11.02 g/pot when applying 400 $kgha^{-1}$ coupled with 40.35 g/pot of TDM for about 425 $kgha^{-1}$ of NPK.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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