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Nitrogen and Phosphorus Optimization and Agronomic Nutrient Use Efficiency for Improved Wheat Performance

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ABSTRACT: This study was carried out to determine the optimum nitrogen and phosphorus rates for achieving optimum yields and nutrient use efficiency for wheat in highlands of Eastern Uganda. An on station randomized complete block design experiment was conducted at Buginyanya Zonal Agricultural Research and Development Institute. Two varieties Fahari and Pasa were treated with four levels of nitrogen (0, 30, 60, & 90 kg ha^{-1}) and three levels of phosphorus (0, 7.5 &15 kg ha^{-1}). The fertilizer treatments were each replicated three times. The highest grain yield of Pasa and Fahari was 3211kg ha^{-1}, 2726 kg ha^{-1} respectively obtained at a nutrient combination of 60 kg N ha^{-1} and 15 P kg ha$^{-1.}$ The same nutrient combination resulted into highest number of tillers: (Pasa 4 and Fahari 5), kernel per spike of 40 for Pasa and 32 for Fahari. Maximum total kernel weight, spike length and plant height were obtained at 90 kg N ha^{-1} and 7.5 kg P ha^{-1} nutrient combinations. Pasa produced a significantly higher Agronomic Nitrogen Use Efficiency and Agronomic Phosphorus Use Efficiency obtained at 30 kg N ha^{-1} and 7.5 kg P ha^{-1} nutrient combinations, compared to Fahari at the same N and P rates. Optimum N and P fertilizer combination for best grain yield of both wheat varieties tested is 60 kg N ha^{-1} and 15 kg P ha^{-1} combinations.

KEYWORDS: Fahari, grain yield, Pasa, Tillers, bread wheat, Uganda.

1 BACKGROUND

Wheat (*Triticum eastivum.* L*)*, is globally the third most important cereal after maize and rice and the most important cereal of the temperate regions [1]. In sub Saharan Africa, wheat is increasingly becoming a valued grain among the cereals, this is particularly true in East and Central Africa [2]. As a food crop, it is majorly eaten as bread, chapatti, macaroni, spaghetti and other confectionaries. Wheat is adapted to highlands of southwestern and on slopes of Mt. Elgon in the east [3]. It is grown under rain fed conditions in areas at an altitude of 1,500-3,000 metres above sea level with a bimodal pattern of rainfall receiving on average 477 mm of rain fall with relative humidity of 64%. Sustained soil fertility management is an important factor in increasing wheat productivity but this is still a challenge especially in Sub-Saharan Africa [4]. Uganda doubles as one with the highest soil nutrient depletion rates and lowest annual inorganic fertilizer application rate in the world at only 1.8 kg ha^{-1} [5]. Major highland areas where wheat is grown; Mt. Elgon in the East, south west in Kigezi sub-region and Mt. Rwenzori are prone to high soil degradation. Consequently, these areas are characterized by low fertility accruing from high soil nutrient and water losses with events of land slides and flooding [6]. Reversing the situation requires replenishing the soil using strategies that optimize and increase nutrient use efficiency for wheat productivity. Uganda's demand for wheat is higher than its supply and hence largely depends on imports since, wheat farmers are few and face a number of challenges among which is soil fertility management. Currently, Uganda's wheat production is at 20,000t on 14,000ha with productivity of 1.43t ha^{-1} mainly on small plots of 0.1 to 6.5 ha [7]. This is far below the expected global average of 3t ha^{-1} [7]. Furthermore, low soil N and P are becoming of major concerns in wheat production and productivity [8]. With the current practices of continuous cropping systems with little or no soil replenishment, wheat yields are likely to decline. N and P use and management is vital in improving grain yield and their deficiency can significantly limit crop growth and subsequent returns. However, knowledge gaps still exist on optimum N and P rates and efficiency of fertilizer use for wheat in Uganda [9]. Therefore, this study was perceived to determine the optimum N and P rates for achieving best yields and nutrient use efficiency for wheat in highlands of Eastern Uganda.

2 MATERIALS AND METHODS

2.1 DESIGN OF EXPERIMENT

A field experiment was conducted in 1st season from October to January 2013 to 2nd season from March to June 2014 on wheat varieties grown in Uganda. The wheat was grown at Buginyanya Zonal Agricultural Research and Development Institute (BugiZARDI) and soils in the study site were sandy clay loam. Four levels of nitrogen (0, 30, 60 & 90 kg N) and three levels of phosphorus (0, 7.5 & 15 kg P) were applied in form of urea and triple super phosphate. All the phosphorus was applied at planting and nitrogen was applied in two splits of half dozes: one at planting and the other at about 28 days prior to stem elongation (Zadoks 30) [10] . Plot size was 5 m by 3 m with inter-row spacing of 0.3 m and continuous within row spacing. The experiment was laid out in a randomized complete block design (RCBD) with three replicates. Wheat varieties; Pasa - a hybrid and Fahari - a local check with a seed rate of 120 kg ha^{-1} were sown in eleven rows on 5th of October for first season and 24th March for second season. The crop management practices mainly included; weeding which was done twice for the two seasons.

2.2 PLANT SAMPLING AND DATA COLLECTION

2.2.1 NUMBER OF TILLERS PER PLANT, FLAG LEAF AREAS (CM^2) AND PLANT HEIGHT

Five plants were sampled from each plot leaving out one border row on each side of the plot, then number of tillers was counted and recorded. The values were added and divided by five to get the average number of tillers per plant at flowerings which were used in statistical analysis.

Flag leaf area was recorded at 50% flowering using a tape measure by selecting in situ five plants leaving out one border row on each side of the plot. Flag leaf is the upper most leaf of the wheat plant that contributes 75% of grain filling in wheat through the process of photosynthesis [11]. Measurements included leaf length from the apex to the inflorescence base and leaf width across the widest part of the leaf. Length and width were multiplied to approximate leaf area. The values were averaged to get the average leaf area for each plot and data used in subsequent statistical analysis.

Plant height was recorded at ripening stage when the kernel was hard and difficult to divide by selecting in situ five plants from each plot leaving out one border row on each side of the plot. Measurements were done in centimeters using a tape measure from ground level to the spike top and values were averaged per plot for subsequent statistical analysis as described by [12].

2.2.2 SPIKE LENGTH, TOTAL KERNEL WEIGHT, KERNEL PER SPIKE AND GRAIN YIELD:

At physiological maturity when the grain reached maximum dry weight and the peduncles were ripe, five spikes were selected per plot and harvested for data collection. These were weighed to get the total kernel weight using an electronic scale (model specification EKO1). Spike length was measured using a tape measure. Each spike was threshed using hands and counting of the kernels was done. Values of each parameter were averaged per plot for subsequent statistical analysis.

Harvesting was done at harvest maturity when the kernel was hard, could not be dented by a thumb nail and all the glumes where dry. Grain yield (kg ha^{-1}) was recorded for nine rows (12 m^2). Spikes harvested from each plot were weighed using a spring balance before threshing. Threshing was done manually to get grains, which were further sun-dried to moisture content of 12.5% and then weighed again using a digital scale as described by [13].

2.2.3 NUTRIENT USE EFFICIENCY CALCULATIONS

Nutrient agronomic efficiency (AE) at different fertilizer rates was computed as described by [14];

$$AE = \frac{(Y - Yo)}{F} \qquad \text{(Equation 1)}$$

Where: Y = yield from treated plot (kg ha^{-1}); Yo = yield from control plot (kg ha^{-1}) and F = amount of fertilizer applied (kg ha^{-1})

2.3 DATA ANALYSIS

The data was subjected to one way analysis of variance (ANOVA) test using Gen Stat Edition 12. Significant means were separated using Least Significance Difference (LSD) at 5% significance level.

3 RESULTS

3.1 EFFECT OF N AND P ON THE GROWTH AND YIELD PARAMETERS OF FAHARI AND PASA BREAD WHEAT VARIETIES

3.1.1 NUMBER OF TILLERS PER PLANT, FLAG LEAF AREA (CM^2) AND PLANT HEIGHT

Application of N and P had no significant effect (P > 0.05) on leaf area of Fahari and Pasa varieties at 50% flowering (Table I) but the effects were significant (P < 0.05) at tillering and on plant height. (Fig. 1 & 2) (Table I). Interactive application of 60 N and 15 P kg ha^{-1} increased tillering up to a peak of five and four tillers per plant for Fahari and Pasa respectively. Beyond the peak point, tillering responded negatively especially at the highest N and P application rates. Overall, the 60N rate emerged superior when combined with 15 kg of P ha^{-1} for Fahari and either 7.5 or 15 kg P ha^{-1} for Pasa at the same N rate. Plant height continuously increased up to maximum of 91.9 and 86.3 cm which was obtained at 90 and 90N-7.5P kg ha^{-1} for Fahari and Pasa respectively. The plant height of Fahari was higher than that of Pasa and all plant heights were significantly different from the control treatment apart from at 0N and 7.5P and 0N and 15P kg ha^{-1} for all the two varieties.

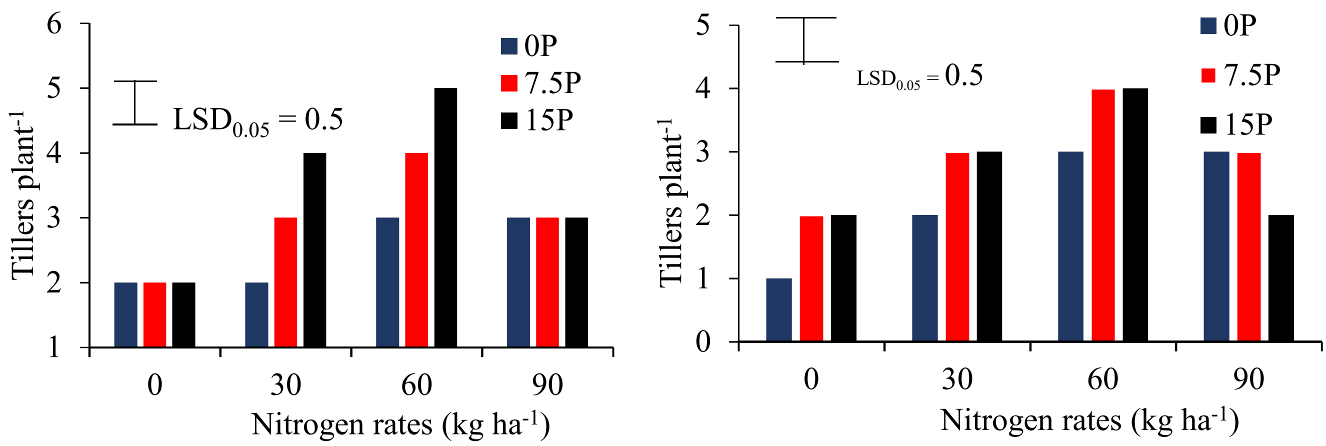


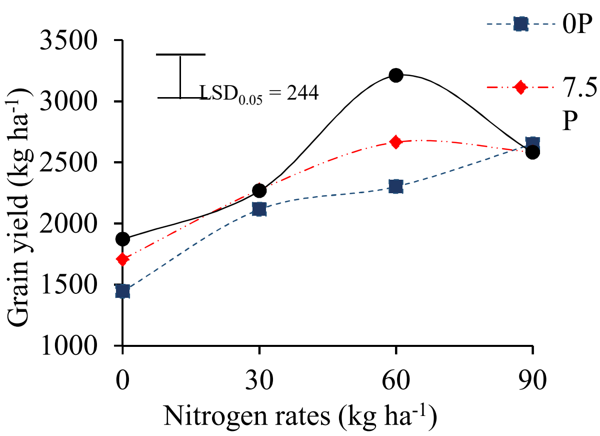
Fig. 1& 2 Interactive effect of N and P rates on number of tillers of Fahari and Pasa bread wheat varieties at 50% flowering at BugiZARDI in Eastern highlands of Uganda

3.1.2 SPIKE LENGTH, TOTAL KERNEL WEIGHT, KERNEL PER SPIKE AND GRAIN YIELD

Application of N and P had a significant (P < 0.05) effect on plant spike length, total kernel weight, kernel per spike and grain yield of Fahari and Pasa varieties (Fig 3 & 4), (Table I). Spike length for the two varieties continuously increased at a marginal rate, with increase in N and P combinations up to a maximum of 9.3 and 8.7 cm at 90 N and 7.5 kg ha^{-1} for Fahari and Pasa. Application of 30 and 60 kg N ha^{-1} resulted into significant increase in spike length of both varieties at all P rates when compared with control treatments. Total kernel weight of Fahari and Pasa increased with increase in N and P up to a maximum of 1.85 and 2.4 g. Application of 15 kg P ha^{-1} at 0 kg N ha^{-1} resulted into a substantial increase in TKW, though further increase in N did not show much effect until at 90 N with 7.5 P kg ha^{-1}, where TKW reached the peak for both varieties. Although the effect of P was marginal, that of N was marked within the N and P combinations for for both varieties on KPS. The 60 kg N ha^{-1} significantly (P < 0.05) increased KPS up to maximum of 32 and 40 at 15 than 7.5 kg P ha^{-1} for Fahari and Pasa respectively. Grain yield increased up to a maximum and then reduced, though response with 0 P was quiet variable for all N rates. The 7.5 kg P ha^{-1} caused a significant spike in yield, which was statistically similar to that of 15 kg P ha^{-1} at 0 N, for Pasa. On the other hand, 15 kg P ha^{-1} caused a significant increase in yield, which was significantly different from 7.5 kg P ha^{-1} for Fahari. Interactive application of the nutrients caused a remarkable increase in yield at 60 N and 15 P kg ha^{-1}, which was significantly different from 7.5 kg P ha^{-1} at the same N rate. The highest N rate (90 kg ha^{-1}) showed no significant difference for all P rates but depressed grain yield at 15 kg P ha^{-1}.

Table 1. Effect of N and P on growth and yield parameters of Fahari and Pasa bread wheat varieties

Varieties	Nitrogen (kg ha^{-1})	Phosphorus (kg ha^{-1})	Leaf area (cm^2)	Plant height (cm)	Total kernel weight (g)	Spike length (cm)	Kernel spike^{-1}
Fahari	0	0	16.5	70	1.043	7.08	19
		7.5	19	76.8	1.207	7.457	21
		15	20.5	80.7	1.278	7.703	25
	30	0	23.9	82.3	1.352	7.817	26
		7.5	25	83.6	1.502	7.945	26
		15	27.9	86.7	1.453	8.162	28
	60	0	28.3	84	1.515	8.273	28
		7.5	32	89.2	1.645	8.32	30
		15	34.7	90.9	1.633	8.687	32
	90	0	28.5	91.9	1.732	8.697	28
		7.5	27.8	91.5	1.852	9.277	28
		15	28.9	90.5	1.788	8.593	28
	LSD		ns	11.9	0.24	0.6	3
	CV%		46.3	12.2	13.6	6.6	10.1
Pasa	0	0	20.8	70.07	1.186	6.593	25
		7.5	22.3	72.47	1.325	7	27
		15	25.6	76.53	1.453	7.223	28
	30	0	29.3	77.6	1.617	7.543	32
		7.5	29.5	78.6	1.723	7.82	33
		15	31.7	78.53	1.737	7.923	34
	60	0	31.7	80.03	1.807	7.998	35
		7.5	35.7	83.1	1.842	8.08	36
		15	37.9	85.13	1.863	8.353	40
	90	0	33.2	85.87	2	8.24	36
		7.5	33.9	86.27	2.408	8.658	35
		15	33.6	82.45	1.975	8.127	36
	LSD		ns	7.7	0.2	0.94	6
	CV%		43.3	8.4	11.2	10.4	14.7



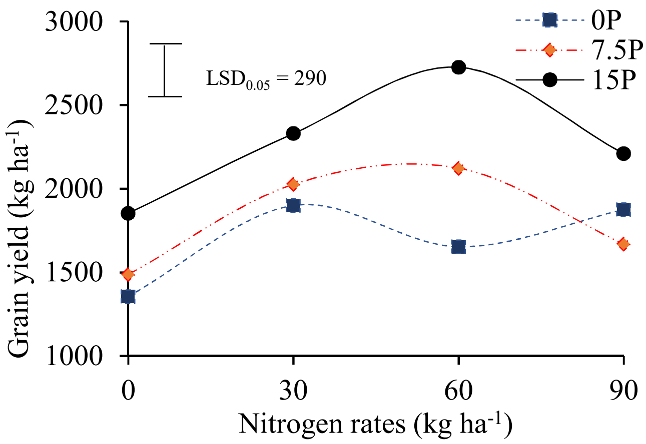


Fig. 3 & 4 Interactive effect of N and P rates on grain yield of Fahari and Pasa varieties at BugiZARDI in Eastern Highlands of Uganda

3.2 AGRONOMIC NITROGEN USE EFFICIENCY

The unit increase in grain yield per unit of nitrogen applied (agronomic nitrogen use efficiency) (AE_N) of Fahari and Pasa UW400 bread wheat varieties was significantly influenced ($P < 0.05$) by amount of N applied (Table 3). AE_N decreased with increase in N application and reaching a peak at 30 kg N ha^{-1} for both varieties. Increasing N to 60 kg ha^{-1} resulted into a lower value, which was significantly different from that obtained at 30 kg N ha^{-1} for both varieties. A higher rate of N (90 kg N ha^{-1}) further decreased AE_N which was significantly different from that obtained at 60 kg N ha^{-1}.

3.3 AGRONOMIC PHOSPHORUS USE EFFICIENCY

The unit increase in grain yield per unit of phosphorus applied (agronomic phosphorus use efficiency) (AE_P) of Fahari and Pasa was significantly influenced ($P < 0.05$) by application of P (Table 2). Generally, AE_P increased up to a maximum then reduced. The highest AE_P was attained at 7.5 kg P ha^{-1} for both varieties. Increasing P to 15 kg P ha^{-1} resulted into a substantial decrease of 40% in AE_P for Pasa. However, Fahari showed no significant decrease in AE_P at 7.5 and 15 kg P ha^{-1}.

Table 2. Agronomic nitrogen and phosphorus efficiencies of bread wheat varieties in the highlands of Eastern Uganda

n = 216

Agronomic Nitrogen use Efficiency (kg kg^{-1})						
	Nitrogen rates (kg ha^{-1})					
Varieties	**0**	**30**	**60**	**90**	**$LSD_{0.05}$**	**CV%**
Fahari	0	24.3*	14.5*	6.7*	4.4	20.0
Pasa	0	25.8*	21.4*	12.9*	4.1	4.3
Agronomic Phosphorus Use Efficiency (kg kg^{-1})						
	Phosphorus rates (kg ha^{-1})					
	0	**7.5**	**15**	**$LSD_{0.05}$ CV%**		
Fahari	0	62.7ns	61.6ns		16.3	17.6
Pasa	0	115.1*	69.2*		22.6	14.4

**significant at $P < 0.05$ from each other for comparisons along the rows, ns- not significant at $P < 0.05$*

4 DISCUSSION

4.1 EFFECT OF N AND P ON THE GROWTH AND YIELD PARAMETERS OF FAHARI AND PASA BREAD WHEAT VARIETIES

4.1.1 NUMBER OF TILLERS PER PLANT AND PLANT HEIGHT

The significant effects of N and P on the number of tillers per plant, irrespective of varieties (Fig. 1 & 2), is evidence that these nutrients were deficient in the study soil. The effect of N on tiller development in wheat, has not been quiet visible as has been the case with rice. The physiological effect of N in regulating rice tiller development is rooted in the fact that external N application suppresses indole-3-acetic acid (IAA) the latter of which suppresses tiller development [15]. On the other hand, [16] asserted that enhanced tillering in wheat was due to the positive effect of N application on the biosynthesis of cytokinins induced particularly by application of ammonium-N, such liberal provision of N to wheat is necessary at the experimental site in order to achieve maximum tillering.

With respect to P, the positive effect on tiller development across varieties has been documented. For instance, [17] reported marked increase in wheat tiller emergency, survival and yield as a result of P application. A similar observation was made earlier when P deficiency decreased the maximum and final number of tillers in wheat [18], [19]. Therefore, research efforts geared at synchronizing the synergistic benefits from N and P management are needed particularly for production of wheat in Uganda. There was no change in tillering when P was applied without N, for Fahari. This indicates that Pasa is more sensitive to the single effect of P than Fahari. The non- response to P observed from Fahari variety may be attributed to insufficient P levels that were applied. According to [20] while working on wheat, P deficiency reduced maximum rate of tiller emergency by increasing phyllochron.

The occurrence of the maximum tillering of both varieties at 60 N and 15 P, implies that those are the optimum levels of nutrient supply to wheat in the study area. Tillering has been linked variously to grain yield for different research on wheat [21], [22]. With respect to plant nutrition, high N and P application rates suppressed number of tillers probably due to reduced number of nodes. Reference [23] while working on wheat, reported that high N produces tall and succulent culms and increases the length of basal internodes, which contribute to lodging.

The significant effect of simultaneous application of N and P on plant height of Fahari and Pasa wheat varieties, indicates that application of the two nutrients plays an important role in plant growth. The plant height of Fahari was higher than that of Pasa, this is because Fahari is a tall variety while Pasa belongs to the dwarf category, according to the breeder's characterization [24]. The response of plant height to N and P was at variance with that of tillering. Whereas the maximum of tillering was obtained at 60 N and 15 kg ha^{-1}, that of plant height was at 90 N and 7.5 P kg ha^{-1}. This implies that the plant requires more N to sustain plant growth in terms of plant height than tillering. The reduction of P requirement for plant height shows that a lower amount of P is required for reaching maximum plant height. These findings are similar to what was reported by [25], where application of N significantly increased plant height up to maximum.

4.1.2 SPIKE LENGTH, TOTAL KERNEL WEIGHT, KERNEL PER SPIKE AND GRAIN YIELD

The significant effect of N and P on spike length of Fahari and Pasa wheat varieties, indicates the importance of those nutrients on increasing crop biomass of the two varieties. The marginal rate of increased in spike length when fed with N and P suggests that, large amounts of nutrients are required to cause substantial increase in spike length. The maximum spike length obtained at 90 N and 7.5 P kg ha^{-1} shows that those are the rates for achieving peak spike length. These results are similar to what has been observed under plant height, where maximum plant height was also obtained at the same rates of N and P. These findings are similar to what was reported by [26], [27]), where spike length was significantly influenced by N nutrition in the soil.

The significant effect of N and P on total kernel weight (TKW) of Fahari and Pasa implies that increased nutrition influences grain yield. This is so because a strong relationship has been variously reported between total kernel weight and grain yield [28] [29]. The TKW of Pasa was higher than that of the local check variety Fahari, which shows that Pasa is more superior TKW than Fahari. The response of TKW to N and P nutrition was similar to that of plant height and spike length but, at variance with that of tillering. Whereas, the optimum tillering was achieved at 60N and 15P kg ha^{-1}, the optimum point for TKW was attained at 90 N kg ha^{-1} and 7.5 P kg ha^{-1} for both varieties. This could be explained by the fact that, for the plant to be able to satisfy the nutrient needs during seed development, greater nutrient supplies are required to cater for both post flowering vegetative growth and ultimate grain yield. For the grain to develop to full capacity, the green parts of the plant had to continue with the necessary demand for nutrients as well, hence resulting into better TKW performance at 90 kg N ha^{-1} than at 60 kg N ha^{-1}.

On the other hand, the revers trend in relation to P nutrition, at both stages of growth, is difficult to explain within the scope of this study. Nevertheless, it can be speculated that at the time of TKW assessment, the P requirement by the plant had dropped dramatically basing on the school of thought that by the time a plant attains 25% of its biomass, it is supposed to have acquired 75% of its P requirement [30]. Therefore, at the TKW stage of growth, the crop is expected to be largely dependent on its internal P sources. This submission requires empirical investigation, as it bears on the nutrient acquisition and remobilization ability of Fahari and Pasa. It has been reported that, N and P improves growth of awns and the grain filling process, all which contribute to TKW. For instance, [31], while working on wheat in Pakistan, reported that TKW responded positively to N and P application.

The significant response of Fahari and Pasa bread wheat varieties (Table I) in terms of kernels per spike (KPS) when fed with N and P is evidence that, fertilizer use is technically beneficial particularly in increasing kernel numbers. Number of kernels per spike is an important trait in yield assessment by wheat breeders [32] [33]. On the other hand, contrasting results are also often evident when total grain yield is dependent on number of kernels as well as their sizes, and sometimes shapes [34]. In terms of N and P nutrition, the greater response to N by both varieties, seems to imply that N was more limiting to growth than P. [35] in Pakistan, reported that application of different rates of N to the soil significantly affected KPS of newly evolved wheat cultivars. Maximum KPS was obtained at 60 N and 15 P kg ha^{-1}, suggesting that this is the optimal nutrient combination.

The significant effect of N and P combinations on grain yield of the two wheat varieties (Fig 3 and 4), shows the role of translocation of assimilates from vegetative parts into grain, which reflects on the grain filling abilities of the two varieties. Increasing soil N supply increases leaf area, leading to enhanced photosynthesis, which results into higher grain yield. Like in the case of number of tillers and kernels per spike (Fig. 1 and 2), (Table I), the maximum grain yield was obtained with 60 N and 15 P kg ha^{-1} for both the study varieties. This, apart from conforming to the close bio-physiological relationships among the three parameters as alluded to by [36], [33], implies that they constitute the optimum combination that should be recommended to the wheat farming communities in Eastern Uganda. However, this level of performance of the nutrient combination requires systematic economic evaluation before they are considered as recommendations to farmers. These findings are contrary to what was earlier reported in the present study under number of tillers per plant, where Fahari emerged superior of the two varieties. This implies that, a variety having a high number of tillers per plant does not certainly result into more grain yield. According to [37], while working on Inqlab-91 wheat variety in Pakistan, application of P significantly increased grain yield.

Higher N rates with P combinations depressed grain yield presumably due to increased vegetative growth which was observed in the total dry matter yield of this study. Increasing N beyond optimal depresses grain yield due to toxicity or deficiency of another nutrient, which affects phyto-hormonal concentration, thus resulting into reduced grain yield. Correspondingly, [38] observed that high levels of N resulted into productivity of more leaves and their persistence because of having high amounts of current photosynthesis which decreased amount of redistribution. In light of the above results, Pasa is a high yielding variety which should be multiplied and disseminated to farmers. However, there is need for further studies on economic returns of using fertilizer N and P combination and resistance to rust diseases (Ug99) which is of major concern in Uganda.

4.2 Agronomic nitrogen use efficiency

The significance of N as reflected by the agronomic nitrogen use efficiency (AE_N) in the two study wheat varieties of Fahari and Pasa (Table II), shows that the status of N in the soil prior to its application, was low. Generally, Pasa had the highest AE_N, while Fahari had the lowest value. With N application rates greater than 30 kg ha^{-1}, Fahari and Pasa varieties maintained significantly different AE_N values while UW400 showed no response. The continued presence of significant responses to N application beyond 30 kg ha^{-1} for Fahari and Pasa, could be due to uniqueness in their genetic composition. It could also be due to differences in root architecture [39], with them having better developed rooting systems that were able to capture nitrogen from a bigger volume of soil. Values of AE_N in the current study were lower than those reported by [40],[41] who worked on wheat and maize in India and Uganda respectively. On the other hand, these values are within expected values >25 kg ha^{-1} for well managed systems or at low soil N supply as observed by [42]. This implies that N in the study site was low and for higher efficiencies, N precision management is a requisite.

4.3 Agronomic phosphorus use efficiency

The significant effect of P on the agronomic phosphorus efficiency (AE_P) of Fahari and Pasa (Table II), shows that those varieties are able to utilize given unit amount of P into grain yield. The most important P is the plant available P, which affects how a plant responds to fertilizer P. In the tropics, there are moderate to high P-fixing soils which have low P content [43]. Therefore, targeting fertilizer application at rates that optimize its use efficiency is very essential, especially with limited P deposits. Considering the study site, the pH (5.95) was within suitable range for wheat production and organic carbon (3.81) was high which contributed to P availability in the experimental site. Application of N can increase P uptake in plants by increasing root growth, ability of roots to absorb and translocate P, and by decreasing soil pH as a result of absorption of $NH4^+$ and thus increasing solubility of fertilizer P. This phenomenon also applies in this current study because application of P was done simultaneously with N. In study done by [44], the wheat root system may be able to use nutrients at a depth of 120 cm and use of varieties with greater capacity for nutrient use contribute to increase in nutrient uptake and thus high yields. Likewise, [45] reported that grain P uptake by wheat is a function of yield rather than changes in grain P concentration.

The highest AE_P was attained at a low rate of 7.5 kg P ha^{-1} for both varieties, this suggests that both varieties perform better (more efficient) under low levels of P. This can be attributed to their genetic capacities in P utilization, environmental and management factors (e.g. temperature). In a previous study done by [46] on wheat in Mexico, the yield increasing effect of the dwarfing genes led to improved phosphorus utilization efficiency and total uptake. AE_P in this study could have been influenced by the dwarfing genes and since Pasa belongs to the semi dwarf category, that recorded high AE_P. On the contrary, [47] reported that having a high AE_P does not always mean efficiency, but rather positive efficiency would indicate that a variety has proportionally more grain yield than P content. This means that determining AE_P is not enough to convincingly tell that a variety is efficient but, rather there is need to determine nutrient recovery and physiological efficiencies. Results in this present study are higher than what was reported by [48] in a study done in Kenya on maize, where AE_P ranged from 20 to 40 kg kg^{-1}. This shows that, nutrient efficiency highly varies with different environments.

5 Conclusions and recommendations

From this work, soft wheat varieties perform best with application of 60 kg N and 15 kg P ha^{-1} in the highlands of Eastern Uganda. However, it is recommended that field trials are conducted to verify these on station results, and the associated economic viability before they are scaled out to the farming communities. In terms of wheat varieties, Pasa was the most responsive to fertilizer N and P, giving the highest grain yields at 60 kg N and 15 kg P ha^{-1}. This variety should be multiplied and together with the fertilizer combinations disseminated to farmers involved in wheat production. Pasa is able to give reasonable yields under low N (30 kg N ha^{-1}). Therefore, it is recommended for the low N input systems including the small scale wheat growers in the region, with low P. However, it is important that recovery and physiological efficiencies of these varieties are determined to be able to conclude which of them is more efficient.

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