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Enhancing economic significance and yield response of hot pepper (*Capsicum annuum L.*) through urea and NPS fertilizers application under irrigation in Abergelle, Waghimra, Eastern Amhara

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ABSTRACT

Hot pepper (Capsicum annuum L.) is a globally significant spice crop, but nutrient deficiencies often hinder its productivity. To address this issue, an experiment was conducted in 2019 and 2020 under irrigation in the Abergelle district of Wag-himra, eastern Amhara, Ethiopia. The objective was to determine the optimum and economically feasible fertilizer rates for sustainable hot pepper production. The trial consisted of four rates of urea (0, 100, 150, and 200 kg ha^{-1}) and three rates of NPS (0, 100, and 150 kg ha^{-1}) with factorial combination in Randomized Complete Block Design (RCBD) with three replications. It was conducted in a plot size of 17.64 m^2 with Mareko Fana variety and irrigated by 5 day intervals under furrow irrigation method with farmer practice water depth. The collected data exposed to analysis of variance using R software version 4.0.5, and mean separation was performed using the Duncan multiple range test (DMRT). The findings of the study demonstrated that the application of urea and NPS fertilizers had a significant influence on growth and yield parameters of hot pepper including plant height, number of pods, pod weight, and green pod yield. The highest green pod yield of 13.86 t ha^{-1} was achieved through the combined application of 150 kg ha^{-1} urea and 150 kg ha^{-1} NPS. A substantial yield of 12.98 t ha^{-1} was obtained using 100 kg ha^{-1} urea and 150 kg ha^{-1} NPS. Cost-benefit analysis also revealed that, in the Abergelle district's Beltarf irrigation command area during the irrigation season, the optimal rates for maximizing green pod pepper yield were 150 kg ha^{-1} urea and 150 kg ha^{-1} NPS, with an alternative option being 100 kg ha^{-1} urea and 150 kg ha^{-1} NPS.

1. INTRODUCTION

Hot pepper (*Capsicum annum* L.) belongs to the genus Capsicum of Solanaceae family. It is one of the most important spice crops widely cultivated around the world for its pungent flavor and aroma (Ikeh et al., 2012). Hot pepper can also contribute the food security of smallholder farmers; hence source of income (Aliyi, 2019). The total area of green pod pepper production was estimated at about 7449.59 and 1331.46 ha, with a total production of 45853.7 and 8521.1 t in the average productivity of 6.2 and 6.4 t ha^{-1} in Ethiopia in general and in Amhara region in particular, respectively. Whereas, the attempts of green pod hot pepper production in Waghimra zone was 27.65 ha in a total production of 68.2 t with an average productivity of 2.5 t ha^{-1} (CSA, 2016). This shows that the productivity in the study area is much lower compared to the national and regional production. Poor agronomic management practices at nursery and field conditions challenges to the productivity of hot pepper. These challenges include inadequate and imbalanced nutrient supply, diseases, inadequate aeration, and the absence of high-yielding cultivars. Among these constraints, nutrient deficiency stands out as the primary factor limiting vegetable crop production in Ethiopia, as emphasized by Alemu and Ermias (2000).

Chemical fertilizers play a crucial role as the primary sources of nutrients for enhancing crop productivity (Tamene et al., 2017). Applying NPSB and urea fertilizers significantly enhances hot pepper yield and economic significance (Muhie et al, 2023; Mensa et al., 2023). Farmers faced challenges in enhancing yield and reducing agricultural production without implementing tailored fertilizer management strategies (Hartono et al., 2022; Susila and Suketi, 2023). Plant nutrients have a vital role in improving crop production and productivity on a sustainable basis; fertilizers are an effective source of plant nutrients. Akram et al. (2007) and Assefa et al. (2020) emphasized the use of higher rates of urea and NPS fertilizers proved to be a valuable practice for maximizing hot pepper production and ensuring a profitable harvest. Knowing crop and site-specific recommendations of fertilizers are ideal for the production of hot pepper. Site specific recommendation take into account the specific nutrient needs of hot pepper and the characteristics of the growing site. Additionally, it also helps farmers to minimize the cost of fertilization and environmental contamination, promoting sustainable agricultural practices. Hence, this study was aimed to determine optimum and economical feasible urea and NPS fertilizer rates for sustainable production of hot pepper in Abergelle district of the Waghimra zone in eastern Amhara.

2. MATERIALS AND METHODS

2.1. Description of the study area

The study was carried out in 2019 and 2020 at Beltarf irrigation scheme, Abergelle district, Waghimra Zone in Amhara Region under irrigation (Figure 1). The command area of the irrigation scheme covers 32 ha. The climate of the area is categorized by unimodal rainfall, with a relatively high amount of rainfall in July and August. The area experiences a mean annual rainfall of 622.37 mm. This precipitation exhibits erratic and uneven distribution across seasons and years. It has a mean annual air temperature of 24.54°C, with mean minimum and maximum temperatures recorded as 19.19°C and 36.08°C, respectively

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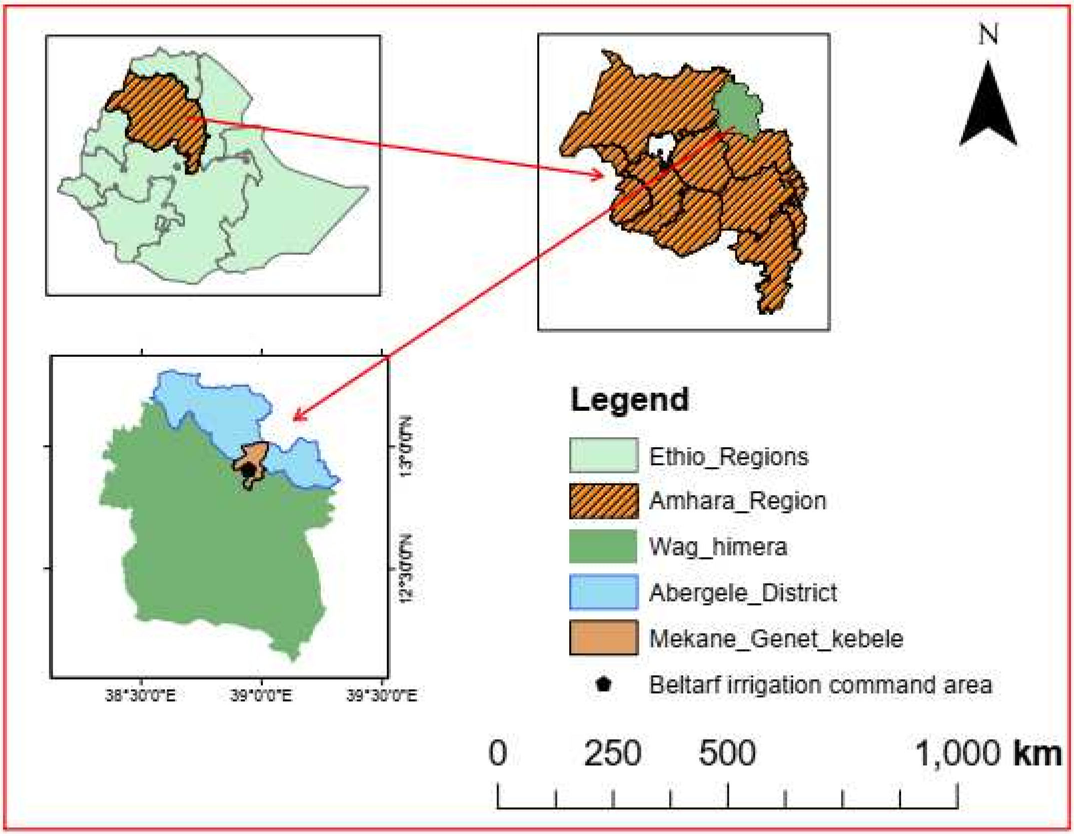

Figure 1: Map of the study area

2.2. Soil sampling, pre-processing and analysis

The representative composite soil samples were collected before planting from a depth of 0–20 cm. It was air dried, ground, and sieved to the required sieve size for the analysis of texture, pH, organic matter, total nitrogen, and available P following the standard procedure. The determination of particle-size distribution was done using the hydrometer procedure (Sahlemedhin and Taye, 2000). Organic carbon was determined by the wet digestion method (Walkley and Black, 1934). The Kjeldahl technique was used to assess the total nitrogen levels (Horneck et al., 2011). The pH of the soil was determined using a

1:2.5 soil sample to water ratio using a digital pH meter, and available phosphorous was determined by Olsen's method (Olsen et al., 1954).
Based on laboratory results, the texture of the soil is grouped as sandy clay loam; the pH of the experimental site was 7.05, which was neutral and suitable for pepper production (Murphy, 1968; Tekalign, 1991). Total nitrogen, available phosphorus, and organic carbon in the soil were rated as very low, low, and low, respectively (Olsen et al., 1954; Murphy, 1968; Berhanu, 1982; Tekalign, 1991) (Table 1). This showed that the application of external input can increase the total nitrogen, available phosphorus, and organic matter. The electrical conductivity of the soil was low, which indicates the soil was free from salt (Landon, 1991).

Table 1: Selected physico-chemical properties of the soil at the experimental field

Soil properties	Values	Rating
pH (by 1:2.5 soil water ratio)	7.05	Neutral
Total nitrogen (%)	0.01	Very low
Available phosphorus(ppm)	0.84	Low
Organic carbon (%)	1.05	Low
Electrical conductivity(mS/m)	0.42	Low
Sand (%)	64	Sandy clay loam
Clay (%)	20	
Silt (%)	16	

2.3. Experimental design and treatments

The experiment consisted of four levels of urea (0, 100, 150, and 200 kg ha^{-1}) and three levels of NPS (0, 100, and 150 kg ha^{-1}) fertilizers in factorial combination in RCBD with three replications (Table 2).

Table 2: Fertilizer amounts in kg ha^{-1} involved in each treatment

No.	Treatments	N:P_2O_5:S
1	Urea 0+NPS 0	0:0:0
2	Urea 0+ NPS100	19 : 38:7
3	Urea 0+NPS150	28.5:57:10.5
4	Urea 100+NPS0	46:0:0
5	Urea 100+NPS100	65:38:7
6	Urea 100+NPS150	74.5:57:10.5
7	Urea 150+NPS0	69:0:0
8	Urea 150+NPS100	88:38:7
9	Urea 150+NPS150	97.5:57:10.5
10	Urea 200+NPS0	92:0:0
11	Urea 200+NPS100	111:38:7
12	Urea 200+NPS150	120.5:57:10.5

2.4. Experimental procedures

Mareko Fana hot pepper variety was used as a test crop due to its adaption to the agro-ecology and high yielding in the study area. The plot size of the experiment was 17.64 m^2 (4.2 m width and 4.2 m length), it accommodates six rows and 14 plants per row with a spacing of 0.3 and 0.7m, between plants and rows, respectively. The seedlings were raised on a seedbed with a length of 5 m and a width of 1 m by hand drilling the seeds at an inter-row spacing of 15 cm and mulched with grass. The seeds were treated with Apron Star before sowing at a rate of 10 grams per 4 kilograms of seed. This treatment aimed to prevent diseases such as damping-off and root rot, as well as control pests like aphids. After the seedlings became 3–4 leaf stages, healthy and vigorous seedlings were transplanted to the well-managed and prepared farmland. The full dose of NPS and half of urea fertilizer was applied two weeks after transplanting of the seedling and the remaining urea fertilizer was applied after 35 days of the first application. The experiment was irrigated at 5 day intervals in the furrow irrigation method (Wale and Girmay, 2019). The amount of water applied to irrigate the pepper plants was based on the farmers' experience.

2.5.Data collection

The agronomic data were collected from the net harvestable plot by excluding one border row from each side and two plants from each end of the row. Growth parameters (plant height) and yield and yield component parameters (numbers of pods per plant, pod weight, green pod yield (t ha^{-1}) were collected. Plant height, pod weight, and number of pods per plant were collected from the five randomly selected plants, while green pod yield was collected from the entirely net-harvestable rows and converted into hectare. The plant height was measured at the time of the third harvest. Before counting the pod number, randomly selected plants were leveled at the time of the first harvest, and measurement was taken following the harvest. The green pod yield was harvested in three phases based on the maturity of the hot pepper.

2.6.Partial budget analysis

To consolidate the results obtained from statistical analysis, an economic analysis was conducted. For economic analysis, cost and return, and MRR were calculated. The actual green pod yield was adjusted down by 10%. The costs that vary among all the treatments were fertilizer cost. Based on the current market, the value of 1 kg green pod was 40 ETB and the cost of 1 kg urea and NPS fertilizers were 14.82 and 14.96 ETB, respectively. Net benefit (NB) and MRR (%) were calculated by setting the treatments in increasing order based on the variable cost. The economic analysis was done based on the formula developed by CIMMYT (1988).

2.7. Data analysis

The combined analysis of variance (ANOVA) over year was carried out for the growth, yield, and yield components using R software version 4.0.5. Treatment effects were significant, the mean separation was done by Duncan multiple range tests (DMRT) at the 5% level of significance.

3. RESULTS AND DISCUSSION

3.1. Response of yield and yield components of hot pepper to urea and NPS

Response of green pod yield

Based on the ANOVA result, green pod yield was highly significantly ($P < 0.001$) affected by rates of urea and NPS fertilizers (Table 3). The highest green pod yield (13.84 t ha^{-1}) was attained by the rate of (urea 150 plus NPS 150) kg ha^{-1}, followed by 12.98 t ha^{-1} (urea 100 with NPS 150) kg ha^{-1}. Whereas the lowest green pod yields (6.41t ha^{-1}) was recorded from 0 kg ha^{-1} of urea and NPS. There was no significant difference in yield between 100 kg urea with 150 kg NPS, 200 kg urea with 150 kg NPS, 150 kg urea alone and 100 kg urea with 100 kg NPS fertilizers rate. These results suggest that the application of urea and NPS fertilizers significantly impacts the green pod yield of the crops. The non-significant treatment showed that a balanced application of these fertilizers is crucial for optimum yield and cost effectiveness. The different levels of fertilizer treatment and the cultivated area's nutrient status in the soil could be the cause of the variation in green pod yield. The application of 150 kg ha^{-1} urea and 150 kg ha^{-1} NPS increases the green pod yield by 7.45 t ha^{-1}, or 116% over the control treatment. Research conducted in many parts of Ethiopia showed that applications of urea and NPS fertilizers increase the dry pod of hot pepper (Meresa, 2019; Assefa et al., 2020; Biratu et al., 2021). However, there was some inconsistency in hot pepper yield under 150 kg ha^{-1} urea with varying NPS application (10.27 t at 0 NPS, 7.81 t at 100 NPS, and 13.84 t at 150 NPS) (Table 4). Highlighting the unexpected decrease in yield at 100 NPS compared to 0 NPS and the subsequent increase at 150 NPS.

Extra increases in applied fertilizers from 150 urea and 150 NPS to 200 urea and 150 NPS kg ha^{-1} reduced green pod yield. This decrease in green pod yield could be attributed to the excessive levels of nitrogen; leads to nutrient imbalance (excessive nitrogen interfered with the plant's ability to absorb other essential nutrients, like phosphorus and sulfur, even though they were present in the soil led to stunting growth, ultimately lower yields). Additionally, excess nitrogen can lead to prioritize vegetative growth over reproductive growth, resulting in more leaves and stems at the expense of pods. This work is supported by Mebratu *et al.* (2014) further increases in applied nitrogen from 100 to 150 kg N ha^{-1} reduced marketable yield of hot pepper by about 42%. Similarly, Fufa et al. (2018) stated that the more increases in applied fertilizers from 150 to 200 NPSBZn kg ha^{-1} led to reduced marketable pod yield of hot pepper. Likewise, Meresa et al. (2019) reported that an increase in NPS fertilizer decreases the marketable yield of hot pepper.

Table 3: Mean square value of ANOVA for urea and NPS fertilizers on selected traits of hot pepper.

Source variation	DF	PH	NPPP	GP	PW
Rep	2	32.66*	2.81^{NS}	357372.50^{NS}	0.25^{NS}
Urea	3	479.70**	167.34**	58304757.00**	1.49**
NPS	2	430.43**	667.80**	76516536.50**	23.92**
Urea*NPS	6	68.89**	44.69**	11434069.33**	2.01**
Year*urea	3	19.56*	18.79**	25568183.33**	0.55^{NS}
Year*NPS	2	104.59**	5.76^{NS}	13338285.50**	0.23^{NS}
Urea*NPS*Year	6	42.27**	31.60**	8339605.50**	1.36**
Error	46	4.924	2.201	160366.58	0.22047

PH = plant height; NPPP = number of pods per plant; GP=green pod; PW= pod weight.

Response of plant height

Based on the ANOVA, application of urea and NPS fertilizer significantly ($p < 0.001$) affect the plant height of the hot pepper (Table 3). The highest plant height was recorded at the rate of urea 200 + NPS 150 kg ha^{-1}, about 65.98 cm, but not significantly different from (150 + 150, 100 + 150, 200 + 100, 100 + 100) kg ha^{-1} urea and NPS, respectively, whereas 44.75 cm was the lowest plant height recorded from the control plot (Table 4). This finding showed that the application of urea and NPS fertilizer has a significant positive effect on the growth of hot pepper plants. The highest plant height was achieved with a combination of urea 200 + NPS 150 kg ha^{-1}, indicating that this specific ratio of fertilizers is most beneficial for maximizing plant height. However, it is worth noting that other combinations of urea and NPS also resulted in similar plant heights, suggesting that varying the ratio of fertilizers within a certain range may still yield the maximum plant height. The control plot, which received no fertilizer, had the lowest plant height, further highlighting the importance of fertilization in promoting plant growth. This suggests that the plant may attain an additional height of 21.23 cm if urea and NPS fertilizer are applied. This might show that the soil NP nutrient status of the experimental area is deficient or has low fertility levels that might affect the plant cell division and elongation.

Similarly, to this result, Ayodele et al. (2015) stated that the application of N fertilizer increases the plant height of hot peppers. According to Melese et al. (2018) the plot s with the greatest and smallest plant heights were found to have received a high concentration of NP fertilizer along with FYM and unfertilized peppers, respectively. Similarly, Fufa et al. (2018) showed that the application of a high rate of blended fertilizer increases the plant height of the hot pepper compared with unfertilized plots. Additionally, Assefa et al. (2020) revealed that the plots with the highest plant heights were those that got the highest amounts of nitrogen fertilizer. On the contrary, adding more nitrogen resulted in a lower plant height of hot pepper (Daniel and Abrham, 2020).

Response of pod number and pod weight

Application of urea and NPS fertilizer had a highly significant ($P < 0.001$) effect on the number of pods per plant and on the pod weight of hot pepper (Table 3). The highest number of pods (35.97) was recorded at a rate of 100 + 150 urea and NPS kg ha^{-1}, but there was no statistical difference at a rate of 200 with 100 kg ha^{-1} urea and NPS correspondingly, and the lowest pod number (15.48) was also recorded from the unfertilized plots (Table 4). These results indicate that the application of urea and NPS fertilizer had a significant positive impact on the number of pods per plant in hot pepper. The highest number of pods was obtained at a rate of 100 + 150 kg ha^{-1} urea and NPS, suggesting that this combination of fertilizers was most effective in promoting pod growth. However, there was no significant difference in pod number between the rate of 200 kg ha^{-1} with 100 kg ha^{-1} urea and NPS, highlights that increasing the fertilizer rate beyond a certain threshold may not provide additional benefits. The lowest pod number was observed in the unfertilized plot, highlighting the importance of fertilizer application for maximizing hot pepper yield. It increased the pod number by 20.49 in number which resulted in 132.4% increase from the control plots. Similarly, Mebratu *et al*. (2014) reported that Plants that received nitrogen at the rates of 50, 100, and 150 kg N ha^{-1} produced a higher number of pods and about 60, 133, and 152%, yield improvement over the unfertilized treatments, respectively. Assefa et al. (2020) showed that the maximum number of pods recorded from the maximum NP treatment.

The highest pod weight was also observed from urea 150 combined with NPS 150, which was about 8.5 g, but was non-significant with 100 with 150 kg ha^{-1} urea and NPS, whereas the smallest pod weight was recorded from the control or unfertilized plot, which was 5.9 g. These results indicate that the combination of urea 150 and NPS 150 had a positive impact on pod weight compared to other treatments. However, it is worth noting that the difference in pod weight between urea 100 and urea 150 combined with NPS was not statistically significant. Additionally, the control plot showed the lowest pod weight, suggesting that fertilization plays a significant role in enhancing pod growth. Applying more urea without the addition of NPS fertilizer does not significantly increase the PW of hot pepper. The increase of NPS along with urea fertilizer resulted in maximum PW. However, maximum N levels (200 kg urea) reduced pod weight. This could have led to excessive vegetative growth at the expense of pod development, explaining the decrease in pod weight at that level. This research aligns with the findings of Fufa et al. (2018), who confirmed that increasing the amount of blended fertilizer and urea led to an increase in pod length compared to the control group. However, they also noted that the maximum application of fertilizer resulted in a reduction in pod length.

Table 4: Response of green pod yield, plant height, number of pod per plant and pod weight of hot pepper to urea and NPS fertilizers.

NPS *rate*	Green pod yield (kg ha^{-1})			
	Urea rate (Kg/ha)			
	0	100	150	200
0 (0 P_2O_5)	6,407^{e}	8,867^{cde}	10,274^{ab}	7,960^{cde}
100 (38 P_2O_5)	7,025^{e}	10,978^{abc}	7,813^{de}	9,143^{cde}
150 (57 P_2O_5)	7,542^{de}	12,980^{ab}	13,841^{a}	12,176^{ab}
Sig.	**			
CV (%)	24.28			
	Plant height(cm)			
0 (0 P_2O_5)	44.75^{f}	54.57^{e}	61.02^{bc}	57.97^{cd}
100 (38 P_2O_5)	50.23^{c}	63.27^{ab}	56.46^{cd}	63.87^{ab}
150 (57 P_2O_5)	58.4^{d}	63.9^{ab}	63.97^{ab}	65.98^{a}
Sig.	**			
CV (%)	4.64			
	Number of pod per plant			
0 (0 P_2O_5)	15.48^{f}	20.57^{e}	19.47^{ef}	22.42^{de}
100 (38 P_2O_5)	21.69^{e}	29.47^{bc}	27.37^{bc}	31.20^{b}
150 (57 P_2O_5)	26.3^{cd}	35.97^{a}	29.47^{bc}	26.06^{cd}
Sig.	**			
CV (%)	14			
	Pod weight (g)			
0 (0 P_2O_5)	5.9^{e}	6.18^{e}	6.07^{e}	6.44^{e}
100 (38 P_2O_5)	7.29^{d}	8.14^{b}	6.41^{e}	7.26^{d}
150 (57 P_2O_5)	7.4^{cd}	8.4^{ab}	8.5^{a}	7.94^{bc}
Sig.	**			
CV (%)	6.8			

Note: Means within a column or row sharing common letter(s) are not significantly different. NPS = Fertilizer that contains nitrogen; phosphorous and sulfur; ** = highly significant level (P= 0.01); CV = Coefficient of variation in percent.

Partial budget analysis

The partial budget analysis of the research showed that the application of 150 kg urea with 150 kg NPS ha^{-1} earned the maximum net benefit of 493,809 ETB ha^{-1} with an MRR of 4,083%, followed by the application of 100 with 150, and 100 with 100 kg ha^{-1} urea and NPS with a net benefit of 463,554 and 392,230 ETB, respectively, and an MRR of 3,240% and 3,256.82% (Table 5).

Table 5: Cost benefit analysis of hot pepper yield on the application of urea and NPS rates

Urea($kgha^{-1}$)	NPS ($kgha^{-1}$)	GPY ($kgha^{-1}$)	TVC(ETB)	AGPY ($kgha^{-1}$)	GB(ETB)	NB(ETB)	MRR%
0	0	6,407	0	5,766.3	230,652	230,652	
100	0	8,867	1,482	7,980.3	319,212	317,730	5,875.71
0	100	7,025	1,496	6,322.5	252,900	251,404	D
150	0	1,0274	2,223	9,246.6	369,864	367,641	6,735.63
0	150	7,542	2,244	6,787.8	271,512	269,268	D
200	0	7,960	2,964	7,164	286,560	283,596	D
100	100	10,978	2,978	9,880.2	395,208	392,230	3,256.82
150	100	7,813	3,719	7,031.7	281,268	277,549	D
100	150	12,980	3,726	11,682.0	467,280	463,554	9,535.29
200	100	9,143	4,460	8,228.7	329,148	324,688	D
150	150	13,841	4,467	12,456.9	498,276	493,809	4,082.99
200	150	12,176	5,208	10,958.4	438,336	433,128	D

*GPY =actual green pod yield; AGPY=adjusted green pod; GB gross benefit; TVC=total variable cost; NB= net benefit; MRR=marginal rate of return; D=dominated treatments

4. CONCLUSION AND RECOMMENDATION

The results of our research showed that most of the agronomic parameters considered were highly significantly affected by both urea and NPS fertilizers. Yield and yield components were significantly enhanced when urea and NPS fertilizer rates were 150 and 150 kg ha^{-1}, respectively. Conversely, the control (unfertilized) plot showed a lower yield and yield-related parameters. Based on the partial budget analysis, the first fertilizer rate for hot pepper at Abergelle and similar agro-ecologies is 150 kg ha^{-1} of urea and 150 kg ha^{-1} of NPS. The second (alternative) fertilizer rate is 100 kg ha^{-1} of urea and 150 kg ha^{-1} of NPS. To enhance the productivity of hot pepper further, it is also recommended to conduct additional research on yield-limiting nutrients and times of nitrogen fertilizer application at different vegetative stages. This research will help optimize the fertilizer application and improve the overall yield of hot pepper.

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DECLARATION OF INTERESTS

The authors affirm that they are free of any known financial conflicts of interest or close personal ties that might have looked to have affected the research presented in this study.

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