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OPTIMISING PLANT DENSITY AND NITROGEN RATES FOR EFFECTIVE POWDERY MILDEW MANAGEMENT IN GARDEN PEAS

OPTIMISATION DE LA DENSITÉ DES PLANTES ET DES TAUX D'AZOTE POUR
UNE GESTION EFFICACE DE L'OÏDIUM DANS LES POIS POTAGER

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ABSTRACT

Garden pea (*Pisum sativum* L.) is crucial in sub-Saharan Africa (SSA), serving both local consumption and export. Its production, however, faces significant challenges mainly due to powdery mildew (*Erysiphe pisi*), which is responsible for yield losses of up to 60%. The objective of this study was to determine the optimum point of N fertiliser interaction with planting densities, for control of powdery mildew disease in garden pea. Treatments included N rates at 0, 15, 30, and 60 kg⁻¹; mode of application (foliar or root base) and plant density (45 cm x 15 cm and 45 cm x 7.5 cm). The treatments were laid out in a randomised complete block design (RCBD), replicated four times. Results showed that disease severity and incidence increased along with N application and plant density; however, yield reduced at both high N rate (60 kg N ha⁻¹) and in the control (0 kg N ha⁻¹) rates. Fertiliser intensity significantly influenced powdery mildew occurrence, pod yield, and plant branches in garden peas, underscoring the need for strategic N management and planting density for sustainable disease management. The study identified 30 kg N ha⁻¹ applied either by foliar or root application, together with 45 cm x 15 cm plant spacing as the most effective combination; which effectively reduced powdery mildew incidence; while improving crop yield.

Key Words: Disease incidence, disease occurrence, disease severity, fertiliser intensity, plant height and yield

RÉSUMÉ

Le pois potager (*Pisum sativum* L.) est crucial en Afrique subsaharienne (ASS), servant à la fois la consommation locale et l'exportation. Sa production, cependant, est confrontée à des défis importants, principalement en raison de l'oïdium (*Erysiphe pisi*), responsable de pertes de rendement allant jusqu'à

60 %. L'objectif de cette étude était de déterminer le point optimal d'interaction de l'engrais azoté avec la densité de plantation, pour lutter contre l'oïdium chez le pois potager. Les traitements comprenaient des doses d'azote à 0, 15, 30 et 60 kg ha⁻¹ ; le mode d'application (foliaire ou racinaire) et la densité de plantation (45 cm x 15 cm et 45 cm x 7,5 cm). Les traitements ont été disposés selon un dispositif en blocs complets randomisés (RCBD), répliqué quatre fois. Les résultats ont montré que la gravité et l'incidence de la maladie augmentaient avec l'application d'azote et la densité de plantation ; cependant, le rendement diminuait à la fois à une dose élevée d'azote (60 kg N ha⁻¹) et aux doses témoins (0 kg N ha⁻¹). L'intensité de la fertilisation a significativement influencé l'apparition de l'oïdium, le rendement des gousses et la hauteur des plants de pois potagers, soulignant la nécessité d'une gestion stratégique de l'azote et d'une densité de plantation adaptée pour une gestion durable de la maladie. L'étude a identifié une application foliaire ou racinaire de 30 kg N ha⁻¹, associée à un espacement de 45 cm x 15 cm entre les plants, comme la combinaison la plus efficace, réduisant efficacement l'incidence de l'oïdium tout en améliorant le rendement des cultures.

Mots Clés : Incidence de la maladie, occurrence de la maladie, gravité de la maladie, intensité de la fertilisation, hauteur et rendement des plants

INTRODUCTION

Garden pea (*Pisum sativum*) is a crop valued for rich nutritional endowment and income sourcing potential in sub-Saharan Africa (SSA). It plays a significant role in food security and is fundamental in supporting smallholder farmers' livelihoods economically (AFA, 2020; Thakur *et al.*, 2023).

Unfortunately, viable production of garden pea is currently challenged by diseases, especially powdery mildew caused by the fungus *Erysiphe pisi*; that occurs globally. The symptomatic appearance of the pathogen is expressed as white, powdery spots on leaves, stems, pods and sometimes invariably covering the whole crop (Ajayo *et al.*, 2021). The pathogen causes high yield losses as it reduces photosynthesis, causing stunted growth, and dropping of leaves and reduces pod quality (Ajayo *et al.*, 2021). The disease leads to poor pod development, flavorless pea and deformed pods (Attanayake *et al.*, 2010); all of which contribute to garden pea grain yield. Thus this disease plays a central role in decreasing the harvest and market quality of the crop, causing preventable economic losses.

Common methods for control of the disease, like use of synthetic fungicides and resistance breeding are generally costly, cause pollutant and pathogen resistance, when

misused (Rana *et al.*, 2023). There is need to explore more sustainable and effective control strategies for the pathogen.

Planting density and strategic soil N management may be an exit strategy, by creating a microclimate that moderates growth and development of powdery mildew. Optimal N rates are known to intensify plant vigor, plant development and boost resistance to the pathogen (Fatima *et al.*, 2020). The right rate of N required is essential for enhancing plant health, by lowering risks to powdery mildew (Simón *et al.*, 2019). Strategic interaction of plant population density and N application rates tends to synergise suppression of the pathogen in garden pea production (Ajayo *et al.*, 2021). However, this approach has not yet been received sufficient research attention, to leverage powdery mildew management (Simon *et al.*, 2019; Fatima *et al.*, 2020). The objective of this study was to determine the optimum point N fertiliser *versus* plant density interaction, for management of powdery mildew disease in garden pea.

MATERIALS AND METHODS

Study site. The study was carried in Mathira and Kieni sub-counties in Nyeri County, in Kenya; in a region renowned for production and dependence on garden pea in the country.

The sites are situated on the leeward side of Mt. Kenya and the windward side of the Aberdare Range on the plateau zone (Sang and Cheruiyot, 2020; Nyeri CIDP, 2020); specifically, at 1° 0' 0" S, 36° 46' 0" E and S 0° 17' 48.408" E 37° 6' 28.116", respectively. The region experiences bimodal rainfall patterns, with long rains occurring from March to May and short rains from October to November. Mean annual rainfall is 1,400 mm during the long rains and 1,000 mm during the short rains (MoALF, 2022). Mean temperature in the region is 16.8 °C.

Experimental layout. The land was deep plowed; and followed by 2-3 harrowing cycles, ensuring a fine seed bed. Four blocks (44 m by 16 m) with treatment plots measuring 2.5 m x 2 m, were established, with a one-meter alley between adjacent plots and a 1.5-meter between blocks. Treatments included N rates at 0, 15, 30 and 60 kg N ha⁻¹; mode of N application (foliar or root base); and plant density at 45 cm x 15 cm and 45 cm x 7.5 cm (Table 1). The experiment was laid out in a randomised complete block design (RCBD), with four replicates; and the study was repeated four times. Staking was applied uniformly across all treatments.

Garden pea variety used. The garden pea used in this study was the Plum variety, procured from Simlaw Seed Company (Table 2). This variety was selected for the research as it is more susceptible to powdery mildew infection, allowing for a better assessment of disease management strategies (Mwangi *et al.*, 2020; Njoroge *et al.*, 2021)

Soil analysis. Prior to planting garden pea seeds, soil physicochemical properties were analysed following the protocols outlined by Rakshit *et al.* (2020). Ten soil samples were randomly collected from each block at a depth of 30 cm, using a soil auger, then thoroughly mixed to form a composite sample per plot, as described by Njuguna *et al.* (2016). A 100 g portion of the composite sample was used to determine total N and available contents; soil acidity, alkalinity and conductivity. The results of these analyses were used to determine the initial soil chemo-physical status before application of the N fertiliser (urea 45% N).

Table 3 presents soil analytical results for the sites (Kieni and Mathira) of this study. Kieni site had higher available nitrogen (2.2 g kg⁻¹ vs. 0.7 g kg⁻¹) and higher available phosphorus (36.9 mg kg⁻¹ vs. 30.9 mg kg⁻¹), making it

TABLE 1. Treatment abbreviations and their meaning

Abbreviation	Meaning
HhB	60 kg ha ⁻¹ Urea, root base application, spacing 45 cm x 7.5 cm
HhF	60 kg ha ⁻¹ Urea, foliar application, spacing 45 cm x 7.5 cm
lhB	30 kg ha ⁻¹ Urea, root base application, spacing 45 cm x 7.5 cm
LhF	15 kg ha ⁻¹ Urea, foliar application, spacing 45 cm x 7.5 cm
HLF	60 kg ha ⁻¹ Urea, foliar application, spacing 45 cm x 15 cm
HLB	60 kg ha ⁻¹ Urea, root base application, spacing 45 cm x 15 cm
LhB	15 kg ha ⁻¹ Urea, root base application, spacing 45 cm x 7.5 cm
lhF	30 kg ha ⁻¹ Urea, foliar application, spacing 45 cm x 7.5 cm
ILF	30 kg ha ⁻¹ Urea, foliar application, spacing 45 cm x 15 cm
ILB	30 kg ha ⁻¹ Urea, root base application, spacing 45 cm x 15 cm
LLB	15 kg ha ⁻¹ Urea, root base application, spacing 45 cm x 15 cm
LLF	15 kg ha ⁻¹ Urea, foliar application, spacing 45 cm x 15 cm
Control	0 kg ha ⁻¹ Urea, root base application, spacing 45 cm x 7.5 cm

TABLE 2. Selection criteria for the garden pea variety (Plum variety) used

Category	Details
Agronomic traits	High yield potential, good adaptability to various soil types, moderate drought tolerance, and susceptibility to powdery mildew, making it ideal for disease management studies (Zayed, 2023).
Genetic characteristics	Belongs to the <i>Pisum sativum</i> species, hexaploid ($2n = 6x = 48$), known for genetic diversity in fruit size, shape, and biochemical properties Rispaal <i>et al.</i> , 2023).
Popularity and usage	Widely cultivated for fresh consumption and processing, recognized for its nutritional benefits, including high fiber and antioxidant content (Zou <i>et al.</i> , 2022; Thavarajah <i>et al.</i> , 2023).

TABLE 3. Site soil analytical results prior to the study

Parameter	Unit	Kieni site	Mathira site
Organic carbon	g kg ⁻¹	30.7	33.6
Cation exchange capacity	cmol. kg ⁻¹	110	120
pH (water)		5.8	5.52
Exchangeable potassium	cmol. kg ⁻¹	7.3	8.4
Available nitrogen	g kg ⁻¹	2.2	0.7
Available phosphorus	mg kg ⁻¹	36.9	30.9

richer in those nutrients. Mathira site had higher organic carbon (33.6 g kg⁻¹ vs. 30.7 g kg⁻¹), higher cation exchange capacity (120 cmol kg⁻¹ vs. 110 cmol kg⁻¹), and higher exchangeable potassium (8.4 cmol kg⁻¹ vs. 7.3 cmol kg⁻¹), meaning it retained nutrients better. pH was slightly lower in Mathira (5.52 vs. 5.8), indicating slightly more acidic conditions. (Table 3).

Pathogenic microbes. Garden pea plant tissues from the study sites, along with soil samples, were tested for the presence of pathogens that attack peas, especially the fungus *Erysiphe pisi* that causes powdery mildew in legumes. The fungal pathogens were initially cultured on Potato Dextrose Agar and examined under a microscope, except for *Uromyces spp.*, which was directly tested using

immunostrip for soil and DAS-ELISA for plant tissues.

The results for cultured fungal pathogens were evaluated using an intensity score scale, ranging from 0 to 5; where 0 indicated 'Not detected,' 1 'Starting infection,' 2 'Light infection,' 3 'Moderate infection,' 4 'Infected,' and 5 'Severely infected' (Hema and Konakalla, 2020). The presence of *Uromyces spp.* was detected using immunostrip tests for soil samples and DAS-ELISA assays for plant tissues. Both procedures provided rapid and visually interpretable results through observable colour changes.

For pea enation mosaic virus, soil samples were prepared and tested through PTA-ELISA. The ELISA tests were conducted in duplicate wells, and read on a plate reader at 410 nm. Sample readings exceeding twice the mean of

the negative control $[(A+B)/2*2]$, were considered positive (Hema and Konakalla, 2020).

Powdery mildew incidence and severity. Powdery mildew disease (PMD) occurrence (incidence) and severity were assessed visually on each experimental plot. Five pea plants per treatment plot were randomly selected for disease assessment, using a zigzag sampling method, with distances of one meter between plants per plot. The disease incidence was determined by the formula outlined by Cao *et al.* (2011), *viz*:

$$\text{Disease incidence\%} = \left\{ \frac{\text{Number of symptomatic plants}}{\text{All sampled pea plants in experimental plot (20)}} \right\} \times 100$$

Powdery mildew disease severity (PMDS) was determined using a scale score of 0-9, described by Prema (2022); where: 0 = disease-free, 1 = specks covering <1% of the leaf area, 3 = lesions covering 1-10% of the leaf area, 5 = lesions covering 11-25% of the leaf area, 7 = lesions coalescing to form large patches covering 26-50% of the leaf area, and 9 = large powdery patches covering 51% or more of the leaf area and defoliation. Area Under Disease Progress Curve (AUDPC) was calculated using the formula described by Binod *et al.* (2016):

$$\text{AUDPC} = \sum \left[\frac{A_i + 1 + A_{i+1}}{2} \times H_{i+1} - H_i \right] \times 100$$

Where:

$A_{i+1} + A_i$: Represents the disease severity measurements at two consecutive time points.

$H_{i+1} - H_i$: Denotes the time interval between the two measurements.

Data recording. Pea branch counts were conducted weekly, beginning one week after

the application of nitrogen-based fertiliser. Five plants were randomly selected from each treatment plot for assessment. The number of branches was recorded sequentially from the plant base up to the topmost growing tip. Upon physiological maturity (when 50% of the pods turned yellow), the pea pods were harvested, and their weights recorded separately for each treatment plot. This was done using a top pan weighing scale with a precision of 0.01-5000 g, after air-drying for 24 hours

Statistical analysis. The plant growth and yield; and disease parameters data were checked for normality, using the Shapiro-Wilk test in R. Thereafter, the data were subjected to analysis of variance, and the significant means separated using Tukey's Honest Significant Difference (HSD) test at a 95% probability level.

RESULTS

Number of branches. The number of branches at both Kieni and Mathira study sites showed significant differences (Fig. 1), where Kieni site, treatments LhF, LLB, LLF, ILB, HLF and control showed significant difference. In Mathira site, the following treatment showed significant difference HhF, HhB, ILB, ILF, LhB, LhF, LLB, LLF and control. At the Kieni site, treatment HLB (60 kg N ha⁻¹ urea, root base application, and spacing 45 cm x 15 cm) produced the highest mean number of branches (7.8) while control treatment recorded least with 4.7 (Fig. 1)

At the Mathira site, treatment HhF (60 kg N ha⁻¹ urea, foliar application, spacing 45 cm x 7.5 cm) achieved the highest mean number of branches, with a mean of 9.75. (Fig. 1).

Disease incidence. The trend lines of DI% reveal significant variations across treatments in Kieni and Mathira sites, with ILF and ILB showing notable differences in both sites; while IhF and LhF exhibited significant effects in Mathira alone for PMD (Fig. 2). PMD was

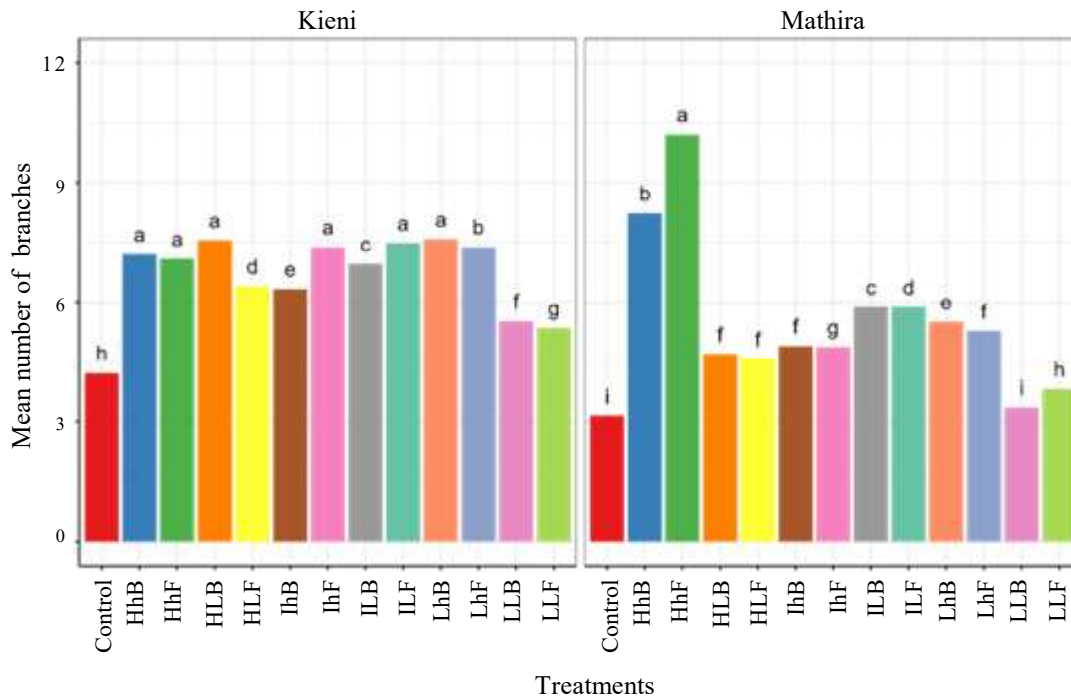


Figure 1. Response of branches of garden pea cultivar to application of N rates and plant densities at the study sites, in Kenya.

first recorded at week 6 after application of nitrogen-based fertiliser, applied two weeks after emergence, with DI% increasing significantly over time.

In Kieni site, the control treatment exhibited a steep upward trend, reaching 95% by week 9 after application; the high N rates, such as HhF (60 kg N ha⁻¹ urea foliar, 45 x 7.5 cm) at 87.5%, also showed increasing trends. Moderate treatments (ILF, ILB, and IhB) demonstrated lower DI%, with ILF (30 kg N ha⁻¹ foliar, 45 x 15 cm) recording the lowest DI% of 63.8% (Fig. 2).

In Mathira site, DI% trends were flatter, with slower progression compared to Kieni site (Fig. 2). The control treatment reached 80% at week 9 after application; while moderate applications like IhF (30 kg N ha⁻¹ foliar, 45 x 7.5 cm) and LhF (15 kg N ha⁻¹ root base, 45 x 7.5 cm) stabilised at 40%. ILF recorded 50% DI in Mathira, while ILB (30 kg N ha⁻¹ root base, 45 x 15 cm) showed 70% in Kieni and

65% in Mathira. The moderate urea treatments (ILF, IhB, LhB, and ILB) consistently led to reduced DI%, demonstrating their effectiveness in disease management (Fig. 2).

Disease severity. The trend lines of disease severity showed distinct patterns across Kieni and Mathira sites, as influenced by N mode of application and plant density treatments (Fig. 3). Disease severity was first recorded at week 6 after application of N based fertiliser guided by disease incidence data, as no visible symptoms were initially present. In Kieni site, the severity increased progressively, with the control (0 kg N ha⁻¹, root application at 45 cm x 15 cm) reaching scale score of 5.6 by week 9 after LLF at score scale of 6.5. LhB (15 kg N ha⁻¹, root application at 45 cm x 7.5 cm), showed the least severity of 2.8, maintaining consistently lower values from weeks 6 to 9. On the other hand, LLB (15 kg N ha⁻¹, root base application at 45 cm x 15 cm) exhibited

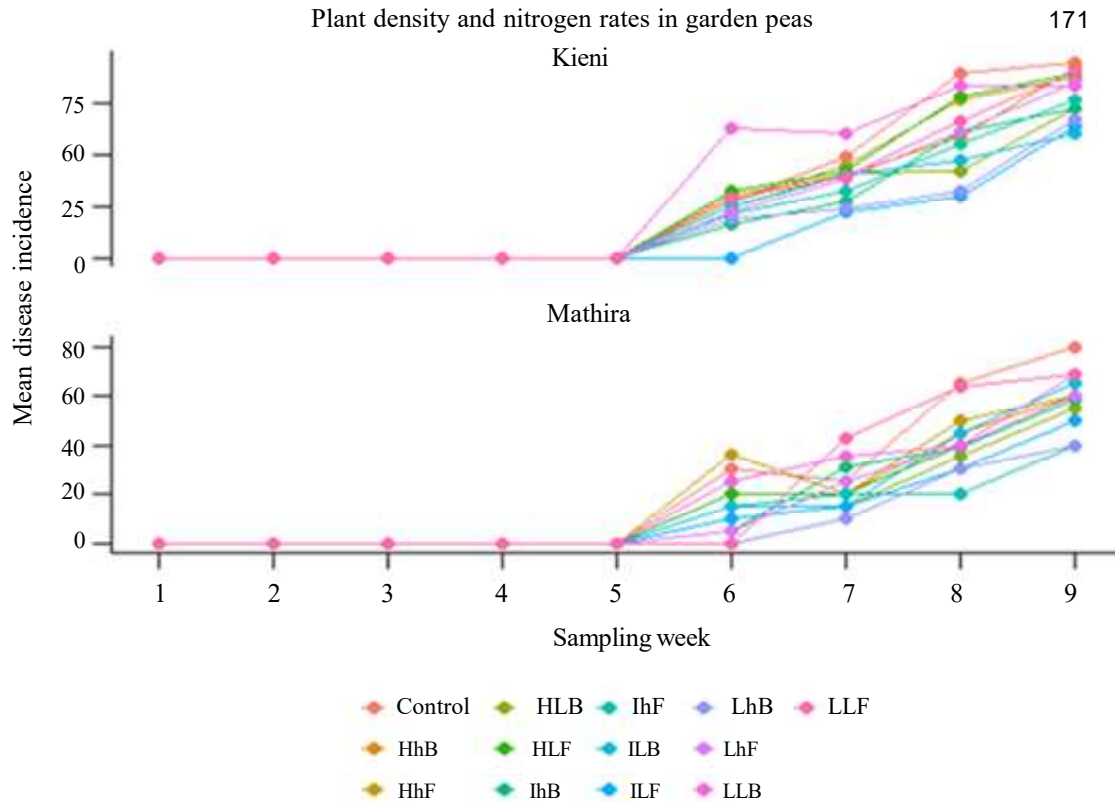


Figure 2. Response of disease incidence of garden pea to application of N rates and plant densities at the study sites, in Kenya.

one of the highest severity score scale throughout reaching the score scale of 7.8 at week 9 (Fig 3).

In Mathira site, the trend lines were more stable, with LhB (15 kg N ha⁻¹, root application at 45 cm x 7.5 cm); and ILB (30 kg N ha⁻¹, root application at 45 cm x 7.5 cm) demonstrating significant disease suppression, and maintaining a severity level of 1.9, by week 9 (Fig. 3). The control treatment recorded the highest severity (5.6); followed by HhF (60 kg N ha⁻¹, applied via foliar application at spacing of 45 cm x 7.5 cm), with a severity score of 5.1 in week 9. Statistical analyses confirmed the superiority of foliar over root base applications in managing disease severity across both sites.

Pod yield. There were significant treatment differences on pod yield across study sites (Fig. 4). At the Kieni site, treatment ILB (30

kg ha⁻¹ urea, root base application, and spacing 45 cm x 15cm) exhibited the highest pod yield (24.0 t ha⁻¹); while treatment LLF (15 kg ha⁻¹ urea, foliar application, and spacing 45 cm x 15 cm), had the lowest yield, which was just about a third of the highest yielder (Fig. 4). Other treatments, which showed significant increases in pod yield included ILF and HLB. At the Mathira site, treatment ILF (30 kg ha⁻¹ urea, foliar application, and spacing 45 cm x 15 cm) displayed the highest level of grain yield (27.5 t ha⁻¹); while treatments LLF and LLB had the lowest grain yield (10.0 t ha⁻¹). Other treatments with significant increases in grain yield were ILB with 26.1 t ha⁻¹ and HLB with 23.1 t ha⁻¹ (Fig. 4).

Area Under Disease Progress Curve. There was a significant difference in the Area Under Disease Progress Curve (AUDPC) across treatments (P<0.05), with the control showing

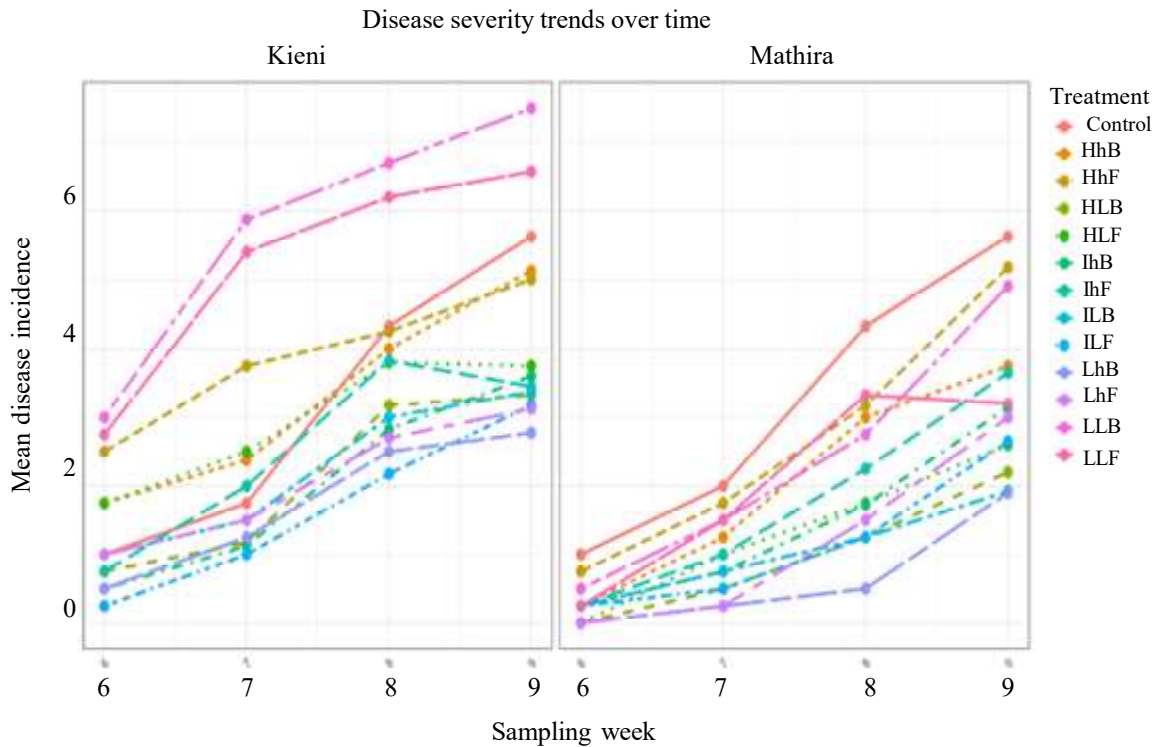


Figure 3. Response of disease severity of garden pea to application of N rates and plant densities at the study sites, in Kenya.

the largest area affected by the disease, compared to other treatments (Fig. 5). In Kieni site, the lowest AUDPC was recorded under T2 (30 kg N ha⁻¹ applied though foliar, and spaced at 45 cm x 15 cm) treatment, with a value of 785.7. In Mathira site, T3 (15 kg N ha⁻¹ applied at the base, spaced at 45 cm x 7.5 cm) was the lowest infected by the diseased, with an AUDPC of 297.5. The highest AUDPC was recorded under the control treatments at both sites, with values of 4353.1 in Kieni and 1731.6 in Mathira (Fig. 5).

Disease occurrence. The results indicate that the treatment combinations significantly influenced disease occurrence (Table 4), being more serious at Kieni ($P=0.00294$) than at the Mathira site ($P=0.0077$). Nitrogen fertiliser level demonstrated a strong association, with P -values of 0.0017 in Kieni and $1.19\text{e-}05$ in Mathira sites. Plant density were moderately

significant for both sites, with Mathira having a P -value of 0.017 and 0.00707 in Kieni site in (Table 4).

Pod yield. Nitrogen fertiliser rate significantly influenced pod yield in both Kieni and Mathira sites, with highly significant p -values of $2.13\text{e-}07$ in Kieni and $1.38\text{e-}05$ in Mathira (Table 5). In contrast, the mode of N fertiliser application and plant density did not show significant effects on pod yield in Kieni ($P=0.252$ and $p=0.863$, respectively); and Mathira ($P=0.94$ and 0.274 , respectively).

DISCUSSION

Number of branches. The study demonstrated that N application and plant density significantly influence branching patterns in garden peas, with notable differences observed across agro-ecological

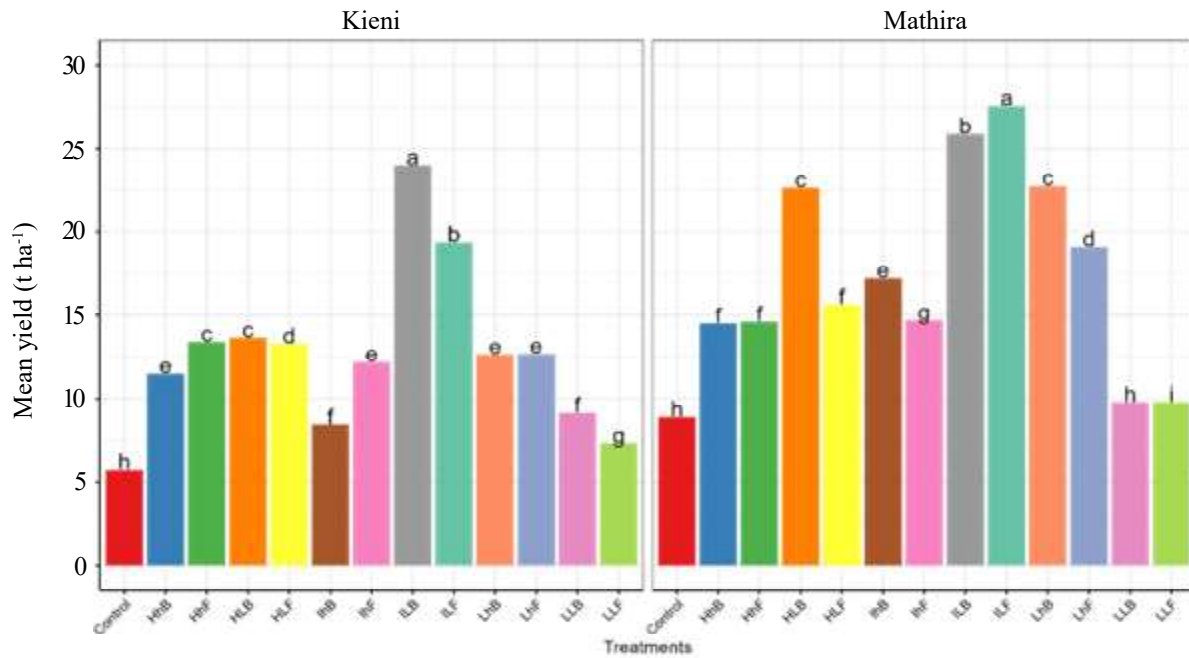


Figure 4. Response of garden pea pod yield to application of N rates and plant densities at study sites, in Kenya.

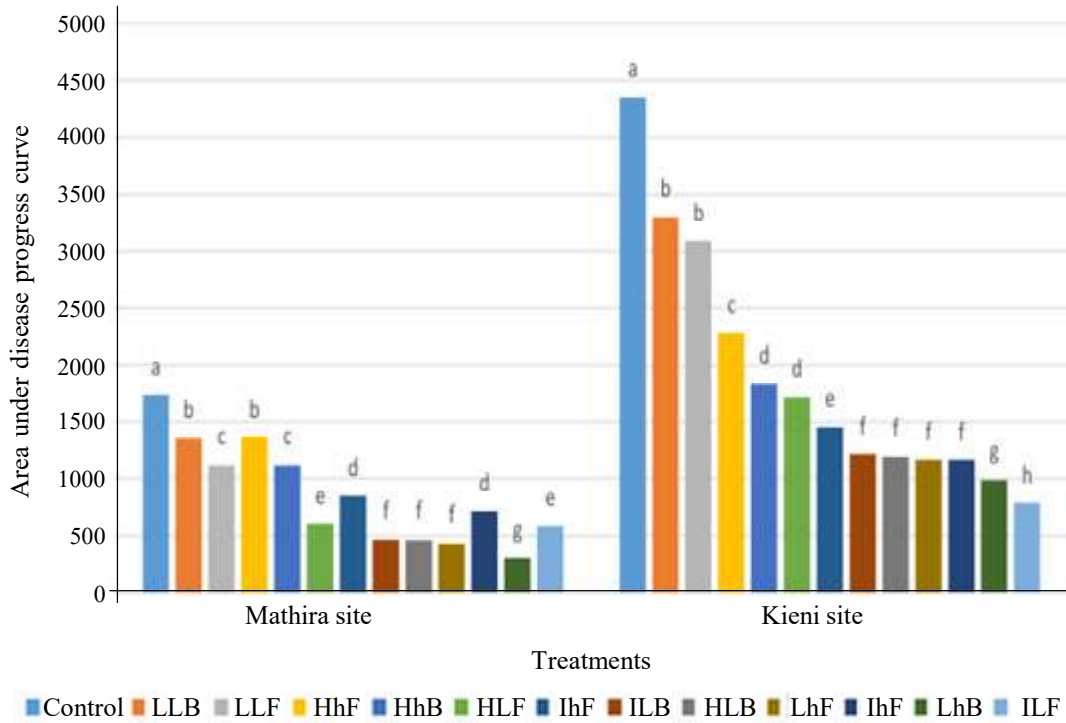


Figure 5. Response of Area Under Disease Progress Curve to application of N rates and plant densities at study sites, in Kenya.

TABLE 4. Variance analysis on cause effect of powdery mildew disease occurrence on garden pea

Factor	Kieni site			Mathira site		
	Original mean square	Log-transformed mean square	P value	Original mean square	Log-transformed mean square	P value
Fertiliser application method						
get(factor)	0.5222	log(0.5222)	0.00294 **	0.7540	log(0.7540)	0.0077 **
Residuals	0.0793	log(0.0793)	-	0.1401	log(0.1401)	-
Fertiliser level						
get(factor)	0.019299	log(0.019299)	0.0017 **	0.06470	log(0.06470)	1.19e-05 ***
Residuals	0.003292	log(0.003292)	-	0.00583	log(0.00583)	-
Planting density						
get(factor)	0.00943	log(0.00943)	0.00707 **	0.03898	log(0.03898)	0.017*
Residuals	0.06582	log(0.06582)	-	0.01529	log(0.01529)	-

Significant at P<0.05, **at P<0.01 and *** at P<0.001

Table 5. Variance analysis on cause effect of garden pea pod yield at the study sites

Factor	Kieni site			Mathira site		
	Original mean square	Log-transformed mean square	P value	Original mean square	Log-transformed mean square	P value
Fertiliser application method						
get(factor)	0.1549	log(0.1549)	0.252	0.00067	log(0.00067)	0.94
Residuals	0.1152	log(0.1152)		0.11701	log(0.11701)	
Fertiliser level						
get(factor)	0.08013	log(0.08013)	2.13e-07 ***	0.05496	log(0.05496)	1.38e-05 ***
Residuals	0.00496	log(0.00496)		0.00503	log(0.00503)	
Planting density						
get(factor)	0.0000569	log(0.0000569)	0.863	0.00179	log(0.001790)	0.274
Residuals	0.0018949	log(0.0018949)		0.001464	log(0.001464)	

Significant at P<0.05, **at P<0.01 and *** at P<0.0

zones (Fig. 1). The number of branches varied significantly among treatments, as illustrated in Figure 1; highlighting the impact of nitrogen levels and spacing on plant architecture.

In the warmer agro-ecological zone (Kieni), treatment HLB (60 kg N ha⁻¹ urea, root base application, 45 x 15 cm) recorded the highest mean number of branches at 7.8; while the control treatment exhibited the lowest count of 4.7. Similarly, in the cooler agro-ecological zone (Mathira site), HhF (60 kg N ha⁻¹ urea, foliar application, 45 x 7.5 cm) achieved the highest mean number of branches at 9.75, reinforcing the mode of N application in determining vegetative growth patterns. Other treatments, including LhF, LLB, LLF, ILB, and HLF, also showed significant differences in branch development, as depicted in Figure 1.

The variations observed in Figure 1 can be attributed to the interaction between nitrogen application and plant architecture (Nguyen *et al.*, 2022). Excess N stimulates vigorous vegetative growth, thus promoting stem elongation at the expense of lateral shoot formation (Brown *et al.*, 2019). High-density planting further restricts branching by directing plant growth upward and reducing light penetration in lower nodes, weakening photosynthetic activity and limiting lateral expansion (Martín-Cabrejas, 2019). Conversely, moderate N application enhances branching by maintaining balanced vegetative growth, improving aeration, and supporting optimal plant development (Nguyen *et al.*, 2022).

These findings emphasize the significance of proper N regulation and optimised planting densities to optimise branching; while avoiding excessive vegetative growth. The data presented in Figure 1 further support the role of N management in determining plant structure and overall crop performance.

Disease incidence. The study confirms that powdery mildew disease, caused by *Erysiphe pisi*, is significantly influenced by environmental conditions, in particular N levels and plant density (Fig. 2). The findings

demonstrate that high-density planting and excessive N application create favourable conditions for pathogen proliferation, reinforcing previous research on disease persistence in agricultural ecosystems (Agrios, 2005; Marschner, 2012; Martín-Cabrejas, 2019). The ability of *Erysiphe pisi* to reduce chlorophyll content and impair photosynthesis aligns with broader concerns about pathogen survival in soil and plant debris, similar to *Uromyces spp.* and pea enation mosaic virus (Jones, 2019). The disease thrives in humid environments where fungal spores can spread easily, making management strategies crucial for limiting its impact.

The observed increase in disease incidence under high nitrogen rates and dense planting highlights the critical role of agronomic practices in disease management. Treatments such as HhF at 87.5 percent (Fig. 2) exhibited higher disease severity, supporting findings that excess N weakens plant defenses (Brown *et al.*, 2019). Conversely, moderate N treatments, such as ILF at 63.8 percent, demonstrated lower disease severity, reinforcing the importance of balanced nitrogen application (Nguyen *et al.*, 2022). The persistence of *Erysiphe pisi* in plant debris further emphasises the need for proper residue management and crop rotation to minimise disease recurrence (Berger *et al.*, 2021). The control treatment, which exhibited the highest disease incidence at 95 percent, reinforces the understanding that dense planting without nitrogen regulation exacerbates disease occurrence.

The findings suggest that integrated disease management strategies are essential for reducing powdery mildew severity and improving crop productivity. Optimised plant densities and moderate N application can enhance plant resilience, thus reducing pathogen survival and disease recurrence. Additionally, resistant cultivars, fungicidal treatments, and improved field sanitation are necessary to mitigate the impact of powdery mildew (Jones, 2019). The study reinforces the importance of early planting and genetic

resistance, as highlighted in previous research on powdery mildew control (Fondevilla and Rubiales, 2012)

To effectively manage powdery mildew disease, future strategies should focus on developing and adopting resistant pea cultivars to minimise pathogen susceptibility, and implement balanced N application to prevent excessive vegetative growth and canopy density, enhancing crop rotation and residue management to disrupt pathogen life cycles; and utilising biological control methods such as mycolytic bacteria and plant extracts to reduce reliance on fungicides (Fondevilla and Rubiales, 2012). Improving aeration and field sanitation will also limit pathogen spread and persistence, contributing to sustainable disease management and ensuring higher yield potential and improved crop health.

The analysis underscores the importance of fertiliser application methods, soil N levels, and plant density in garden pea crop health and productivity. Effective N management plays a crucial role in optimising plant resilience, influencing disease pressure and yield stability (Table 4). Nitrogen fertiliser application methods affect nutrient absorption efficiency, impacting disease resistance and plant vigour (Tilman *et al.*, 2021). Similarly, N fertiliser levels must be carefully adjusted to ensure adequate nutrient supply without overstimulating vegetative growth, which could promote conditions favorable for pathogen proliferation (Jones and Smith, 2022).

Plant density influences competition for resources, airflow and humidity; all of which contribute to disease dynamics and crop performance. Overcrowding can intensify stress and facilitate pathogen spread, whereas balanced spacing helps mitigate fungal infections by improving ventilation (Berger *et al.*, 2021).

Disease severity. The severity of powdery mildew disease varied across different agro-ecological zones, with notable differences observed depending on N application rates and

plant densities (Fig. 3). Excessive N encouraged lush vegetative growth, creating a dense canopy that retained moisture and provided ideal conditions for pathogen proliferation, as described by Marschner (2012). This was evident in treatments with high N levels, such as HhF (60 kg ha⁻¹ urea foliar, 45 x 7.5 cm), which exhibited increased disease severity.

Findings from the warmer agro-ecological zone (Kieni site) further indicated that treatments with high N rates contributed to weakened plant defenses, supporting observations by Jones (2019) that excess N compromises cell wall integrity and increases susceptibility to fungal penetration. The control treatment also demonstrated heightened disease severity, reinforcing the impact of dense planting without nitrogen regulation.

By contrast, moderate N applications, particularly ILF (30 kg N ha⁻¹ urea foliar, 45 x 15 cm), resulted in lower disease severity, aligning with Nguyen *et al.* (2022), who emphasised the role of balanced nutrient management in enhancing plant resistance. The cooler agro-ecological zone showed a more gradual disease progression, although the control treatment continued to exhibit notable levels of infection, highlighting the influence of environmental conditions and agronomic practices.

Pod yield. The study findings confirmed that N application and plant density significantly influence pod yield in garden peas, with notable differences observed across agro-ecological zones. As illustrated in Figure 4, pod yield varied significantly among treatments, reinforcing the role of nitrogen management in optimising crop productivity (Meitei *et al.*, 2022).

At the Kieni site, treatments with moderate N application, such as ILB, recorded the highest pod yield; while LLF exhibited the lowest yield, approximately one-third of the highest yielder. Similarly, at the Mathira site,

ILF achieved the highest yield, while LLF and LLB recorded the lowest yield (Zuazo *et al.*, 2021). Other treatments, including ILB and HLB, also demonstrated significant increases in pod yield, reinforcing the importance of balanced N application.

These results align with previous research indicating that N application enhances pod yield by promoting vegetative growth and nutrient uptake (Wysokinski and Lozak, 2021). Additionally, Meitei *et al.* (2022) demonstrated that balanced N and micronutrient application significantly improves pea yield, reinforcing the importance of site-specific fertilisation strategies (Zuazo *et al.*, 2021).

The observed differences between the modes of N application (root base and foliar), suggest that application method plays a crucial role in nutrient absorption and utilisation (Meitei *et al.*, 2022). Root base application, as seen in ILB, may provide more sustained nutrient availability, leading to higher pod yield; whereas foliar application, as observed in LLF, may result in lower yield due to limited nutrient uptake efficiency (Zuazo *et al.*, 2021).

In summary, integrated N management strategies should be adopted to maximise pod yield while maintaining soil health (Wysokinski and Lozak, 2021). Future research should explore the long-term effects of N application methods on yield stability and environmental sustainability (Zuazo *et al.*, 2021). These findings provide valuable insights into nitrogen regulation and its role in improving pea productivity, reinforcing the need for site-specific fertilisation approaches. The findings emphasize the strong influence of fertiliser level on plant growth and disease interactions, with highly significant effects observed in both study sites. This reinforces the importance of nutrient optimisation in sustaining crop productivity and minimising pathogen susceptibility (Jones and Smith, 2022). Conversely, the fertiliser application method showed limited impact, suggesting that nutrient availability may depend more on rate than method in these conditions (Tilman *et al.*, 2021).

CONCLUSION

The study revealed that application of N at 30 kg ha⁻¹, with a plant density of 45 cm x 15 cm was the most effective in reducing powdery mildew incidence; while improving garden pea yield. Excess N (60 kg N ha⁻¹) increased disease susceptibility, while lower N rates (< 15 kg N ha⁻¹) weakened plant resistance. Dense planting (45 cm x 7.5 cm) intensified disease pressure; whereas wider spacing improved aeration and resilience.

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