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# Synergistic effect of seed dressing fungicides, vermicompost application and varieties on Fusarium wilt intensity, yield, and yield components of chickpea (*Cicer arietinum* L.)

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## Abstract

Background: Chickpea Fusarium wilt is the foremost devastating fungal disease that leads to massive grain yield loss in chickpea. Field experiments were therefore carried out to appraise the synergistic effect of seed dressing fungicides, vermicompost and chickpea varieties on Fusarium wilt intensity, and yield of chickpea. Methods: Treatment combinations were arranged in a factorial randomized complete block design. Results: The finding revealed that the interaction among seed dressing fungicides, chickpea varieties and vermicompost application had a significant impact on wilt intensity, yield, and related yield attributes of chickpea. Thus, the Natoli variety when treated with Goldazim 500SC seed dressing fungicide and supplemented with vermicompost showed the lowest wilt incidences (0.35%) and percent severity index (PSI) (0.6%) at Fogera site. Conversely, untreated Dehra variety retained the highest mean incidence and PSI of 27.26% and 31.07%, respectively at Bahir Dar Zuria. The maximum grain yield recorded was 2953.8 kg ha$^{-1}$ achieved by the Natoli treated with Goldazim 500SC and receiving vermicompost application. The study also noted that the highest grain yield loss due to Fusarium wilt were 27.8% at Bahir Dar Zuria and 23.96% in Fogera district correlating with increased disease incidence and severity. The correlation analysis between disease intensity parameters and yield components in chickpeas demonstrated significant negative relationships, indicating that the increased Fusarium wilt intensity adversely affected yield and yield contributing components. Conclusion: The integrated application of seed dressing fungicides and vermicompost, in moderately resistant varieties like Natoli, offers a promising strategy for minimizing the adverse impact of Fusarium wilt and maximizing chickpea productivity.

**Keywords:** percent severity index, wilt incidence, and yield loss

## Introduction

The global population continues to grow and urban development is encroaching on substantial agricultural land. Additionally, various risk factors related to climate change are rendering crop production increasingly difficult (Gebeyaw *et al*., 2024a). The sharply changing climate is threatening the food security for the fast-growing global population (Farooq *et al*., 2023). The influence of such issues is starkly evident in Ethiopia, a nation where the livelihood of its economy hinges on the success of its agricultural sector. In this land, where fertile plains stretched across the horizon, the prosperity of the entire country relies heavily on the productivity and resilience of its farmers (Biru *et al*., 2017). Thus, the importance of pulse crops like chickpea should not be disregarded because of their foremost contribution in harmonizing and maintaining soil health, generating income, sustaining food and nutritional security, and increasing the foreign exchange of the country (Gebeyaw *et al*., 2024a). Growing legumes like chickpea and soybean provides significant benefits to cropping systems and the environment due to their natural ability to perform symbiotic nitrogen fixation, which enhances both soil fertility and water-use efficiency (Thudi *et al*., 2016; Sahruzaini *et al*., 2020).

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Chickpea (*Cicer arietinum* L.) is an important pulse crop in the world, with diverse benefits, including rich nutritional value, high-income generation potential, and the ability to carry out atmospheric nitrogen fixation to improve soil fertility (Fikre and Bekele, 2020; Sahruzaini *et al*., 2020). It is currently grown on approximately 13.7 million hectares of land worldwide, with an average annual production of 12.8 million tons (Afzal, 2021). Asia remains the top producer of pulses, accounting for 82% of global chickpea production between 2010 and 2019, with the rest of the world accounting for about 18%. Asia, Oceania and Africa contribute 82%, 6%, and 5% of world chickpea production, respectively (Merga and Haji, 2019; Afzal, 2021). It plays an important role in the diet of human beings as a source of fiber, vitamins, carbohydrates, mineral salts, unsaturated fatty acids, and β-carotene (Shevkani *et al*., 2019). It is considered one of the most important food pulse legume, providing a major source of low-cost protein, calcium, iron, phosphorus and other minerals for millions of people especially in developing countries (Nasr Esfahani *et al*., 2014; Merga and Haji, 2019). It has occupied a prominent position among legumes due to its superior nutritional contents and health protective values (Jendoubi *et al*., 2017; Hussain *et al*., 2022). Its significant contribution to the food security of low-income countries like Ethiopia is an indisputable truth and it is a key component of subsistence agriculture (Varshney *et al*., 2014). Incorporating this crop into farming systems like crop rotations, the crop serves as an effective break crop for managing weeds and preventing outbreaks of soil and stubble borne diseases. Furthermore, its ability to fix atmospheric nitrogen into available and usable forms enhances soil fertility, offering valuable benefits for the following cereal crops (Fikre *et al*., 2020; Richards *et al*., 2022).

In Ethiopia, where 90% of chickpea production is achieved in sub-Saharan Africa; it is an economically valuable pulse crop grown by about one million smallholder farmers (Korbu *et al*., 2022). Chickpea has been an important food source for centuries and has long history in Ethiopia, where they are consumed in various forms including “Eshet” (immature pods), “Kolo” (soaked, roasted), “Nifro” (boiled seeds) and “wot” (stew) in the form of “shiro” (grounded chickpea flour). These preparations are often blended with cereals and/or legumes to create a nutritious meal for infants and young children (Fikre and Bekele, 2020). Despite its significance for economic stability and food security in Ethiopia, it experiences alarmingly low average productivity levels, currently at only 2 tons per hectare (CSA, 2022). This productivity falls far short of its potential of 5 tons per hectare (Keneni *et al*., 2012; Verkaart *et al*., 2017). The underlying causes of this underperformance in chickpea yield can be attributed to various biotic and abiotic constraints, with chickpea Fusarium wilt emerging as a particular determinant factor (Fikre and Bekele, 2020). This fungal disease, known for its widespread occurrence, has led to an estimated annual yield loss of 12–15%, depending upon disease incidence and severity (Trapero-Casas and Jimenez-Diaz, 1985).

The impact of chickpea Fusarium on production beyond immediate yield losses; it threatens the livelihood of farmers and exacerbates food insecurity in a region heavily reliant on chickpea as a staple crop. The disease not only reduces the quantity of the harvest but also compromises the quality, making affected products less marketable (Alsamman *et al*., 2023). *Fusarium oxysporum* f.sp. *ciceris,* causing chickpea Fusarium wilt, is a vascular pathogen that perpetuates in seed and soil making it difficult to manage by the use of chemical control alone (Sharma *et al*., 2012). Thus, the urgent need for effective and sustainable integrated Fusarium wilt management is apparent, as addressing Fusarium wilt is crucial for improving chickpea productivity. Moderately resistant chickpea varieties treated with seed dressing fungicides can reduce Fusarium wilt incidence by 60% (Zewdie 2019). Similarly, Mengist *et al*. (2018) reported that a minimum Fusarium wilt incidence of 23.4% was recorded on the Shasho chickpea variety treated with Apron Star fungicide which was much lower than the 65.6% incidence rate recorded in the untreated local variety. Additionally, fungicides such as Ridomil, Carbendazim and Bavistin have been found to be effective when used as a component of the integrated management of chickpea Fusarium wilt (Hossain *et al*., 2013; Venkataramanamma *et al*., 2023a,b). However, attempts on integrating two or more compatible management practices of Fusarium wilt that can lead to sustainable chickpea production are clearly limited. Besides, there is a noticeable gap in knowledge regarding the synergistic effects and compatibility of various management strategies on Fusarium wilt and chickpea performance. Assuring effective sustainable management is critically important, as it is heavily dependent on an integrated management approach. Therefore, the current research was initiated to: (1) appraise the synergistic effect of seed dressing fungicides, vermicompost application and varieties on Fusarium wilt pressure and yield of chickpea and pick out the best combinations; (2) evaluate the partial economic feasibility of the integrated chickpea Fusarium wilt management options.

## Methods

### DESCRIPTION OF STUDY AREAS

Field experiments were conducted in naturally Fusarium wilt infected fields in two selected districts, Bahir Dar Zuria and Fogera. Mixed farming system and unimodal rainfall distribution are common features of the two aforementioned experimental districts (Figs. 1 and 2). The dominant Fusarium wilt races in Ethiopia were race 2, 3 and race 4, which are widely distributed across major chickpea growing areas of the country, threatening chickpea production and productivity (Meki *et al*., 2008).

#### *Bahir Dar Zuria*

It is situated in the north-west part of Ethiopia and belongs to one of the districts in West Gojjam Administrative Zone within the Amhara National Regional State. The area is bordered to the south by the Yilmana Densa district, to the south-west by Mecha district, to the north-east by Gilgel Abay River, to the north by Lake Tana and to the east by South Gondar Zone. It is geographically located at 11° 15′ north latitude and 37° 10′ east longitude, with an altitude ranging from 1700 to 2300 m above sea level (Bimrew 2018; Debebe and Miteku 2023) (Fig. 1). Agriculture is the primary economic activity in the study area, with nearly the entire population depending on this sector (CSA 2021). The major crops grown in the area include maize (*Zea mays* L.), teff (*Eragrostis teff*), wheat (*Triticum aestivum* L.), and chickpea (*Cicer arietinum* L.) (CSA 2021). The soil in Bahir Dar Zuria has a clay texture, a black color, a pH of approximately 6.5. Furthermore, it possesses a cation exchange capacity of 58.7 meq/100 g and contains 3.3% organic carbon and total nitrogen of 681 mg/kg (Abewa *et al*., 2019).

#### *Fogera*

Fogera district located on the south-eastern shore of Lake Tana under south Gondar Administrative Zone about 55 km north of Bahir Dar, the capital city of Amhara National Regional State. It is bordered to the north by Libokemkem district, to the south by Dera district, to the west by Lake Tana and to the east by Farta district (Alebachew *et al*., 2023). It is geographically located 37°35′0″ E–37°58′0 0″ E and 11° 57′ 0″ N–12° 30′ 0″ N in the north-west highland of the Amhara Region of Ethiopia (Alebachew *et al*., 2023) (Fig. 1). The major crops grown in this district are rice (*Oryza sativa* L.), maize (*Zea mays* L.), and Teff [*Eragrostis tef* (Zucc.)] (Tiruneh *et al*., 2021). The district is also among the top producers of chickpea in the Amhara Region of Ethiopia (Warner *et al*., 2015). The soil pH in the cultivated lands of Fogera has reached up to 8.9 and is characterized by low organic carbon content ranging from 2% to 4% in 87.66% of the cropping land. Additionally, the available phosphorus in the area is above 20 ppm in 61.05% of the cropped land, with a cation exchange capacity of 0.75–2% found in 60.98% of the crop land (Tiruneh *et al*., 2021).

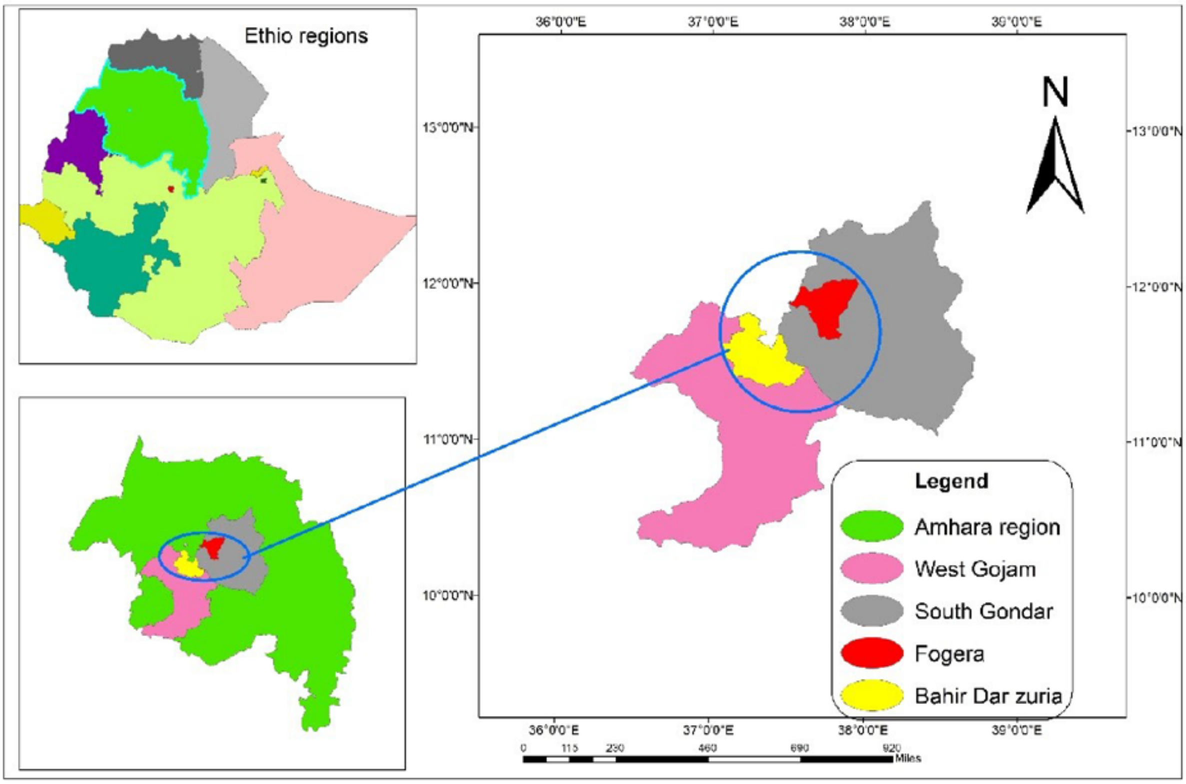


**Fig. 1.** Map displaying the geographical location of experimental location, Fogera and Bahir Dar Zuria districts.

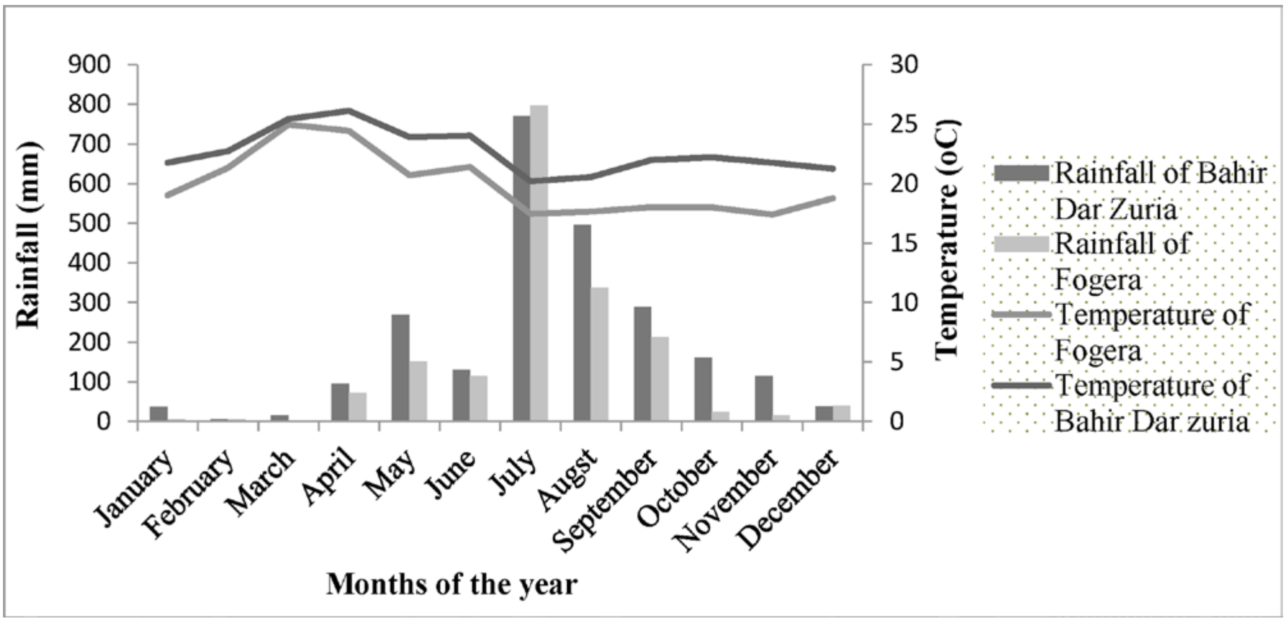


**Fig. 2.** Mean monthly rainfall and temperature of Bahir Dar Zuria and Fogera districts during the study period 2023 cropping season (source: Bahir Dar national meteorological agency).

## TREATMENTS AND EXPERIMENTAL DESIGN

Overall, 18 treatment combinations were randomly arranged in factorial randomized complete block design replicated three times. The treatments consisted of three chickpea varieties (Dehara, Natoli, and Arerti) combined with two seed dressing fungicides (Goldazim 500SC, Nobel 250 EC, and untreated) and vermicompost application (treated and untreated). The varieties were obtained from Debre Zeit Agricultural Research Center and Debre Berhan Agriculture Research Center. Goldazim fungicide is manufactured by Chimac-Agriphar SA of with active ingredients of 500 g/L carbendazim active ingredient. Nobel is manufactured by HELM AG and the fungicide contains Triadimefon as an active ingredient. Vermicompost was sourced from local farmers.

The inter-row and intra-row spacing were 30 and 15 cm, respectively. Each treatment was assigned randomly to experimental units within a block. The gross plot size was 1.5 m by 2 (3 $m^2$) with a distance of 1 and 0.5 m between blocks and plots, respectively. Each gross plot was consist of five rows of 2 m length.

### DATA COLLECTIONS

*Disease data*

Disease data were collected upon the appearance of common Fusarium wilt symptoms typically wilting and yellowing. Data collection was commenced at 42 days after sowing and continued at 10 days interval until 82 days after planting. Chickpea plants exhibiting wilting and yellowing symptoms were counted separately in each plot. Severity of Fusarium wilt disease was noted in a 1 $m^2$ quadrat using a five-point severity scale (0–4) based on percentage of foliar tissue exhibiting wilting and yellowing symptoms (Ali and Terefe 2021); where, 0 = 0% wilted plant; 1 = 1–20% wilted plant; 2 = 21–50% wilted plant; 3 = 51–100% wilted plant and 4 = plants collapsed or dead. Percent severity index (PSI) was determined from the severity scores for analysis. Diseases incidence and PSI was calculated using the mathematical formula as follows as

$$\text{Diseases incidence}\,(\%) = \frac{\text{No. of infected plants per quadrat}}{\text{Total number of plants inspected per quadrat}} \times 100 \quad (1)$$

$$\text{PSI}\,(\%) = \frac{\text{Sum of numerical ratings}}{\text{Total number of plants scored} \times \text{maximum score on scale}} \times 100 \quad (2)$$

Area under disease progress curve (AUDPC) was calculated for each treatment from the assessment of disease incidence by using the following formula:

$$\text{AUDPC} = \sum_{i-1}^{n-1} 0.5\left(x_{i+1} + x_i\right)\left(t_{i+1} - t_i\right) \quad (3)$$

where $x_i$ is the disease incidence in percentage at ith assessment, $t_i$ is the time of the ith assessment in days from the first assessment date, and $n$ is the total number of disease assessments.

*Crop data*

All relevant data on crop growth, yield, and yield attribute parameters were recorded from each plot starting from the date of sowing. The data for growth parameters and yield-related traits of chickpea was recorded from 10 randomly pre-tagged plants in each experimental plot. The number of branches per plant and the number of pods per plant were counted, while plant height was measured as the distance from the soil surface to the topmost point of the plant canopy, all at maturity stage. Grains were harvested and weighed. The resulting weight was adjusted to 11% grain moisture content and then computed to hectare basis. The other above ground organs (stems and leaves) were dried and weighed. The weight was considered as dry biomass when the weight remained constant over time. The total above ground biomass included grain, chaff, leaves, and stem biomasses.

Harvest index of each treatment was computed by dividing the weight of grain yield to the weight of total biomass yield as follows.

$$\text{Harvest index}\,(\%) = \frac{\text{Grain yield}}{\text{Biomass yield}} \times 100 \quad (4)$$

Besides, relative yield loss was computed on the basis of grain yield in each respective treatment using the formula as follows.

$$\text{Grain yield loss} = 1 - \frac{\text{Grain yield of chickpea in treatment}}{\text{Grain yield of chickpea in treatent } Y} \times 100 \quad (5)$$

where; $Y$ = the treatments which gave maximum grain yield over the other.

### STATISTICAL ANALYSIS

The collected data were subjected to analysis of variance (ANOVA) using SAS software (version 9.4). Mean comparison among all treatments was performed based on the least significant difference (LSD) test at 5% level of significance upon the presence of significant difference among treatments for ANOVA. Pearson's correlation analysis was employed to test the relationship between disease incidence and the various yield-related components and grain yield of chickpea.

### PARTIAL ECONOMIC ANALYSIS

As farmers endeavor to evaluate the economic benefits of one management practices over the other, partial budget analysis was done to identify the payoff treatments. The economic feasibility of treatments was determined based on net benefit analysis and marginal rate of return following the procedure developed by CIMMYT (1988). The cost and benefit of each treatment were analyzed partially, and the marginal rate of return was computed by considering the variable cost available in the respective treatment. CIMMYT (1988) reported that marginal analysis is concerned with the process of making choice, between alternative factor-product combinations considering small change. Economic analysis was conducted to evaluate the profitability of chickpea Fusarium wilt management options. The study included three chickpea varieties and assessed the effect of two seed dressing fungicides and vermicompost application. Average chickpea yield (kg $ha^{-1}$) was recorded for each treatments and adjusted yield was calculated. Thus, yield from on–farm experimental plots was adjusted downward by 10% for management difference to reconcile the difference between the experimental yield and the yield that farmers could expect from the same treatment. Gross revenue (\$ $ha^{-1}$) was determined by multiplying adjusted yield by the prevailing market price of chickpea. Total variable costs, including seed, fungicide, vermicompost and application costs, were recorded for each treatment. Net benefit (\$ $ha^{-1}$) was calculated by subtracting total variable costs from gross revenue of respective treatments. The marginal rate of return was also calculated to assess the profitability of incremental investments. Dominance analysis was performed to identify economically inefficient treatments. Treatments were considered dominated if another treatment yielded a higher net benefit with a lower or equal total variable cost.

## Results

### CHICKPEA FUSARIUM WILT INCIDENCE AND PERCENT SEVERITY INDEX

The ANOVA revealed that Fusarium wilt incidence and PSI were significantly impacted by the integrated management practices in both locations. The mean incidence of Fusarium wilt varied from 0.35% in Goldazim 500SC-treated Natoli variety with vermicompost application to 26.83% in the untreated Dehara variety. Similarly, the lowest PSI (0.81%) was recorded in the Natoli variety treated with Goldazim 500SC and vermicompost. In contrast, the untreated Dehara variety exhibited the highest PSI (25.94%) followed by the Dehara variety treated with only vermicompost, which had a PSI of 22.675 and the untreated Arerti variety with a PSI of 20.27% (Table 1). Overall, varieties that received both seed dressing fungicides and vermicompost exhibited the lowest incidence rates and PSI compared to their untreated counterparts (Fig. 3). The study results showed that the maximum relative yield loss of chickpea grain due to chickpea Fusarium wilt interference was

**Table 1.** Effect of integrated management on incidence, PSI and the yield loss caused by it at Fogera and Bahir Dar Zuria district during 2023/2024 cropping season.

| | Bahir Dar Zuria | | | Fogera | | |
|---|---|---|---|---|---|---|
| **Treatments** | **Inc. (%)** | **PSI (%)** | **YL (%)** | **Inc. (%)** | **PSI (%)** | **YL (%)** |
| Dehra (untreated) | 26.83$^{a}$ | 25.94$^{a}$ | 27.80 | 21.8$^{a}$ | 20.48$^{a}$ | 22.96 |
| Dehra + vermicompost | 24.47$^{ab}$ | 22.67$^{ab}$ | 19.40 | 19.3$^{ab}$ | 17.73$^{ab}$ | 17.62 |
| Arerti (untreated) | 21.72$^{bc}$ | 20.27$^{bc}$ | 14.17 | 17.5$^{bc}$ | 14.81$^{bc}$ | 12.27 |
| Dehra + Nobel 250 EC | 20.86$^{cd}$ | 19.04$^{cd}$ | 19.01 | 16.2$^{cd}$ | 14.6$^{c}$ | 17.22 |
| Arerti + Nobel 250 EC | 18.44d$^{e}$ | 16.7$^{de}$ | 14.04 | 15.8$^{cd}$ | 14.5$^{c}$ | 12.14 |
| Dehra + Nobel 250 EC + vermicompost | 18.23$^{de}$ | 16.6$^{de}$ | 17.69 | 15.7$^{cd}$ | 13.82$^{c}$ | 19.37 |
| Dehra + Goldazim 500SC | 18.07$^{de}$ | 16.12$^{de}$ | 18.42 | 15.6$^{cd}$ | 12.33$^{c}$ | 16.61 |
| Arerti + vermicompost | 18.02$^{de}$ | 16.03$^{de}$ | 13.8 | 15.1$^{cd}$ | 12.26$^{cd}$ | 11.94 |
| Dehra + Goldazim 500SC + vermicompost | 17.15$^{e}$ | 15.07$^{e}$ | 14.01 | 14.4$^{d}$ | 10.68$^{cd}$ | 12.1 |
| Arerti + Goldazim 500SC | 13.34$^{f}$ | 11.28$^{f}$ | 12.1 | 11.2$^{e}$ | 9.52$^{de}$ | 10.12 |
| Natoli + vermicompost | 13.08$^{fg}$ | 11.09$^{f}$ | 4.06 | 10.9$^{e}$ | 9.2$^{def}$ | 1.81 |
| Natoli (untreated) | 12.8$^{fg}$ | 10.69$^{f}$ | 7.34 | 10.7$^{e}$ | 8.85$^{efg}$ | 5.52 |
| Natoli + Nobel 250 EC | 12.16$^{fg}$ | 9.94$^{fg}$ | 6.64 | 10.2$^{e}$ | 8.6$^{efg}$ | 4.57 |
| Arerti + Nobel 250 EC + vermicompost | 10.3$^{gh}$ | 8.14$^{fgh}$ | 14.0 | 8.6$^{ef}$ | 7.02$^{efg}$ | 12.09 |
| Arerti + Goldazim 500SC + vermicompost | 8.9$^{hi}$ | 6.94$^{gh}$ | 8.46 | 7.4$^{fg}$ | 6.4$^{fgh}$ | 6.43 |
| Natoli + Nobel 250 EC + vermicompost | 8.83$^{hi}$ | 6.89$^{gh}$ | 6.38 | 7.3$^{fg}$ | 7.8$^{gh}$ | 4.31 |
| Natoli + Goldazim 500SC | 7.05h$^{i}$ | 5.05$^{h}$ | 4.12 | 5.9$^{g}$ | 4.19$^{h}$ | 2.01 |
| Natoli + Goldazim 500SC + vermicompost | 0.67$^{j}$ | 1.61$^{i}$ | 0.00 | 0.6$^{h}$ | 0.35i | 0.00 |
| p-value | 0.036 | 0.046 | — | 0.034 | 0.49 | — |
| CV | 11.38 | 13.63 | — | 12.91 | 15.28 | — |
| $LCD_{(0.05)}$ | 3.2 | 3.42 | — | 2.67 | 2.81 | — |

Means followed by the same letters in the same columns are statistically not significant; Where; Inc. = incidence; PSI = percent severity index; and YL = yield loss due to chickpea Fusarium wilt disease.

22.9% in the Bahir Dar Zuria and 27.8% in the Fogera district, both recorded in the untreated Dehra variety in the plots with the highest wilt intensity at these locations.

## DISEASE PROGRESS RATE AND AREA UNDER DISEASE PROGRESS CURVE

The progression rate of chickpea Fusarium wilt incidence in tested chickpea varieties, treated with the seed dressing fungicides Goldazim 500SC and Nobel 250 EC alongside untreated control and application of organic matter is compellingly illustrated in Fig. 4. Notably, the incidence of chickpea Fusarium wilt rose significantly from the initial to final assessments, showcasing a concerning upward trend in disease development among all three chickpea varieties. This evidence underscores the critical impact of fungicide treatments in managing chickpea Fusarium wilt, highlighting the importance of integrated Fusarium wilt management practices to safeguard chickpea crop health. The results indicate that the Fusarium wilt progression rate was slower in the Natoli variety followed by the Arerti variety, compared to the Dehara variety (Figs. 4 and 5). Chickpea Fusarium wilt progress rate in three chickpea varieties treated with seed dressing fungicides is illustrated in Figs. 4 and 5. Thus, the result revealed that the rate of Fusarium wilt progression was slowest in varieties treated with Goldazim 500SC followed by those treated with Nobel 250 EC, compared to untreated varieties. ANOVA showed that AUDPC %-day was significantly influenced by chickpea varieties, seed dressing fungicides, organic matter application, and their interaction at $p < 0.05$. Notably, the Natoli variety treated with Goldazim 500SC seed dressing fungicide and organic matter exhibited the lowest AUDPC %- day value. The Arerti variety, under similar treatment conditions, also showed a comparable performance. In contrast, the untreated Dehara variety retained the highest AUDPC %- day value followed by the untreated Arerti variety.

## YIELD COMPONENTS OF CHICKPEA

The ANOVA revealed that the interaction of seed dressing fungicides, vermicompost application, and varieties had significantly influenced the number of pods per plant, hundred seeds weight, pods per plant, and grain yield of chickpea. In general, all treated varieties had at least a better mean value over untreated similar varieties. Thus, the Natoli variety treated with seed dressing Goldazim 500SC and application of vermicompost scored the maximum number of pods per plant (45.6), number of branches per plant (7.7) at Bahir Dar Zuria, and hundreds seed weight (30.74) at Fogera. However, the lowest number of pods and branches per plant was recorded from untreated Dehra variety with mean values of 32.2 and 4.8, respectively. The least hundred seed weight was acquired from untreated Arerti variety having mean value of 18.09 (Table 2). In addition, the harvest index was also greatly impacted by the integrated management

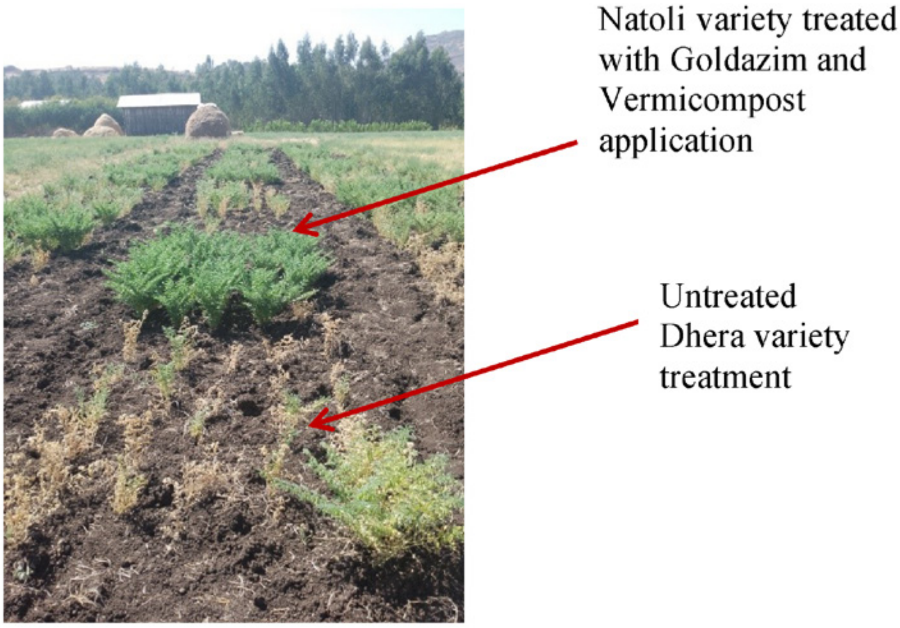


**Fig. 3.** Chickpea Fusarium wilt intensity as impacted by integrated managements: Natoli variety treated with Goldazim 500SC and vermicompost application and Dhera variety without any treatment in Bahir Dar Zuria district.

practices. The highest (49.6%) harvest index was obtained from Natoli variety treated with Goldazim 500SC and vermicompost, which was statistically in par with other management combinations with Natoli except the untreated one (Table 3).

## YIELD OF CHICKPEA

The ANOVA depicted that seed dressing fungicides, vermicompost application, and varieties optimally interacted and significantly influenced grain and biological yield of chickpea. Broadly speaking, the grain yield of chickpea harvested from vermicompost-treated plots and seed dressing fungicides was increased over untreated varieties. In examining the three-way interaction effects, the Natoli variety stands out with an impressive grain yield of 2965.1 kg ha$^{-1}$ when treated with Goldazim 500SC and organic matter at Bahir Dar Zuria, reflecting the remarkable potential of this combination. The Arerti variety also displayed a significant result, yielding 2714.3 kg ha$^{-1}$ under the same treatment. Conversely, untreated Dehara variety fell short, producing only 2334.1 kg ha$^{-1}$ in Fogera.

## ASSOCIATION OF DISEASE, YIELD AND YIELD COMPONENTS

The correlation analysis reveals a clear and concerning trend: the intensity of chickpea Fusarium wilt, measured by incidences and PSI is strongly and negatively correlated with grain yield in both Bahir Dar Zuria and Fogera. This indicates that as disease pressure increases, there is a significant reduction in harvestable grain. In Bahir Dar Zuria, incidence of chickpea Fusarium wilt showed a strong negative correlation between number of pods per plant ($r = -0.814$), number of branches per plant ($r = -0.756$), grain yield ($r = -0.857$), and harvest index ($r = -0.795$). Thus, as chickpea Fusarium wilt incidence increases these yield component parameters decrease significantly. Similar to Bahir Dar Zuria, incidence exhibited a strong negative correlation with number of pods per plant ($r = -0.823$), grain yield ($r = -0.831$) and harvest index ($r = -0.806$) in Fogera. On the other hand, plant height and 100 seed weight were strongly correlated in a positive manner. However, it was due to the characteristics of varieties in which the Dhera variety was taller and had large seeds, whereas Natoli and Arerti were characterized by short height and smaller seeds.

The high correlation coefficient (r) with negative values, particularly between grain yield and number of pods per plant, highlights direct and harmful impact of chickpea Fusarium wilt on key yield components. Furthermore, the analysis reveals a complex relationship between Fusarium wilt and various factors that contribute to yield. Notably, the strong positive correlations observed between plant height and 100-seed weight, suggest that taller plants tend to produce heavier seeds. This may indicate a link between plant vigor and seed development. However, the significant negative correlation between disease intensity and harvest index is particularly noteworthy, as it suggests a reduction in the plant's efficiency to convert biomass into grain under diseases pressure. This implies that not only does disease reduce overall yield, but it also disrupts the allocation of resources, consequently affecting both the quality and quantity of the harvest. Finally, the consistent correlation patterns observed between Bahir Dar Zuria and Fogera suggest that these relationships are not confined to specific locations but reflect a broader trend in chickpea production. Overall, the correlation analysis offers valuable insight into the impact of chickpea Fusarium wilt disease, emphasizing the importance of integrated management approaches to mitigate yield loss and ensure sustainable production (Table 4).

## PARTIAL BUDGET ANALYSIS

The result of the partial economic analysis showed that the uppermost total variable cost (\$ 164.48 ha$^{-1}$) was recorded for the Dehara variety treated with Nobel 250 EC and receiving vermicompost application. The maximum net benefit of USD 2048.93 ha$^{-1}$ was achieved in the Natoli variety treated with Goldazim 500SC fungicide. This was followed by the Natoli variety treated with Goldazim 500SC and supplemented with the application of vermicompost, which resulted in the net benefit of \$ 1998.07 ha$^{-1}$. The highest marginal rate of return of \$ 628.92 ha$^{-1}$ was observed in the Natoli variety treated with Goldazim 500SC and supplemented with vermicompost. This was followed by the Natoli variety receiving only vermicompost, which gave a marginal rate of return of \$ 519.96 per hectare. Thus, Natoli-based treatments, particularly those involving Goldazim 500SC and vermicompost,

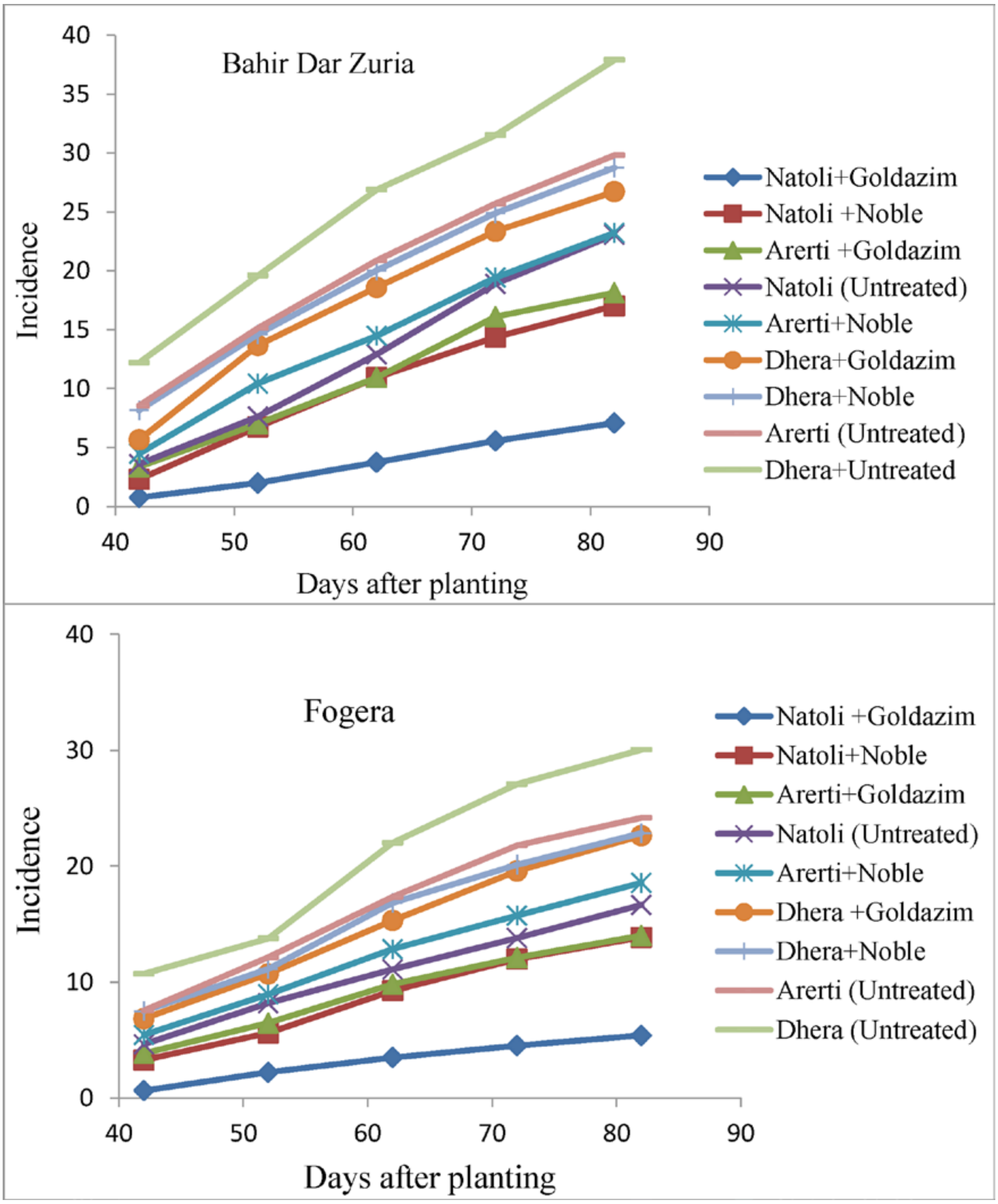


**Fig. 4.** Comparative progress of chickpea Fusarium wilt incidence in chickpea varieties treated with seed dressing fungicides at Bahir Dar Zuria and Fogera district.

consistently demonstrate the highest net benefits and marginal rate of return, suggesting they are the most profitable options. On the other hand, untreated controls treatments involving Dehara generally show lower net benefits and often dominance, indicating they are less economically viable (Table 5).

## Discussion

Chickpea Fusarium wilt, which is a globally recognized menace, wielding substantial deleterious impacts on chickpea crop yields and quality (Alsamman *et al*., 2023). The significant disparity in disease intensity, yield component, and yield of chickpea across different treatments stems from the affirmative interaction of dressing fungicides, varieties, and vermicompost application. The aforementioned three factors could greatly contribute to the reduction of the causal pathogen epidemics, promoting the rapid growth and establishment of chickpea crop, thereby reducing overall wilt intensity and enhancing the upcoming grain yield. Chickpea Fusarium wilt incidence and PSI were significantly influenced by the application of integrated management. Thus, the highest mean wilt incidence (26.83%) and PSI (25.94%) were recorded from untreated Dehra variety. On the other hand, the Natoli variety treated with Goldazim 500SC seed dressing fungicide supplemented with vermicompost application expressed mean wilt incidence and PSI of less than 1%. The synergetic interaction could lead to a reduction of inoculum amount in the soil and hinder the development and subsequent infection of Fusarium wilt to the host crop. Likewise, Alefe *et al*. (2022) reported that moderately resistant chickpea varieties treated with dressing fungicides reduced the disease incidence to a considerable extent in Sekota

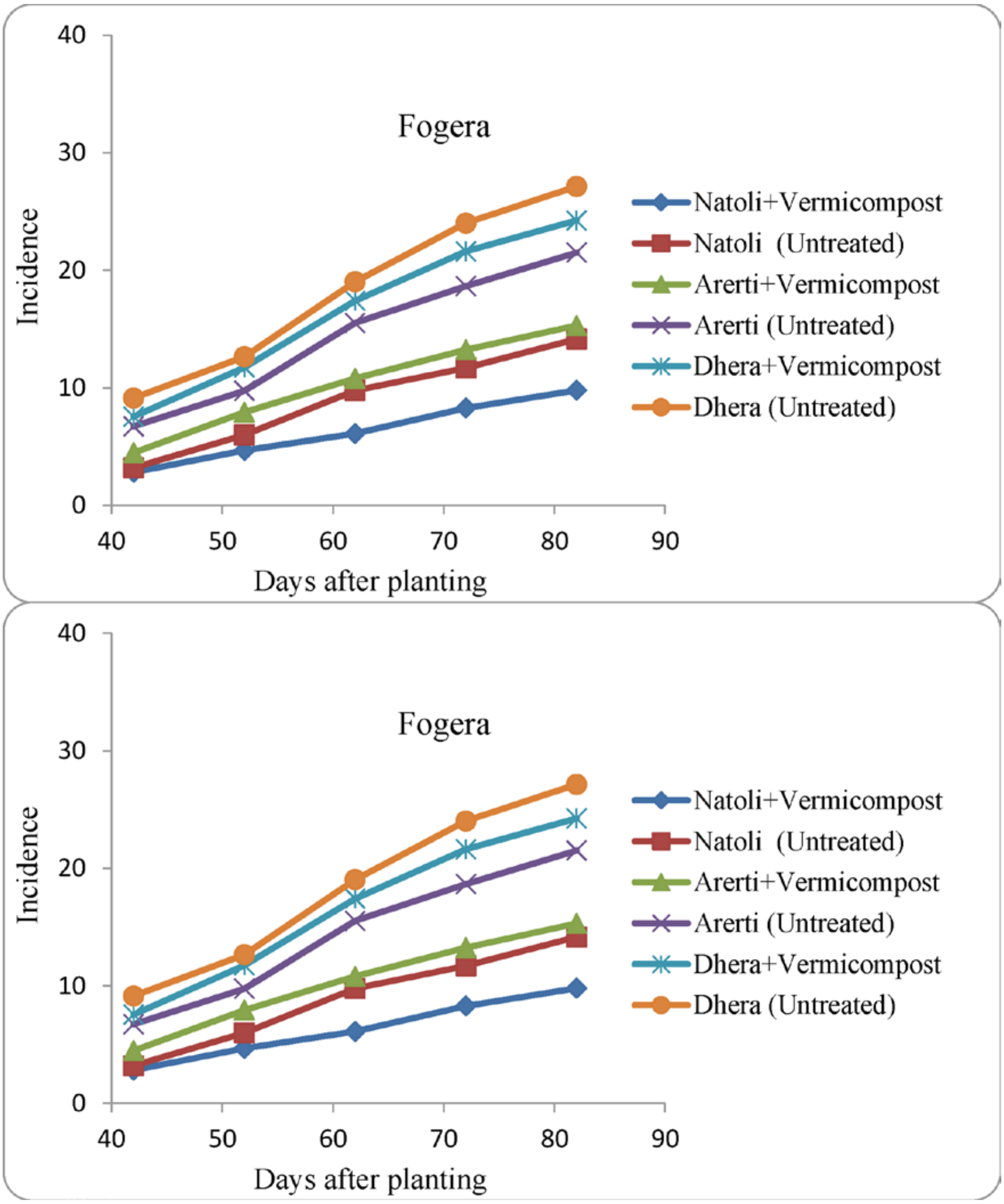


**Fig. 5.** Comparative progress of chickpea Fusarium wilt incidence in chickpea varieties treated with and without vermicompost at Bahir Dar Zuria and Fogera district.

Zuria and Lasta Lalibela districts. Besides, Zewdie (2019) reported that Arerti variety treated with seed dressing fungicide resulted in a lower incidence of Fusarium wilt in Ethiopia. Further to this, Bhimani (2020) reported that Carbendazim 50% wettable powder (WP) showed the least disease incidence of 23.33% and 76.66% increase over control, which retained an incidence of 99.98%. According to Sahni (2021), the combined treatment of 15% vermicompost, seed bacterization and pre-inoculation foliar spray of salicylic acid resulted in complete suppression against *Fusarium oxysporum* f.sp. *ciceris*. Different chickpea varieties expressed significant variation in terms of wilt incidence ranging from 2.7% in Dalota variety to 13.5% in the local check at Adet in West Gojjam zone of Amhara regional state (Gebeyaw *et al*., 2024b). A study conducted on cucumber plant showed that vermicompost treatment showed a significant reduction in the incidence of Fusarium wilt and increased plant height, stem diameter, leaf area, and ultimately increased fruit yield (Zhang *et al*., 2020).

The yield and yield components of chickpea were significantly influenced by the integrated management. Grain yield, biomass yield, and yield attributes of chickpea, including number of primary branches per plant, number of pods per plant, and hundred seed weight, were significantly affected by the interaction of seed dressing fungicides and vermicompost application in different varieties. Thus, varieties that received seed dressing fungicide treatment and vermicompost application retained improved yield and yield components over untreated one. The highest yield in varieties treated with both seed dressing fungicides and vermicompost compared to untreated varieties is likely due to a reduction in disease pressure. This resulted in a better crop stand;

**Table 2.** Effect of integrated chickpea Fusarium wilt management on yield attributes of chickpea at Bahir Dar Zuria district and Fogera during 2023/2024 cropping season.

| | Bahir Dar Zuria | | | Fogera | | |
|---|---|---|---|---|---|---|
| Treatments | NPP | NBP | HSW | NPP | NBP | HSW |
| Natoli + Goldazim 500SC + vermicompost | 45.6[a] | 7.7[a] | 28.64[de] | 43.98[a] | 6.79[a] | 30.74[bcd] |
| Natoli + Goldazim 500SC | 38.4[b] | 6.2[b] | 28.49[ef] | 36.97[b] | 5.94[ab] | 29.76[cde] |
| Natoli + vermicompost | 38.1[b] | 6.1[b] | 28.75[cde] | 37.07[b] | 5.88[b] | 30.02[bcde] |
| Natoli + Nobel 250 EC + vermicompost | 37.5[b] | 5.9[bc] | 28.68[cde] | 36.47[bcd] | 5.77[bc] | 29.95[bcde] |
| Natoli + Nobel 250 EC | 37.4[bc] | 5.8[bc] | 27.00[f] | 36.37[bcd] | 5.65[bcde] | 28.27[e] |
| Natoli (untreated) | 37.1[bc] | 5.9[bc] | 27.76[ef] | 35.79[bcde] | 5.70[bcd] | 29.03[de] |
| Arerti + Goldazim 500SC + vermicompost | 36.7[bcd] | 5.8[bcd] | 21.93[g] | 35.65[bcde] | 4.94[cdefg] | 23.2[f] |
| Arerti + Goldazim 500SC | 35.2[cde] | 5.5[cde] | 21.45[gh] | 34.21[bcde] | 5.33[bcdef] | 22.72[f] |
| Arerti + vermicompost | 34.5[def] | 5.4[def] | 20.33[h] | 33.48[bcde] | 5.19[bcdef] | 23.16[f] |
| Arerti + Nobel 250 EC + vermicompost | 34.4[efg] | 5.3[def] | 20.90[gh] | 33.44[bcde] | 5.45[bcdef] | 22.17[f] |
| Dehra + Goldazim 500SC + vermicompost | 34.4[efg] | 5.3[def] | 32.40[a] | 32.57[bcdef] | 5.35[bcdef] | 34.15[a] |
| Arerti + Nobel 250 EC | 34.4[efg] | 5.4[def] | 21.55[gh] | 33.42[bcde] | 5.18[bcdef] | 22.32[f] |
| Arerti (untreated) | 34.3[efgh] | 5.3[def] | 18.09[i] | 33.37[bcde] | 4.83[defg] | 17.95[g] |
| Dehra + Nobel 250 EC + vermicompost | 32.9[fgh] | 5.2[efg] | 30.11[bcd] | 32.14[bcdef] | 4.90[cdefg] | 31.51[bc] |
| Dehra + Goldazim 500SC | 32.7[fgh] | 5.0[fg] | 30.26[bc] | 31.68[cdef] | 4.84[defg] | 31.53[bc] |
| Dehra + Nobel 250 EC | 32.4[fgh] | 4.9[fg] | 30.21[bcd] | 31.44[def] | 4.79[fg] | 31.08[bc] |
| Dehra + vermicompost | 32.3[gh] | 4.9[fg] | 30.98[ab] | 30.89[ef] | 4.76[fg] | 32.01[a] |
| Dehra (untreated) | 32.2[h] | 4.8[g] | 30.48[b] | 27.90[f] | 4.11[g] | 30.41[bcde] |
| $LCD_{(0.05)}$ | 2.18 | 0.47 | 1.58 | 2.69 | 0.88 | 2.2 |
| CV | 3.7 | 5.06 | 3.5 | 4.74 | 10.05 | 4.9 |
| p-value | 0.048 | 0.041 | 0.042 | 0.042 | ns | 0.039 |

Means followed by the same letters in the same columns are statistically not significant; Where; NPP = number of pods per plant and NBP = number of branches per plant, HSW = hundred seed weight.

increased branching, and greater accumulation of dry matter. Seed dressing fungicides effectively reduce the causal pathogen inoculum, while vermicompost provides essential nutrients and improves soil health, improves soil health and supports beneficial soil organisms. Together these factors enhance yield attributes and chickpea yield. This resulted in enhancing yield attributes and yield of chickpea. Studies indicate that chickpea receiving vermicompost fortification exhibited significantly higher plant height, aboveground biomass, number of pods per plant and photosynthetic pigments, significantly enhanced the chickpea productivity (Yadav and Garg 2015; Rehman *et al*., 2023). This aligns with finding from Abera *et al*. (2011), who reported that incorporating green manure and dried plant residue enhanced chickpea grain yield. Furthermore, Mengist *et al*. (2018) revealed that chickpea varieties treated with protective fungicides Apron Star achieved maximum grain yield and most yield-related traits of chickpea in north-west Ethiopia. Application of vermicompost alone at the rate of 5t $ha^{-1}$ gave the maximum yield of 1679 kg $ha^{-1}$ and harvest index of 43.88%, which resulted in a yield advantage of 27.4% over the control (Kaur *et al*., 2023). According to Yadav and Garg (2015), the number of pods per plant is an important yield contributing parameter in chickpea and it was significantly affected by the application of vermicompost, which varied from 5.3 in the control to 19.3 in vermicompost-treated chickpea at a rate of 20%.

The grain yield loss of chickpea due to Fusarium wilt represents a significant challenge to chickpea growers, impacting both productivity and economic viability. As noted, the yield loss of 22.96% and 27.8% at the maximum disease incidence and severity could be due to the influence of chickpea Fusarium wilt affecting yield contributing components, and ultimately the grain yield. Meki *et al*. (2008) highlighted about 30% loss of grain yield of chickpea due to chickpea Fusarium wilt interference under Ethiopian conditions, showcasing the impact of chickpea Fusarium wilt in chickpea production. Besides, the yield losses due to Fusarium wilt could escalate to 100% reliant on varietal susceptibility, favorable climatic variables (Chand and Khirbat, 2009). Furthermore, Mengist *et al*. (2018) reported that relative grain yield losses due to chickpea Fusarium wilt varied from 13.4% in Arerti variety treated with Apron Star fungicide to 95.38% in untreated local chickpea variety under sick plot condition. The susceptibility of chickpea varieties to Fusarium wilt also plays a critical role in determining yield losses, as plant resistance to disease is a result from the dynamic interaction between host, pathogen, environment, and temporal factors (Shikha *et al*., 2024). Besides, it is considerable capital value to consider that yield loss caused by Fusarium wilt is not only attributed to direct damage but also to secondary effects such as lower quality seeds (Navas-Cortes *et al*., 2000; Alsamman *et al*., 2023). Seeds sourced from wilted chickpea plants are often

**Table 3.** Effect of integrated management on yield, biomass yield and harvest index at Fogera and Bahir Dar Zuria district during 2023/2024 cropping season.

| | Bahir Dar Zuria | | | Fogera | | |
|---|---|---|---|---|---|---|
| **Treatments** | **Yield (kg ha$^{-1}$)** | **BioY (kg ha$^{-1}$)** | **HI (%)** | **Yield (kg ha$^{-1}$)** | **BioY (kg ha$^{-1}$)** | **HI (%)** |
| Natoli + Goldazim 500SC + vermicompost | 2965.1$^{a}$ | 5979.2$^{a}$ | 49.6$^{a}$ | 2819.5$^{a}$ | 6153.8$^{a}$ | 46.34$^{a}$ |
| Natoli + vermicompost | 2844.7$^{b}$ | 5955.6$^{ab}$ | 48.68$^{ab}$ | 2768.4$^{a}$ | 6142.6$^{a}$ | 44.97$^{ab}$ |
| Natoli + Goldazim 500SC | 2842.8$^{b}$ | 5905.2$^{abc}$ | 48.2$^{ab}$ | 2763.2$^{ab}$ | 6123.7$^{a}$ | 45.12$^{ab}$ |
| Natoli + Nobel 250 EC + vermicompost | 2775.9$^{c}$ | 5704.2$^{abcdef}$ | 48.18$^{ab}$ | 2698.1$^{bc}$ | 5915.1$^{bcde}$ | 45.63$^{ab}$ |
| Natoli + Nobel 250 EC | 2768.1$^{c}$ | 5742.6$^{abcde}$ | 48.14$^{ab}$ | 2690.6$^{c}$ | 5951.4$^{bc}$ | 45.2$^{ab}$ |
| Natoli (untreated) | 2747.6$^{c}$ | 5702.4$^{abcdef}$ | 47.89$^{b}$ | 2664.0$^{c}$ | 5912.9$^{bcde}$ | 43.36$^{c}$ |
| Arerti + Goldazim 500SC + vermicompost | 2714.3$^{C}$ | 5666.9$^{bcdef}$ | 47.76$^{b}$ | 2638.3$^{d}$ | 5876.6$^{bcde}$ | 44.89$^{b}$ |
| Arerti + Goldazim 500SC | 2607.2$^{d}$ | 5715.7$^{abcdef}$ | 45.63$^{c}$ | 2534.2$^{de}$ | 5927.1$^{bcd}$ | 42.77$^{c}$ |
| Arerti + vermicompost | 2554.3$^{d}$ | 5608.1$^{cdef}$ | 45.59$^{cd}$ | 2482.8$^{ef}$ | 5815.6$^{cdef}$ | 42.74$^{c}$ |
| Arerti + Nobel 250 EC + vermicompost | 2550.1$^{d}$ | 5708.8$^{abcd}$ | 44.23$^{cde}$ | 2478.7$^{ef}$ | 6023.27$^{ab}$ | 41.15$^{d}$ |
| Dehra + Goldazim 500SC + vermicompost | 2549.8$^{d}$ | 5789.8$^{abcd}$ | 44.1d$^{e}$ | 2478.4$^{ef}$ | 6007.3$^{ab}$ | 41.26$^{d}$ |
| Arerti + Nobel 250 EC | 2548.7$^{d}$ | 5777.4$^{abcd}$ | 44.04$^{e}$ | 2477.3$^{ef}$ | 5991.2$^{ab}$ | 41.35$^{d}$ |
| Arerti (untreated) | 2544.8$^{d}$ | 5784.4$^{abcd}$ | 44.02$^{e}$ | 2473.6$^{f}$ | 5998.4$^{ab}$ | 41.12$^{d}$ |
| Dehra + Nobel 250 EC + vermicompost | 2440.6$^{e}$ | 5544.1$^{def}$ | 43.98$^{e}$ | 2273.3$^{g}$ | 5749.2$^{efg}$ | 41.26$^{d}$ |
| Dehra + Goldazim 500SC | 2419.0$^{e}$ | 5561.6$^{def}$ | 43.90$^{e}$ | 2351.2$^{g}$ | 5767.4$^{defg}$ | 40.77$^{d}$ |
| Dehra + Nobel 250 EC | 2401.4$^{e}$ | 5429.2$^{f}$ | 43.75$^{e}$ | 2334.1$^{g}$ | 5630.1$^{gh}$ | 41.46$^{d}$ |
| Dehra + vermicompost | 2389.8$^{e}$ | 5461.8$^{ef}$ | 43.49$^{e}$ | 2322.8$^{g}$ | 5663.9$^{fgh}$ | 41.01$^{d}$ |
| Dehra (untreated) | 2140.7$^{f}$ | 5428.4$^{f}$ | 39.45$^{f}$ | 2172.2$^{h}$ | 5559.3$^{h}$ | 37.49$^{e}$ |
| LCD (5%) | 63.59 | 165.79 | 1.503 | 65.91 | 269.52 | 1.218 |
| CV (%) | 1.47 | 1.75 | 1.99 | 1.57 | 2.02 | 1.72 |
| p-value | 0.011 | 0.032 | 0.0023 | 0.013 | 0.018 | 0.047 |

Means followed by the same letters in the same columns are statistically not significant; Bio Y = Biological yield; HI = harvest index

lighter, rougher, and duller, hindering the production of viable seeds than those harvested from healthy chickpea plants (Navas-Cortes *et al*., 2000).

## CONCLUSION

The study comprehensively evaluated the efficacy of integrated management practices, including seed dressing fungicides and vermicompost application on different varieties, in mitigating chickpea Fusarium wilt and enhancing yield of chickpea. The results unequivocally demonstrate that integrated approaches significantly reduce disease incidence and severity, leading to substantial improvement in yield and yield components of chickpea. The Natoli variety particularly when treated with Goldazim 500SC and Vermicompost, consistently exhibited the lowest disease incidence and severity, alongside the highest grain yield, number of pods per plant and hundred seeds weight. This highlights the synergetic effect of combining fungicides and organic interventions. Goldazim 500SC effectively reduces pathogen inoculum, while vermicompost improved soil health and nutrient availability, fostering robust plant growth and resilience. In conclusion, this study provides valuable insights into the effective management of chickpea Fusarium wilt. The integrated application of seed dressing fungicides and vermicompost, in moderately resistant varieties like Natoli, offers a promising strategy for minimizing the adverse impact of Fusarium wilt and maximizing chickpea productivity.

## CONFLICT OF INTEREST

All the authors declare that there is no potential conflict of interest.

## ETHICS STATEMENT

The authors confirm that the research meets any required ethical guidelines, including adherence to the legal requirements of the study country.


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## AUTHOR CONTRIBUTIONS

All authors contributed equally to the development of this article.

## AUTHORS' DECLARATIONS

The author declare that the manuscript has not been submitted to any publisher.


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No external fund is received for this work.

**Table 4.** Correlation coefficient (r) between disease intensity parameters and yield and yield contributing components of chickpea in Bahir Dar Zuria and Fogera during 2023 cropping season.

| | | **INC** | **PSI** | **PH** | **NPP** | **NBPP** | **GRY** | **BMY** | **HI** | **100SW** |
|---|---|---|---|---|---|---|---|---|---|---|
| Bahir Dar Zuria | INC | 1.00** | | | | | | | | |
| | PSI | 0.949** | 1.00** | | | | | | | |
| | PH | −0.104 | −0.109 | 1.00** | | | | | | |
| | NPP | −0.814** | −0.764** | 0.150 | 1.00** | | | | | |
| | NBPP | −0.756** | −0.669* | 0.141 | 0.915** | 1.00** | | | | |
| | GRY | −0.857** | −0.798** | 0.097 | 0.878** | 0.754** | 1.00** | | | |
| | BMY | −0.652* | −0.624* | 0.087 | 0.685* | 0.548* | 0.755** | 1.00** | | |
| | HI | −0.795** | −0.776** | 0.155 | 0.745* | 0.685* | 0.870** | 0.469 | 1.00** | |
| | 100SW | 0.091** | 0.095 | 0.892** | −0.007 | 0.011 | −0.124 | 0.224 | −0.057 | 1.00** |
| Fogera | INC | 1.00** | | | | | | | | |
| | PSI | 0.958** | 1.00** | | | | | | | |
| | PH | −0.088 | −0.102 | 1.00** | | | | | | |
| | NPP | −0.823** | −0.812** | 0.104 | 1.00** | | | | | |
| | NBPP | −0.642 | −0.707* | 0.126 | 0.736** | 1.00** | | | | |
| | GRY | −0.831** | −0.808** | 0.071 | 0.863** | 0.649* | 1.00** | | | |
| | BMY | −0.493 | −0.435 | −0.143 | 0.546* | 0.485 | 0.695* | 1.00** | | |
| | HI | −0.81** | −0.813** | 0.164 | 0.816** | 0.574* | 0.912** | 0.339 | 1.00** | |
| | 100SW | 0.056 | 0.038 | 0.884** | −0.006 | 0.157 | −0.062 | −0.169 | 0.003 | 1.00** |

Where, INC = incidence; PSI = percent severity index; PH = plant height; NBPP = number of branches per pod; NPP = number of pods per plant; GRY = grain yield; BMY = biomass yield; HI = harvest index; 100SW = hundred seeds weight. The symbols ** and * indicate strong and moderate correlations respectively.

**Table 5.** Partial economic analysis of integrated chickpea management options, showing the impact of varieties, fungicides, and vermicompost treatments.

| Treatments | Average yield (kg ha$^{-1}$) | Adjusted yield (kg ha$^{-1}$) | Gross revenue (\$ ha$^{-1}$) | Total variable cost (\$ ha$^{-1}$) | Net benefit (\$ ha$^{-1}$) | MRR (\$ ha$^{-1}$) | Dominance |
|---|---|---|---|---|---|---|---|
| Arerti (untreated) | 2509.2 | 2258.3 | 1829.21 | 40.5 | 1788.71 | | |
| Natoli (untreated) | 2705.8 | 2435.2 | 2021.23 | 41.5 | 1979.73 | 191.02 | |
| Dehra (untreated) | 2156.5 | 1940.8 | 1669.32 | 43.0 | 1626.32 | ¯235.61 | D |
| Arerti + Goldazim 500 SC | 2570.7 | 2313.6 | 1874.04 | 43.98 | 1830.06 | 207.9 | |
| Arerti + Nobel 250 EC | 2513.0 | 2261.7 | 1831.98 | 44.46 | 1787.52 | −88.63 | D |
| Natoli + Goldazim 500 SC | 2803.1 | 2522.8 | 2093.91 | 44.98 | 2048.93 | 502.71 | |
| Natoli + Nobel 250 EC | 2729.4 | 2456.5 | 2038.86 | 45.48 | 1993.38 | −111.1 | D |
| Dehra + Goldazim 500SC | 2385.1 | 2146.6 | 1846.07 | 46.48 | 1799.59 | −193.79 | D |
| Dehra + Nobel 250 EC | 2367.7 | 2130.9 | 1832.60 | 46.96 | 1785.64 | 29.06 | |
| Arerti + vermicompost | 2518.6 | 2266.7 | 1836.05 | 158.0 | 1678.05 | −0.97 | |
| Natoli + vermicompost | 2806.6 | 2525.9 | 2096.53 | 158.5 | 1938.03 | 519.96 | |
| Dehra + vermicompost | 2356.3 | 2120.7 | 1823.78 | 160.5 | 1663.28 | −137.38 | D |
| Arerti + Goldazim 500 SC + vermicompost | 2676.3 | 2408.7 | 1951.02 | 161.48 | 1789.54 | 128.84 | |
| Arerti + Nobel 250 EC + vermicompost | 2514.4 | 2263.0 | 1832.99 | 161.96 | 1671.03 | −246.89 | |
| Natoli + Goldazim 500 SC + vermicompost | 2892.3 | 2603.1 | 2116.55 | 162.48 | 1998.07 | 628.92 | |
| Natoli + Nobel 250 EC + vermicompost | 2737.0 | 2463.3 | 2044.54 | 162.96 | 1881.58 | −242.69 | D |
| Dehra + Goldazim 500 SC + vermicompost | 2514.1 | 2262.7 | 1945.92 | 163.98 | 1781.94 | −97.69 | |
| Dehra + Nobel 250 EC + vermicompost | 2356.9 | 2121.2 | 1824.24 | 164.48 | 1659.76 | −244.36 | D |

## DATA AVAILABILITY

The data used to support the findings of this study can be provided upon reasonable request via the aforementioned corresponding author's email.

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