

Soil Fertility Dynamics and Xanthomonas Wilt Incidence in Enset (Ensete Ventricosem) Based Farming at Chench, Southern Ethiopia

Tesfaye Hajiso Hadaro¹, Sabura Shara², Zenebe Mekonnen Adare^{2,*}

¹South Ethiopia Regional State, Ari Zone, Bureau of South Ari Agriculture

²Department of Horticulture, Department of Plant Science, College of Agricultural Sciences, Arba Minch University, P.O. Box 21, Arba Minch, Ethiopia

Research Article
Open Access &
Peer-Reviewed Article

DOI: 10.14302/issn.2639-3166.jar-25-5495

Corresponding author:

Zenebe Mekonnen Adare, Department of Horticulture, Department of Plant Science, College of Agricultural Sciences, Arba Minch University, P.O. Box 21, Arba Minch, Ethiopia

Keywords:

Dynamics, enset management, nutrition, soil fertility, Xanthomonas wilt

Received: April 01, 2025

Accepted: April 25, 2025

Published: May 10, 2025

Citation:

Tesfaye Hajiso Hadaro, Sabura Shara, Zenebe Mekonnen Adare (2025) Soil Fertility Dynamics and Xanthomonas Wilt Incidence in Enset (Ensete Ventricosem) Based Farming at Chench, Southern Ethiopia. Journal of Agronomy Research - 5(3):44-59. <https://doi.org/10.14302/issn.2639-3166.jar-25-5495>

Abstract

Enset (*Ensete ventricosum*) is a vital food security crop cultivated in South and South-western parts of Ethiopia. However, enset production and the farming families have been threatened by Xanthomonas wilt and its spread in the farming system. Thus, this study was conducted to investigate the soil fertility and plant management practices association on the incidence of Enset Xanthomonas wilt. Data on soils fertility and diseases from enset based farming clustered into inner, outer and outfield farm zone were sampled and surveyed. The result indicated that soil chemical properties significantly ($p \leq 0.05$) varied from inner to outfield farm zone. Significantly maximum nutrients store revealed in inner enset farm zones. Disease incidence reduced from inner to the outfield enset farm zone. Disease prevalence and disease incidence scored 28.5% and 11.6%, respectively depending on altitude and genotypes. Soil fertility levels in the enset inner and outfield plots were varied purposely to cultivate enset products as kocho, bulla or amicho (cooking type). The variations in soil fertility and Xanthomonas wilt incidence was associated with management practices applied for desired enset products. Therefore, management practices in enset based farming, soil fertility and location of enset planting zones found to be major indicators for disease incidence addressing to device control interventions.

Introduction

Enset (*Ensete ventricosum*) is a multi-purpose perennial plant mainly cultivated in southern and southwest highlands of Ethiopia for food, feed, medicine, fiber, construction material and many cultural practices [1,2,3,4,5,6]. The plant belongs to order Scitamineae, family Musaceae and genus Ensete [7]. It is a staple food security crop recognized for its higher productivity,

environmental sustainability and adaptability than most cultivated cereal crops in Ethiopia [8,9]. Enset supports more than 20 million people in Ethiopia [10]. Enset based farming is a sustainable traditional agricultural system predominantly as home gardens and the outfields are used for annual crops. It is one of the most reliable and strategic crop resisting transient droughts, heavy rain and flooding that would typically destroy other crops especially during adverse climatic conditions [11]. The crop is grown and distributed at altitudes between 1500 and 3100 m.a.s.l., but best suited between 2000 and 2750 m.a.s.l., with an average annual rainfall of 1100 to 1500 mm (Brandt et al., 1997). It grows well in areas with fertile soils, temperatures between 16 and 20°C, relative humidity 63% and 80%, pH range between 5.6 and 7.3.

Enset based farming is solely reliant on nutrient supply from animal manure and household waste without application of inorganic fertilizer. Soils of enset near to home gardens were more fertile when compared to other farm enterprises due to frequent provision of manures and household [12,13,14]. Hence, there exists a change in soil nutrient content. Gradients in soil fertility within the enset home garden as a result of difference in management practices with distance from the house were reported by Sabura et al. (2021).

A reconnaissance survey at highlands of Chench, Gamo zone showed that farmers dominantly practice enset cultivation in home gardens but annual crops surround the enset home gardens or outfields [14]. The home garden were perceived cultivating enset landraces mainly for processing types while the outfield, which is found at a distance from the home garden, is presumed as being planted with cooking type enset landraces locally called 'Cheero' ([14]. Planting location (distance from homestead) also differ depending on enset product preferred for food type and soil fertility of the garden [14]. As Shara et al. (2021) report, soil fertility status of a garden was related with farmer' management practices applied for a preferred enset product within the enset home garden and altitude which in turn linked to Xanthomonas wilt (EXW) incidence. Studies in banana, family of enset, show that fine tuning disease management strategies on-farm has helped to reduce EXW [15,16]. This indicates that exploring farm management practices in enset still remains very important strategy to reduce disease spread. It also prevent new infections, as an immediate disease control option, suggesting need for thorough understanding of the status of farm management tactics in enset systems and the association with disease incidence at various distances from the house.

Furthermore, experimental evidence showed that deficiencies in certain nutrients such as phosphorus hasten susceptibility to EXW in Gamo highlands [17]. However, information on disease incidence over the farming zones within an enset farm linked with farm management per enset product type is not available. Although the disease has been observed in entire enset belt, the extent of disease incidence and spread varies from region to region at landscape level. The variation observed was linked with environment that favors disease development or plant susceptibility, mainly altitude driven moisture and temperature as well as management practices such as soil fertility [18,19,14]. The knowledge of such management practices and the link to disease spread may help to develop management measures for EXW. Therefore, studying crop management practices related to growing enset for processing type (kocho and bulla) and direct cooking (amicho), quantifying soil fertility, characterizing landraces in inner, outer and outfield or 'Cheero' zones (plots) and the association with xanthomonas wilt incidence may help to understand the EXW pathogen niche in a complex traditional enset farming systems and to devise context specific options for disease management.

Materials and methods

Study area description

The study was carried out at Chencha, South Ethiopia Regional State, geographically located at 37° 29' 57" to 37° 39' 36" E longitude and 6° 08' 55" to 6° 25' 30" N latitude during March 2022 to February 2023 (Figure 1). The area is attributed with quite marked topographic variation (rolling mountains, steep slopes, flat to undulating plateaus [20,14] and soil types of reddish, deeply weathered Nitisols and Luvisols [21].

Sampling design and treatments

Enset farm established in farmers' field within 2500 to 3000 altitudinal range of the study area was purposively selected consisting four randomly selected villages namely Doko yoyira, Tsida, Lakana maldo and Dorze holo. Three households were randomly selected in each village. Each household enset farm clustered into three farm zones [inner (IR), outer (OR) and outfield (OF) i.e. cheero plots].

The altitudinal range used for the study was selected due to dominance of enset based farming system and uniformity of households over the range for sampling. The inner home garden (IR) is enset farm within 4 to 6 m of homestead that receives more solid and liquid manure, organic waste, ashes and house residues, the outer home garden (OR) is enset farm that receive less amount of manure, organic wastes and house residues and the outfield or locally called cheero is enset farm which receives organic manure only at transplanting time and used for enset plant cultivated only amicho production.

The total list of 1450 households was collected from the agricultural extension office. Accordingly, a sample size of 35, 48, 31, 65 households from the respective villages were selected with the procedure suggested by Yemane (1967). The selected households were used for interview with open structured questionnaire and focus group discussion.

$$n = \frac{N}{1 + N(e^2)} \quad K = \frac{N}{n}$$

Where,

N= is the population size

e= is the level of precision (5% to 10%)

n= is sample size

K= is the interval the sample would be taken

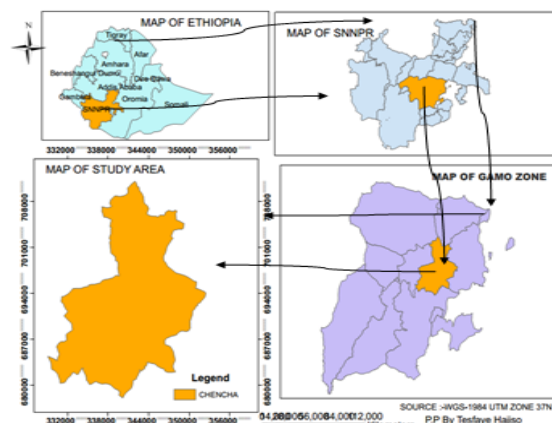


Figure 1. Geographical location of the study area.

Data collection

Soil physical and chemical analysis

Soils of the upper 25cm depth in which most of the plant roots typically distributed (Zewdie et al., 2008), [14] was sampled in each farm zone from five spots by using auger and a composite sample per farm zone used for analysis. One composite soils for each farm zone (IR, OR and OF) were collected replicated in three household farm per village/kebele. The total of 36 composite soil sample size were air dried at room temperature, grounded and sieved with 2 mm size and used to analyze pH, EC, soil texture, available phosphorus, OC and OM at the Arba Minch University botany and environmental science laboratory. The measures of OM and available phosphorus were used as indicators for soil quality and to compare the amount of soil nutrients at enset garden and to infer the relationship between inner, outer and outfield home garden.

The OM content was extracted by the dichromate oxidation method (Walkey and Black, 1934). Available phosphorus was estimated by Olsen's procedure [22]. The soil EC and pH was measured using disinfected digital EC and pH meter, respectively. Soil texture was determined by the hydrometer method [23].

Farm management practices and Enset Xanthomonas wilt

Farm management practices such as manure application, cultivation, leaf pruning, enset landraces and reaction to EXW and Enset Xanthomonas wilt (EXW) incidence at inner, outer and outfield enset farm plots were interviewed on sampled households with semi-structured questionnaire. The characteristic visual symptoms such as yellowing and wilting of leaf, yellowish or creamy bacterial ooze at cut leaf petiole/ edge of pseudostem for claimed disease presence were visually observed, Bacterial ooze collected from petiole or pseudostem of suspected plant was cultured in a semis elective media for further confirmation (Thwaites et al., 2000) [24].

Focus group discussion

Association of farm management practices with enset production type, soil fertility gradient, xanthomonas wilt disease incidence, transmission and indigenous practices of control was carried out with groups of participants comprised of four elder groups, four women, four development agents, two expert, four village leaders and four model farmers. Semi structured questions and open ended subjects were used to initiate free discussion among the focus group participants and to minimize subjective responses.

Disease incidence (DI%): Disease incidence was calculated by counting the number of infected enset plants assessed in each farm zones and dividing to the total number of enset plants in each garden plot of the sampled households (HHs) [25].

$$\text{Disease incidence (DI\%)} = \frac{\text{Number of infected plants}}{\text{Total number of plants assessed}} \times 100$$

Disease prevalence (DP %): Disease prevalence was determined as the presence and absence of EXW in enset fields assessed, and calculated using the formula:

$$\text{Disease prevalence (DP\%)} = \frac{\text{Number of infected farm}}{\text{Total number of farm assessed}} \times 100$$

Data analysis

Data for normality were tested with normal probability plot (P-P and Q-Q) and histogram. The soil physical and chemical properties indicating the gradient in soil fertility between IR, OR and OF was determined with a one-way ANOVA analysis data with SAS version 9.0. The mean difference between the soil fertility records was tested with least significant difference (LSD) at 5% probability level. For every sample analysis, the mean and standard deviation was computed for the three replications of each sample. The strength and weakness of purpose of enset production with enset management practices, soil fertility levels and enset xanthomonas wilt disease incidences was tested with simple correlation analysis. Data collected during interview and focus group discussion analyzed using SPSS version 20.

Results and discussion

Enset management practices across farming zones

Indigenous management practices varied across enset farm zones, with the intensity of management decreasing from the homestead towards the outfield (Tables 1). Household surveys and group discussions revealed a consistent trend: the frequency of hoeing, weeding, leaf pruning, and manure application diminished from the inner farm zone outwards. Specifically, hoeing/weeding and leaf pruning were performed twice per year in the inner farm zone by 83.24% of respondents, compared to 76.54% in the outer zone (Table 1). Notably, 97.21% of respondents reported hoeing their outfield enset plots and pruning leaves only at the time of transplanting. This suggests that enset home gardens (homestead and closer gardens) receive more intensive management and care. This finding aligns with Tsegaye and Struik (2002), who reported that enset home gardens are weeded periodically, 2-3 times a season, and Kebede et al. (2021), who noted weeding frequencies ranging from once every 1–5 years depending on elevation.

Regarding manure application, 91.06% and 74.86% of respondents reported frequent annual application in the inner and outer farm zones, respectively. In contrast, nearly all respondents (almost 100%) applied manure in the outfield only at the time of transplanting (Table 2). This perceived fertility gradient across enset farm zones, acknowledged by 82.7% of respondents (Table 3), suggests the impact of varying soil management practices by farming families. The frequent application of manure and household waste management around the homestead likely contribute significantly to the soil fertility gradient observed in enset home gardens [14]. This aligns with Tsegaye and Struik (2002), who also reported that the rate, timing, and method of manure application result in soil fertility differences between home gardens and the wider enset farm.

Enset landrace and enset product type alignment with planting farm zone

Interviews and field observations revealed that enset landraces selected for kocho production exhibited vigorous growth and high yields when cultivated in the inner farm zones. As shown in Table 4, 69.3% of informants employed specific enset landraces and clustered planting arrangements based on the intended food product. Respondents consistently identified kocho, bulla, and amicho as the primary enset food products. Particularly, 60.03% reported cultivating varieties for kocho and bulla in both inner and outer farm zones, while 87.15% grew enset for amicho production further away from home gardens (OF) (Table 4). This suggests that enset plants grown for kocho production benefit from close supervision, fertile soil, and frequent management. Supporting this, Sabura et al. (2021) observed that manure, organic wastes, ashes, and household refuse were frequently applied in enset farm zones closer to the homestead but not in the outfield zones.

Table 1. Hoeing/weeding and leaf pruning frequency per onset farm zone per year

Hoeing/Weeding and Leaf Pruning by Farm Zone						
Farm zone	3×		2×		1×	
	Frequency	Percent	Frequency	Percent	Frequency	Percent
IR	23	12.85	149	83.24	7	3.91
OR	9	5.03	137	76.54	33	18.44
OF			5	2.79	174	97.21

Key: 3x, 2x, 1x is farmers practicing the hoeing/weeding three times, two times, one time per year per farm zone; IR = inner farm zone, OR= outer farm zone, OF= out field farm zone.

Table 2. Manure application frequency per onset farm zone per year.

Manure application frequency per year								
Farm zone	Frequently		3x		2x		1x	
	Frequency	Percent	Frequency	Percent	Frequency	Percent	Frequency	Percent
IR	163	91.06	9	5.03	7	3.91	0	0
OR	134	74.86	39	21.79	6	3.35	0	0
OF							179	100

Table 3. Soil fertility and leaf harvesting practices per onset farm zone.

Management questions	Category	Frequency	Percentage
Soil fertility gradient in inner, outer and cheero plots	Yes	148	82.7
	No	31	17.3
Onset plants and leaves most frequently harvested for home use from farm zone	IR	169	94.4
	OR	10	5.6
	OF	0	0
Onset plants and leaves not harvested for home use from farm zone	IR	12	6.7
	OR	18	10.05
	OF	149	83.2

Table 4. Enset landraces per enset food/product types allocation per farm zone

Management questions	Category	Frequency	Percent
Major food products from enset	Kocho	179	100
	Bulla	179	100
	Amicho	179	100
Enset planting clustered spatially per enset food type	Yes	124	69.3
	No	55	30.7
Planting zone of Enset landraces for kocho production	IR	49	27.4
	OR	22	12.3
	OF	0	
	Both IR and OR	108	60.3
Enset food type preferred planting at cheero plots (outfield zones)	Kocho		
	Amicho	156	87.15
	Both	23	12.85

Table 5. The effects of farm zones on soil texture in chencha districts

Farm zones	Sand (%)	Silt (%)	Clay (%)	Textural
IR	39.27	32	28.73	Clay loam
OR	36.27	32	31.73	Clay loam
OF	29.27	32	38.73	Clay loam
LSD (0.05)	16.24	7.89	12.25	
p-value	0.4249	1	0.2355	

Soil fertility gradient over enset farm zone related to enset product types

Soil particle size distribution in enset farm zones

Analysis of soil particle size distribution in the IR, OR, and OF (cheero plot) farm zones revealed no significant differences. The soil texture across all farm zones was classified as clay loam (Table 5). The consistent percentage of silt content suggests that the dominant mineral particle in the enset farm zone is relatively uniform. However, despite the uniform particle size distribution, the results also indicated that soil management practices and the type of enset cultivars grown across the farm zones do have a significant influence on particle size distribution. Similarly, the consistent percentage of silt content in enset farm zones was also documented by Kebede et al. (2021).

Soil chemical properties gradient across farm zone and enset food product

Analysis of soil chemical properties revealed significant differences ($p \leq 0.05$) among the farming zones, with mean values generally decreasing from the inner/home garden (IR) to the outfield (OF) zones (Table 6). Specifically, the IR farm zone exhibited significantly higher values for available phos-

phorus (28.52 mg/kg), electrical conductivity (EC) (2.11 dS/m), pH (6.63), organic matter (OM) (3.66%), and organic carbon (OC) (2.12%) compared to the OF zone, which recorded minimum values of 3.29 mg/kg for available phosphorus, 0.69 dS/m for EC, 5.78 for pH, 2.69% for OM, and 1.56% for OC. The higher phosphorus availability in the IR zone is likely related to its optimal pH range for phosphorus solubility, while the lower availability in the OF zone may be attributed to aluminum fixation at its lower pH values. The significantly lower pH observed in the outfield enset farm zone (5.78) compared to the inner farm zone (home garden) (6.63) and outer home garden (6.08) aligns with findings by Sabura et al. (2021) regarding soil fertility status and nutrient distribution between the inner and outfield farm zones.

These results highlight the impact of household waste and frequent manure application practices by the farming community, consistent with farmer responses during the survey. Enset plants in the OF zone typically receive manure only at the time of transplanting (sucker stage). The observed gradient in soil fertility levels across farm zones likely arises from variations in farmers' management practices, which are also linked to preferred enset products. Field surveys indicated that landraces for kocho production are primarily cultivated in the IR farm zone, while those for amicho production are grown in the outfield zone. This finding is supported by Sabura et al. (2021), who reported significantly higher soil chemical properties in the inner zone compared to the outer zone, with the exception of available aluminum.

Association of EXW incidence, enset food product type based management and soil fertility gradient

Prevalence and incidence of EXW disease in enset farm zones

Of the 179 enset gardens surveyed (including the 12 households or 36 farm zones where soil properties were analyzed), 51 farms (28.49%) exhibited disease symptoms, while 128 gardens (71.51%) showed no symptoms (Table 7). The observed variation in disease prevalence across kebeles/villages could be due to differences in enset landrace tolerance or susceptibility to EXW, or variations in altitude influencing disease incidence. Furthermore, disease incidence is linked to cropping history, particularly if the land previously hosted infected plants or if susceptible landraces were used for planting. Overall,

Table 6. Soil chemical properties (means \pm SD) across enset farm zones.

Farm zone	OC (%)	OM (%)	pH	EC (dS/m)	P _{av} (mgkg ⁻¹)
IR	2.12 \pm 0.18 ^a	3.66 \pm 0.32 ^a	6.63 \pm 0.44 ^a	2.11 \pm 0.52 ^a	28.52 \pm 6.5 ^a
OR	1.89 \pm 0.27 ^b	3.46 \pm 0.50 ^a	6.08 \pm 0.41 ^b	1.06 \pm 0.38 ^b	12.32 \pm 6.39 ^b
OF	1.56 \pm 0.20 ^c	2.69 \pm 0.34 ^b	5.78 \pm 0.37 ^b	0.69 \pm 0.23 ^c	3.29 \pm 1.58 ^c
Mean	1.86 \pm 0.32	3.27 \pm 0.57	6.16 \pm 0.54	1.29 \pm 0.72	14.71 \pm 11.78
LSD (0.05)	0.18	0.33	0.34	0.32	4.43
CV%	11.96	12.1	6.73	30.44	36.29
p-value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

Where means with the same letters within a column are not significantly different ($p \leq 0.05$); pH = power of hydrogen; EC = soil electrical conductivity; OC = organic carbon; OM = organic matter; Pav=available phosphorus; SD = standard deviation.

the results indicated a low distribution of the disease across the onset production zones, with higher severity observed in regions with a history of the disease. Similar results were presented by Muzemil et al. (2021) who reported considerable variation between onset land races towards xanthomonas wilt.

EXW disease incidence and farm management practices

The result indicated that disease incidence was observed in both inner and outer zones of the onset farms, with a consistent decrease from the inner to the outer zones across all surveyed kebeles. (Table 8). No incidence of EXW disease was observed in the outer areas of the onset farms across all sampled study sites. This suggests a potential link between the disease and factors associated with the inner farm zones, such as the intensity of farm management practices and soil fertility gradients. The higher incidence of the disease in inner farm zones, where frequent hoeing and leaf pruning are common alongside higher soil fertility and plots dedicated to onset processing, further supports this association. The result showed the association of disease incidence for soil attributes results presented in Table 6 where significant high score for OC, pH, EC and Pav content observed from inner to outfield farm zones. Reduced probability of disease spread on cooking type onset landraces planted in the outfields with less frequency of hoeing and leaf pruning also indicated importance of farm tools in spreading disease. In addition, outfield farm zones practiced with less manure application indicating the reduced incidence of EXW relation with low fertility status of the soil. The present findings are consistent with the work of Tsegaye and Struik (2000), which indicated that a single transplant and reduced field practices of onset suckers, accelerates maturity, ensures a reasonable yield, and diminishes susceptibility to diseases and pests. The findings indicate a correlation between increased plant contact during field operations and a higher incidence of disease.

Growth stage and incidence of EXW disease

Field observations, group discussions, interview data, and farmers' experiences consistently showed that onset plants are susceptible to EXW infection at all growth stages. However, the results indicated a higher susceptibility to Xanthomonas wilt disease during the middle growth stage (77.7%), compared to the younger (11.7%) and productive stages (10.6%) (Table 9). This suggests an inverse relationship between onset plant maturity and susceptibility to the disease, with susceptibility decreasing as the plant ages. This finding contrasts with Gizachew et al. (2008), who reported higher susceptibility in younger onset plants to infection via contaminated tools. In the IR farm zone, frequent harvesting and

Table 7. Prevalence and incidence of EXW disease in the study area.

Sample kebeles	Number of assessed	Number of symptomatic	Disease Prevalence (%)	Disease Incidence (%)
Lakana maldo Dorze holo	31	9	29.03	11.6
	65	14	21.54	12.7
Tsida Doko yoyira	35	13	37.14	11.4
	48	15	31.25	10.6
Total Mean	179	51	118.96	46.3
		12.75	29.74	11.6

Table 8. Incidence of EXW disease (DI %) across enset farm zones (N= 179)

Farm zones	Total number of enset plants counted	Total number of symptomatic plants	DI%
IR	560	119	21.5
OR	725	97	13.4
OF	809	0	0
Mean			11.6

Table 9. Age of enset and EXW disease susceptibility at IR, OR and OF farm zones

Management questions	Category	Frequency	Percent
Age difference in enset plants to reach for food at IR, OR and OF farm zone	Yes	158	88.3
	No	21	11.7
Stage the enset plants susceptible to enset xanthomonas wilt disease	younger stage (1-2) year	21	11.7
	middle stage (2-4) year	139	77.7
	productive stage (≥ 4 years)	19	10.6

leaf pruning for home use likely contribute to disease transmission through farm tools. Furthermore, consistent with the soil fertility gradient across farm zones, the study also revealed that 88.3% of respondents observed differences in the time it takes for enset plants to reach maturity for food production across these zones (Table 9).

Incidence of EXW disease and soil fertility

Analysis of variance revealed significant differences ($p \leq 0.05$) in available phosphorus (Pav) across farm zones. Specifically, the IR farm zone exhibited the highest Pav levels, while the OF farm zone showed the minimum, in both symptomatic and non-symptomatic plots (Table 10). Similarly, significant differences ($p \leq 0.05$) were observed for pH and electrical conductivity (EC), with the IR farm zones recording higher values in both symptomatic and non-symptomatic gardens. In contrast, the analysis showed no significant difference in organic carbon (OC) and organic matter (OM) between the IR and OR farm zones for both symptomatic and non-symptomatic gardens. Notably, the soil chemical properties did not differ significantly between symptomatic and non-symptomatic farm zones in this study. However, Sabura et al. (2021) reported higher levels of Pav and available calcium (Caav) in symptomatic gardens compared to non-symptomatic ones. Although specific recommendations for enset are lacking, existing literature suggests a link between variations in soil fertility management and plant susceptibility to Xanthomonas wilt disease in enset [14,19,26] and banana [27]

Enset landraces and their reaction to Xanthomonas wilt disease

Enset landraces under cultivation of the study area and their reaction for EXW disease was interviewed with local farmers. The study recorded about 27 types of enset landraces and the interaction with EXW disease as local farming community report (Table 11). The result showed only two enset landraces (Masa maze and Maze) show less susceptibility to EXW disease while 25 landraces reported susceptible to the disease. The findings of Abera (2017) from the south-western Ethiopia region, also showed

that over 82.5% of enset landraces were susceptible to EXW and enset landraces, ‘Mazziya and Shododinya’, were relatively better tolerance to EXW disease. Similarly, Fikre & Gizachew (2007) reported that enset variety, Mazia, was tolerant to EXW.

The disease incidence also associated with planting zone of enset around homestead. According to the survey data, 93.3% of informants showed disease devastation at the inner farm zone and 88.3% responded the disease incidence at both inner and outer farm zones (Table 12) suggesting the association of disease with farm management and fertility of the garden (Table 6 and Table 8). Landraces of enset used for processed products (kocho and Bulla) were recommended planting at around homestead and amicho was used to plant at OF farm zone.

The finding was similar with Sabura et al. (2021), who reported that enset varieties grown for the fermented product of the pseudostem were transplanted to the fertile inner zone and varieties for eating the cooked corm remain in the outer, less fertile zone and receive manure only during their earlier growth stages.

Table 10. Properties of soil (mean \pm SD) among symptomatic and non-symptomatic enset farm zones (N=36).

	Farm zone	pH	EC (dS/m)	OC (%)	OM (%)	P _{av} (mg/kg)
Soil properties of symptomatic	IR	6.61 \pm 0.61 ^a	2.06 \pm 0.54 ^a	2.10 \pm 0.17 ^a	3.62 \pm 0.30 ^a	23.09 \pm 4.74 ^a
	OR	6.06 \pm 0.41 ^{ab}	1.05 \pm 0.44 ^b	1.81 \pm 0.31 ^a	3.35 \pm 0.60 ^a	15.40 \pm 7.75 ^b
	OF	5.62 \pm 0.46 ^b	0.72 \pm 0.23 ^b	1.47 \pm 0.23 ^b	2.55 \pm 0.40 ^b	3.11 \pm 1.66 ^c
	LSD (0.05)	0.62	0.52	0.30	0.55	6.56
Soil properties of non-symptomatic garden (n= 18)	IR	6.66 \pm 0.26 ^a	2.16 \pm 0.53 ^a	2.14 \pm 0.21 ^a	3.69 \pm 0.36 ^a	27.12 \pm 4.47 ^a
	OR	6.11 \pm 0.45 ^b	1.07 \pm 0.34 ^b	1.98 \pm 0.22 ^a	3.58 \pm 0.41 ^a	9.24 \pm 2.63 ^b
	OF	5.93 \pm 0.24 ^b	0.67 \pm 0.28 ^b	1.65 \pm 0.14 ^b	2.84 \pm 0.23 ^b	3.48 \pm 1.64 ^c
	LSD (0.05)	0.41	0.48	0.23	0.41	3.86
	CV%	5.28	30.16	9.9	9.98	23.66

Table 11. Enset landraces, identity and reaction to EXW disease

No	Enset landraces	Uses	Tolerant		Susceptible		Midrib color	pseudostem color
			Frequency	Percent	Frequency	Percent		
1	Alanga	Kocho	94	52.5	85	47.5	Grey	Green
2	Beshera	Kocho and amicho	42	23.46	137	76.54	Black	Black
3	Bodha	Kocho and amicho	38	21.23	141	78.77	Brown	Brown
4	Booza	Kocho	33	18.43	146	81.56	Red	Red
5	Cacao	Amicho	21	11.7	158	88.3	Black	Black
6	Camise	Kocho and amicho	17	9.5	162	90.5	Black brown	Black brown
7	Charga	Kocho	83	46.4	96	53.6	Red	Green
8	Chamo	Kocho	70	39.1	109	60.9	Red	Green
9	Cooce	Amicho	24	13.4	155	86.6	Black brown	Black
10	Dokoze	Kocho and amicho	66	36.9	113	63.1	Grey	Green
11	Falake	Kocho	53	29.6	126	70.4	White	White
12	Gadha zinke	Amicho	51	28.5	128	71.5	Deep red	Black
13	Gena	Kocho	58	32.48	121	67.6	Red brown	Red brown
14	Geze zinke	Amicho	88	49.2	91	50.8	Black	Black
15	Kalsa	Kocho	75	41.9	104	58.1	Black	Brown
16	Katise	Kocho	113	63.1	66	36.9	Green	Grey
17	Katane	Kocho	43	24	136	76	Brown	Black
18	Kunka	Amicho	39	21.8	140	78.2	Red	Black red
19	Lofe	Amicho and medici-	26	14.5	153	85.5	Light red	Light red
20	Masa maze	Kocho	179	100	0	0	Black	Black
21	Maze	Kocho	179	100	0	0	Brown	Black
22	Orgozo	Kocho and amicho	21	11.7	158	88.3	White	White
23	Phello	Amicho	33	18.4	146	81.6	Brown	Black
24	Sorghe	Kocho	126	70.4	53	29.6	Brown	Grey
25	Suyite	Amicho and medici-	71	39.7	108	60.3	Wine	Wine
26	Wossa' ayfe	Kocho	68	38	111	62	White	White
27	Zinke	Amicho	41	22.9	138	77.1	Deep red	Brown

Table 12. EXW disease symptoms and farm zones observed and level of infestation

Management questions	Category	Frequency	Percent
Disease symptoms observed in enset farm zones	Yellowing of leaf	179	100
	Wilting of leaf	179	100
	Bacterial ooze yellowish excretion	179	100
Farm zones observed for EXW disease symptoms	All farm zones	21	11.7
	IR and OR farm zones	158	88.3
	Outfield	0	0
Enset farm zone high in EXW disease devastation	IR	167	93.3
	OR	0	0
	IR and OR	12	6.7
	OF	0	0

Conclusion

The study results revealed a soil fertility gradient across enset farming zones, decreasing towards the outfield, and variations in farm management practices (manure application, hoeing frequency, weed management, and leaf pruning) based on the preferred enset food type. Processed enset food products (Kocho, Bulla) were typically cultivated around the homestead and in plots receiving frequent management to maintain soil fertility. In contrast, the cooking type (Amicho), which does not require fertile soil or intensive management, was predominantly grown in outfield farm zones. The spatial arrangement of enset cultivars was also linked to the desired food product quality, with landraces for Kocho and Bulla being allocated to fertile plots to enhance pseudostem and corm production. Notably, the study showed a higher disease incidence in the IR farm zone compared to the OF farm zone, suggesting an association between disease, soil fertility gradients, and management practices. Furthermore, very few enset landraces exhibited complete resistance to EXW disease.

Acknowledgments

The authors acknowledge the financial support given by Arba Minch University to conduct the study.

Conflict of interests

All authors have seen and approved the final version of the manuscript being submitted. The authors have declared no any conflict of interests.

The Declaration of Interests

I have nothing to declare.

Data statement

Portion of the research data is attached with the manuscript. The survey data is available in the manuscript, Table 11.

References

1. Kebede, W., Birhanu, B., Vegard, M., Jan, M., 2021. Soil organic carbon and associated soil properties in Enset (*Ensete ventricosum* Welw. Cheesman)-based home gardens in Ethiopia, *Soil & Tillage Research*, 205: 1-11.

2. Abreham, S., Gecho, Y., Tora, M., 2012. Diversity, challenges and potentials of enset production, *Food science and quality management*, 7: 24–31.
3. Tesfaye, B., Lüdders, P., 2003. Diversity and distribution patterns of enset landraces in Sidama, Southern Ethiopia, *Genetic Resource. Crop Evol*, 50: 359–371.
4. Nurfeta, A., Tolera, A., Eik, L.O., Sundstøl, F., 2008. Yield and mineral content of ten enset (*Ensete ventricosum*) varieties, *Trop. Anim. Health Prod*, 40: 299-309.
5. Tsehaye, Y., Kebebew, F., 2006. Diversity and cultural use of enset (*Ensete ventricosum* (Welw.) Cheesman) in Bonga in situ conservation site, Ethiopia, *Ethno botany research and applications*, 4: 147-157.
6. Yemataw, Z., Mekonen, A., Chala, A., Tesfaye, K., Mekonen, K., Studholme, D.J., Sharma, K., 2017. Farmers' knowledge and perception of enset xanthomonas wilt in southern Ethiopia, *Agric. Food secure*, 6: 1-12.
7. Brandt, S.A., Spring, A., Hiebsch, C., McCabe, J.T., Tabogie, E., Diro, M., Wolde-Michael, G., Yntiso, G., Shigeta M., and Tesfaye S, 1997. The tree against hunger. Enset-based agricultural systems in Ethiopia, Washington DC: American association for the advancement of science, 56.
8. Tsegaye, A., Struik, P.C., 2001. Enset (*Ensete ventricosum* (Welw.) Cheesman) kocho yield under different crop establishment methods as compared to yields of other carbohydrate-rich food crops, *NJAS-Wagen. J. of life sci.*, 49 (1): 81–94.
9. Hunduma, T., Sadessa, K., Hilu, E., Oli, M., 2015. Evaluation of enset clones resistance against enset bacterial wilt disease (*Xanthomonas campestris* pv. *musacearum*), *J. Veterinary Sci. Techno-*lo, 6.
10. Borrell, J.S., Biswas, M.K., Goodwin, M., Blomme, G., Schwarzacher, T., Heslop- Harrison, J.S., Wendawek, A.M., Berhanu, A., Kallow, S., Janssens, S., Molla, E.L., Davis, A.P., Woldeyes, F., Willis, K., Dемиссеw, S., Wilkin, P., 2019. Enset in Ethiopia: A poorly characterized but resilient starch staple, *Ann. Bot.*, 123: 747-766.
11. Awol, Z., Zerihun, Y., Woldeyesus, S., Sadik, M., Daniel, A., 2014. On farm cultivar diversity of enset (*Ensete ventricosum* (Welw.) in Southern Ethiopia, *Institute of Development Studies*, 4(1): 63-83.
12. Amede, T., Taboge, E., 2007. Optimizing soil fertility gradients in the enset (*Enset ventricosum*) systems of the Ethiopian highlands. Trade-offs and local innovations. In *advances in integrated soil fertility management in Sub-Saharan Africa: challenges and opportunities*, 289-297.
13. Zelleke, G., Getachew, A., Abera, D., Rashid, S., 2010. Fertilizer and soil fertility potential in Ethiopia: Constraints and opportunities for enhancing the system, IFPRI, Ethiopian Institute of Agricultural Research, Addis Ababa, Ethiopia, 63.
14. Sabura, S., Swennen, R., Deckers, J., Weldesenbet, F., Vercammen, L., Eshetu, F., FelekeWoldeyes, F., Blomme, G., Merckx, R., Vancampenhout, K., 2021. Altitude and management affect soil fertility, leaf nutrient status and xanthomonas wilt prevalence in enset gardens, *Soil* 7: 1-14.
15. Blomme, G., Kim, J., Walter, O., Fen, B., Jules, N., Charles, S., Fred, S., Valentine, N., Jerome, L.K., Tinzaara, W., Flory, M., Lambert, L., Eldad, K., 2014. Fine tuning banana xanthomonas wilt

- control options over the past decade in east and central Africa, *European J of Plant Path.*, 139 (2): 1-17.
16. Blomme, G., Dita, M., Jacobsen, K.S., 2017. Bacterial diseases of bananas and enset. Current state of knowledge and integrated approaches toward sustainable management, *Frontiers in plant science*, 8: 1290.
 17. Sabura, S., 2022. Environment and management influence early performance and xanthomonas wilt in enset (*Ensete ventricosum*) in Gamo Highlands, Southern Ethiopia. PhD thesis, KU Leuven, Belgium.
 18. Zerfu, A., Gebre, S.L., Berecha, G., Getahun, K., 2018. Assessment of spatial distribution of enset plant diversity and enset bacteria wilt using geostatistical techniques in Yem special district, Southern Ethiopia, *Environ. Syst. Res.*, 7:1-13.
 19. Haile, B., Fininsa, C., Terefe, H., Hussen, S., Chala, A., 2020. Spatial distribution of Enset bacterial wilt (*Xanthomonas campestris* pv. *musacearum*) and its association with biophysical factors in southwestern Ethiopia, *Ethiop. J. Agric. Sci.* 30 (3): 33-55.
 20. Minda, T.T., Van Der Molen, M.K., Struik, P.C., Combe, M., Jiménez, P.A., Khan, M.S., De Arelano, J.V.G., 2018. The combined effect of altitude and meteorology on potato crop dynamics: A 10-year study in the Gamo Highlands, Ethiopia, *Agric. For. Meteorol.*, 262 166-177.
 21. Coltorti, M., Pieruccini, P., Arthur, K.J., Arthur, J., Curtis, M., 2019. Geomorphology, soils and palaeosols of the Chench area (Gamo Gofa, south western Ethiopian Highlands, *J. of Afr. Earth Sci.*, 151: 225-240.
 22. Olsen, S.R., Cole, C.V., Watanabe, F.S., Dean, L.A., 1954. Estimation of available phosphorus in soils by the extraction with sodium bicarbonate. U.S. Dep. of Agric. Circ. 939.
 23. Bouyoucus, C.J., 1951. A recalibration of the hydrometer method for making mechanical analysis of soils, *Soil Sci. J.*, 59:434-438.
 24. Tushemereirwe, W., Kangire, A., Smith, J., Ssekiwoko, F., Nakyanzi, M., Kataama, D., Musiitwa, C., Karyaija, R., 2003. An outbreak of bacterial wilt on banana in Uganda, *InfoMusa*, 12 (2): 6-8.
 25. Broders, K.D., Wallhead, M.W., Austin, G.D., Lipps, P.E., Paul, P.A., Mullen, R.W., Dorrance, A.E., 2009. Association of soil chemical and physical properties with *Pythium* species diversity, community composition, and disease incidence, *Phytopathology*, 99: 8.
 26. Gebre, S.L., Ashenafi, W., Kefelegn, G., Alemayehu, R., Manuel, T.M., 2021. Determinants of the spatial distribution of enset (*Ensete ventricosum* Welw. Cheesman) wilt disease: Evidence from Yem special district, Southern Ethiopia, *Cogent Food & Agriculture*, 7(1).
 27. Atim, M., Beed, F., Tusiime, G., Tripathi, L., Van Asten, P., 2013. High potassium, calcium, and nitrogen application reduce susceptibility to banana *Xanthomonas* wilt caused by *Xanthomonas campestris* pv. *musacearum*, *Plant Disease*, 97:123-130.
 28. Abera, S. 2017. Survey of enset bacterial wilt distribution in Mareka woreda. M.Sc Thesis. Arba Minch University. Arba Minch.
 29. Fikre, H., Gizachew, W., 2007. Evaluation of enset clone meziya against enset bacterial wilt, *Afri. Crop Sci. Con. Proc.*, 88:87- 890.

30. Gizachew, W., Kidist, B., Blomme, G., Addis, T., Mengesha, T., Mekonnen, D.S., .2008. Evaluation of enset clones against enset bacterial wilt, African Crop Sc. J., 16: 89 – 95.
31. Muzemil, S., Alemayehu, C., Bezuayehu, T., David, J. S., Murray, G., Zerihun, Y., Temesgen, M. O. 2021. Evaluation of 20 enset (*Ensete ventricosum*) landraces for response to *Xanthomonas vasicola* pv. *musacearum* infection. Eur. J. Plant Pathol., 161:821–836.
32. Thwaites, R., Eden-Green, S.J., Black, R., 2018. Diseases caused by bacteria and phytoplasmas. In: Jones D.R. (Ed). Handbook of diseases of banana, abacá and enset. CABI publishing, Wallingford, Pp. 296-391.
33. Tsegaye, A., Struik, P.C., 2002. Analysis of enset (*Ensete ventricosum* (Welw.) Cheesman) indigenous production methods and farm-based biodiversity in major enset-growing regions of southern Ethiopia. Experimental Agriculture 38(3). (in press). PhD Thesis Wageningen University.
34. Tsegaye, A., Struik, P.C., 2000. Influence of repetitive transplanting and leaf pruning on dry matter and food production of enset (*Ensete ventricosum* Welw. Cheesman), Field Crops Res, 68: 61–74,
35. Yemene, B., 1967. Random sampling selection administrator registration list depending on their population size by applying the formula.