

Research Article

Evaluation of Released Finger Millet Varieties in the East Wollega Zone of Western Oromia for Yields and Acid Soil Tolerance

Mamo Mekonnen^{*} , Temesgen Temena , Shiferaw Tadesse, Bayisa Baye

Oromia Agricultural Research Institute, Bako Agricultural Research Centre, Western Oromia, Ethiopia

Abstract

On the sub humid regions of western Oromia, many finger millet cultivars were released and produced, but their performance on acid soils was not well researched. A field experiment consisted of two factors (nine finger millet varieties and two lime rates, limed and un-limed treatments) were laid out in factorial arrangement, Randomized Complete Block Design with three replications. The experiment was carried out at three locations (Bako, Diga and Gute) during 2019 and 2020 main cropping seasons to identify and recommend finger millet varieties better performing to acid soils of sub humid areas of western Oromia. The interaction effect of variety by lime for two years over three locations was significant for biomass weight and grain yield. Bako 09 produced significantly the highest mean biomass weight and produced increments of 10% biomass weight and 7% grain yield by application of lime compared to un-limed treatment. At Bako, Kumsa, Bako 09, Boneya and Addis 01 produced significantly the highest biomass weight and grain yield compared to others but not significantly different from each other and produced 4% to 12% yield advantage over all mean grain yield. At Diga and Gute, Bako 09 produced significantly high grain yield. Consequently, application of lime increased finger millet grain yield, soil pH, available P, organic carbon and total nitrogen. Considering higher grain yield, production of Bako 09 under limed condition is recommended for the sub-humid western Oromia. Besides lime application and varietal selection, cropping system managements like rotation, integrated use of organic and inorganic fertilizers, and split application of fine particle lime to acid soils require further research attention for sustainable crop production in acidic soils.

Keywords

Finger Millet, Released Varieties, Acid Soils, Lime, Fertility

1. Introduction

Crop tolerance to low soil pH has become significant in the agricultural development of humid tropics since many of those soils have low pH, and some plants are more tolerant to low pH than others [1]. These crops possess unique characteristics that enable them to endure acidic soils with low pH

levels [2]. Tolerance mechanisms included a significant tolerance of low Ca and high Al, a requirement for low pH, and high amounts of toxic Al and Mn [3]. Aluminum tolerance varies among cultivars of rice, alfalfa, tomato, soybean, cotton, maize, sunflower, pea, and sweet potato. In addition to crops

^{*}Corresponding author: mamekonnen59@gmail.com (Mamo Mekonnen)

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that can withstand high levels of Al, maize and rice have been proven to be more tolerant to high soil Mn than soybean and barley, while clover and oats are more tolerant than cowpea and sweet clover [4]. Wheat, cotton, and soybeans have all been shown to demonstrate varietal tolerance. Mn tolerance in forage legumes appears to be primarily composed of two components: restriction of Mn entry into the plant and improved internal tolerance. Maize is assumed to have higher Mn tolerance than peanuts because less Mn is transferred to the leaves, [5]. While most legume-associated rhizobia thrive at pH levels ranging from 6.3 to 7, those associated with lupine thrive at pH levels as low as 4.0. Yield discrepancies between genotypes were discovered during the performance evaluation of ten acid-tolerant soybean lines in Indonesia at a pH of 4.3. The results indicated that G x E for crop phenology, yield, and yield components were significant [6]. Wheat genotypes that can tolerate aluminum produce more malic acid than those that cannot. The addition of malic acid to feeding solutions protected Al-sensitive seedlings from normally phytotoxic aluminum concentrations, [7]. Because these wheat species have an Al-tolerance mechanism that involves the excretion of malic acid induced by aluminum. It was successful in identifying maize genotypes that are Al-tolerant and P-efficient, restricting Al uptake in the transition zone towards the apex h malic acid overall, which was initially present within the root apices [8].

While genotypes resistant to Al-toxicity prevented its uptake into the root apex via released citrates, Al-induced callus formation is a sensitive damage. Although there are currently no viable mechanical methods for deep lime incorporation, lime treatment of acid soil has been used in Brazil to decrease the damaging effects of aluminum on the roots [9]. As a result, it has proven more cost-effective to combine liming techniques for surface soil acidity with the selection of plant species that are more resistant to aluminum toxicity. Hirpa et al.'s 2003 study found that 5 of 25 popular bean types grown on acidic soils (pH 4.6) had equivalent yields in both lime-lime and unlimed plots. Haematoxyline staining and root development measurements were used to discriminate between Al-sensitive and Al-tolerant genotypes [10]. Some of the 28 tef genotypes tested were able to survive the toxicity of aluminum [11]. According to the author, organic acids may act as a tef tolerance mechanism, excluding Al from roots.

In addition to increasing soil pH from 5.38 to 6.17 and 5.9, and accessible P from 12.75 ppm to 18.92 ppm and 17.50 ppm, the application of 12 t ha⁻¹ biochar and 2 t ha⁻¹ lime reduced exchangeable acidity, improved CEC, increased soil OC, and increased soil TN. By applying 12 t ha⁻¹ and 2 t ha⁻¹ lime, respectively, tef biomass yield was improved by 35% and 23%, while grain yield was increased by 46% and 41%, (10), [12]. In Ethiopia in general and western Oromia in particular, finger millet is considered acid tolerant because it is grown and performs better in areas where others do not grow well. There are views and thoughts that finger millet thrives well in acidic soils. However, there is no re-

search finding indicating tolerance of the crop to soil acidity. Bako agricultural research center released about 10 finger millet varieties which are well adapted to Diga and Gute areas of East Wollega zone of western Oromia. No matter these varieties have differences in yield potential, the extent to which they perform under acidic soil condition is not well studied. The objective of this study was to identify and recommend finger millet variety (varieties) better performing to acid soils of the sub-humid areas of western Oromia.

2. Materials and Methods

The experiment was carried out at Bako Agricultural Research Center, Diga Farmers' Training Center and Gute, Bako Agricultural Research centre Sub-site on acid soil with pH of 5.26, 4.80 and 4.43, respectively. Available P, organic carbon, and total nitrogen of all test sites were rated as medium/moderate. Metrological data were available only for Bako. The area has a warm-humid climate, mean annual rainfall of 1237 mm that varies between 887 mm, (year 2019) to as high as 1605 mm (year 2020) with maximum precipitation occurring from May to August. Annual mean minimum and mean maximum air temperatures of area ranges between 13.5 °C and 29.7 °C with a mean annual relative humidity of 52.15%.

A total of 9 regionally and nationally released finger millet varieties and two limed and un-limed treatments were tested in factorial arrangement laid out in Randomized Complete Block Design with three replications. Lime was applied a month before planting based on exchangeable acidity at the rates of 2.63, 6.43 and 8.33 t/ha⁻¹ for Bako, Diga and Gute, respectively. A plot area of 3.2 m (8 rows) x 3 m (9.6 m²) was considered at 40 cm x 10 cm spacing between rows and plants; respectively according to the recommendation of seed rate of 15 kg/ha⁻¹. A total of 6 rows (7.2 m²) were used for data collection and harvesting. Fertilizer was applied at the recommended rate for the crop.

Data Collection and Measurements

1) Crop

The biomass yield was chopped, weighed on a sensitive balance, and the average weight was computed. and grain yield adjusted to 12.5% moisture content standard.

2) Soils

Composite soil sample before planting and samples from each plot after crop harvest was collected at the depth of 20 cm from each experimental site. The soil samples were air dried, sieved to pass through 2 mm and grinded to smaller particles. The sample was analyzed for soil pH, available P using, [13], total N using Kjeldahl methods. While Walkley-Black method was used to obtain organic carbon, [14].

3. Results and Discussion

Overall limed mean biomass weight and grain yield were 7839 kg ha⁻¹ and 2186 kg ha⁻¹ compared to 6726 kg ha⁻¹ and 2015 kg ha⁻¹, respectively for un-limed treatments. Both overall mean biomass weight and grain yield were higher by 6% during year 1 compared to year 2, might have attributed due to the fine lime particle which could show complete mix up with the soil during application, very high rainfall, as high as 1605 mm during 2020 and mono-cropping of finger millet that might have utilized the same soil nutrients. The result agree with lime application to acid soils could be used to decrease toxic effects of Al to the roots, but practical me-

chanical methods for deep lime incorporation were not occasionally applicable, [15].

The interaction effect of variety by lime for two years over three locations were significant for biomass weight and grain yield. Finger millet variety, Bako 09 produced significantly the highest mean biomass weight (9428 kg ha⁻¹) and the highest grain yield (2728 kg ha⁻¹) under limed condition. This variety produced increments of 10% biomass weight and 7% grain yield by application of lime compared to un-limed treatment. Variety, Kumsa also produced the highest biomass weight which was not significantly different from Bako 09 under limed condition. It also produced the second highest grain yield (2505 kg ha⁻¹) under lime application (Table 1).

Table 1. Interaction of finger millet variety by lime over three locations and two years.

Varieties	Biomass weight kg/ha-1		Grain yield kg/ha-1	
	With lime	Without lime	With lime	Without lime
Kumsa	8867 ^{ab}	7129 ^{efgh}	2505 ^b	2087 ^{efgh}
Bako 09	9428 ^a	8489 ^{bc}	2728 ^a	2532 ^b
Diga 1	7717 ^{de}	6771 ^{ghi}	2211 ^{def}	2014 ^{hi}
Adis 01	8597 ^{bc}	7056 ^{efgh}	2465 ^{bc}	2064 ^{efgh}
Gudetu	7801 ^{de}	6583 ^{hi}	2190 ^{defg}	1950 ^{hi}
Gute	7445 ^{ef}	6603 ^{hi}	2111 ^{efgh}	1967 ^{hi}
Bereda	7074 ^{efgh}	6361 ⁱ	1999 ^{hi}	1888 ⁱ
Wama	7256 ^{efg}	6811 ^{ghi}	2042 ^{efghi}	2025 ^{ghi}
Boneya	8036 ^{cd}	7457 ^{ef}	2329 ^{cd}	2235 ^{de}
LSD (5%)	578.77		174.03	
CV %	11.72		12.14	

The mean biomass weight and grain yield of finger millet were influenced by the main effects of variety and lime at Bako during 2019 and 2020 main cropping seasons. As a result, varieties, Kumsa, Bako 09, Boneya and Addis 01 produced significantly the highest biomass weight and grain yield but not significantly different from each other to other. These four high yielder varieties produced 13% to 20% mean grain yield advantage over the lowest yielder finger millet variety, Wama and 4% to 12% yield advantage over all mean grain yield (Table 2). Application of lime also significantly increased finger millet means biomass weight and mean grain yield during 2019 and 2020 main cropping seasons. Subsequently, application of lime increased mean grain yield of finger millet by 8% which might have attributed due to P availability for better crop phenology in lime reclaimed acid soils compared to un-limed ones, [16]. Findings by confirmed crops grown in acid soils, extend their roots down to

the sub soil and spreading the lateral roots at the surface, are exposed to various concentrations of higher P and lower Al at different depths in the soil profile. [17].

Mean biomass weight and mean grain yield at Diga were significantly higher for finger millet variety, Bako 09 (8902 kg ha⁻¹) and (2606 kg ha⁻¹), respectively and followed by Kumsa with mean biomass weight of 7846 kg ha⁻¹ and mean grain yield of 2279 kg ha⁻¹. Similar to the mean yields, Bako 09 significantly out yielded other varieties during both, 2019 and 2020 cropping seasons (Table 3). Effects due to lime were also significant whereby application of lime showed mean yield increment of 9% compared to un-limed treatments.

At Gute, similar to Bako and Diga, mean grain yield for Bako 09 was significantly highest (2906 kg ha⁻¹) followed by Addis 09 (2438 kg ha⁻¹). Similar work on soybean varieties in Indonesia by, [18] identified varietal difference of tolerating low pH of 4.3. At Gute, similar to varietal effect, lime appli-

cation also increased grain yield of finger millet by 10% compared to un-limed treatments (Table 4).

Table 2. Biomass weight and grain yield of finger millet as influenced by the main effects of variety and liming at Bako during 2019 and 2020 main cropping seasons.

Varieties	Mean yields (kg/ha)		Biomass weight (kg/ha)		Grain yield (kg/ha)	
	Biomass weight	Grain yield	2019	2020	2019	2020
Kumsa	8294 ^a	2399 ^a	8588 ^a	8001 ^a	2454 ^a	2344 ^a
Bako 09	8192 ^{ab}	2379 ^a	8542 ^a	7842 ^a	2479 ^a	2278 ^{ab}
Diga1	6854 ^c	1994 ^c	7138 ^{bc}	6569 ^{bc}	2071 ^{bc}	1917 ^{cd}
Addis 01	7645 ^b	2193 ^b	8048 ^{ab}	7242 ^{ab}	2321 ^{ab}	2066 ^{bc}
Gudetu	6841 ^c	1956 ^c	7043 ^{bc}	6638 ^{bc}	2012 ^c	1901 ^{cd}
Gute	6737 ^c	1942 ^c	6822 ^c	6653 ^{bc}	1984 ^c	1900 ^{cd}
Bereda	6426 ^c	1841 ^c	6464 ^c	6389 ^c	1893 ^c	1789 ^d
Wama	6644 ^c	1905 ^c	6899 ^c	6383 ^c	1983 ^c	1828 ^d
Boneya	7906 ^{ab}	2296 ^{ab}	8025 ^{ab}	7788 ^a	2308 ^{ab}	2284 ^{ab}
LSD (5%)	639.66	177.58	1038.20	800.71	292.24	235.57
Lime						
With lime	7839 ^a	2186 ^a	8061 ^a	7617 ^a	2250 ^a	2122 ^a
Without lime	6726 ^b	2015 ^b	6954 ^b	6497 ^b	2084 ^b	1946 ^b
LSD (5%)	301.54	83.71	489.42	377.46	137.76	111.05
CV (%)	10.83	10.42	11.79	9.67	11.49	9.87

Table 3. Biomass weight and grain yield of finger millet as influenced by the main effects of variety and liming at Diga during 2019 and 2020 main cropping seasons.

Varieties	Mean yields (kg/ha)		Biomass weight (kg/ha)		Grain yield (kg/ha)	
	Biomass weight	Grain yield	2019	2020	2019	2020
Kumsa	7846 ^b	2279 ^b	8337 ^{ab}	7356 ^b	2437 ^b	2121 ^{ab}
Bako 09	8902 ^a	2606 ^a	9568 ^a	8235 ^a	2930 ^a	2283 ^a
Diga1	7388 ^{bc}	2162 ^b	7803 ^b	6973 ^{bc}	2319 ^b	2005 ^{bc}
Addis 01	7465 ^{bc}	2163 ^b	7651 ^b	7279 ^b	2222 ^b	2103 ^b
Gudetu	7487 ^{bc}	2201 ^b	8164 ^b	6810 ^{bcd}	2419 ^b	1983 ^{bc}
Gute	6945 ^c	2057 ^b	7457 ^b	6432 ^{cd}	2231 ^b	1883 ^{cd}
Bereda	6967 ^c	2040 ^b	7643 ^b	6292 ^d	2288 ^b	1793 ^d
Wama	7152 ^{bc}	2103 ^b	7436 ^b	6867 ^{bcd}	2218 ^b	1989 ^{bc}
Boneya	7793 ^b	2287 ^b	8201 ^b	7384 ^b	2439 ^b	2134 ^{ab}
LSD (5%)	806.6	251.25	1290.9	676.37	371.31	171.32
Lime						
With lime	8009 ^a	2309 ^a	8483 ^a	7534 ^a	2495 ^a	2124 ^a

Varieties	Mean yields (kg/ha)		Biomass weight (kg/ha)		Grain yield (kg/ha)	
	Biomass weight	Grain yield	2019	2020	2019	2020
Without lime	7090 ^b	2112 ^b	7575 ^b	6605 ^b	2283 ^b	1941 ^b
LSD (5%)	380.23	118.44	608.54	318.84	175.04	80.75
CV (%)	13.18	14.02	13.80	8.21	13.34	7.23

Table 4. Biomass weight and grain yield of finger millet as influenced by the main effects of variety and liming at Gute during 2019 and 2020 main cropping seasons.

Varieties	Mean yields (kg/ha ⁻¹)		Biomass weight (kg/ha ⁻¹)		Grain yield (kg/ha ⁻¹)	
	Biomass weight	Grain yield	2019	2020	2019	2020
Kumsa	7845 ^{bc}	2209 ^{bc}	7732 ^c	7958 ^b	2206 ^c	2212 ^{bcd}
Bako 09	9848 ^a	2906 ^a	10599 ^a	9998 ^a	3241 ^a	2571 ^a
Diga1	7516 ^c	2181 ^{cd}	7922 ^{bc}	7110 ^{cde}	2293 ^{bc}	2069 ^{cde}
Addis 01	8437 ^b	2438 ^b	8994 ^b	7880 ^{bc}	2656 ^b	2221 ^{bc}
Gudetu	7250 ^{cd}	2052 ^{cd}	7355 ^c	7146 ^{cde}	2117 ^c	1986 ^e
Gute	7366 ^{cd}	2118 ^{cd}	7638 ^c	7094 ^{de}	2214 ^c	2021 ^{de}
Bereda	6708 ^d	1949 ^d	6769 ^c	6646 ^e	2008 ^c	1890 ^e
Wama	7289 ^{cd}	2092 ^{cd}	7621 ^c	6956 ^e	2217 ^c	1967 ^e
Boneya	7656 ^c	2264 ^{bc}	7494 ^c	7817 ^{bcd}	2224 ^c	2304 ^b
LSD (5%)	728.06	242.72	1186.5	772.78	399.69	193.99
Lime						
With lime	8356 ^a	2364 ^a	8601 ^a	8111 ^a	2475 ^a	2253 ^a
Without lime	7181 ^b	2127 ^b	7426 ^b	6935 ^b	2231 ^b	2023 ^b
LSD (5%)	343.21	114.42	559.32	364.29	188.42	91.45
CV (%)	11.57	13.34	12.71	8.82	14.58	7.79

3.1. Soil pH and Available P

Initial soil pH was extremely acidic (4.43), very strongly acidic (4.80) and strongly acidic (5.26) for Gute, Diga and Bako, respectively. Moderate initial AVP, 7.33 for Bako and 6.72 for Gute were recorded but relatively adequate initial AVP, 10.96 was recorded for Diga. Application of lime significantly increased soil pH (from strongly acidic to acidic) at Bako. Remarkable increase for soil pH at Diga and Gute were also recorded by application of lime whereby the increase of soil available P was also recorded with the increase of soil pH (Figure 1). The result is supported by the work of [19] liming of the top soil reduces soil acidity if it doesn't drive from below the tillage layer.

3.2. Soil Organic Carbon and Total Nitrogen

Initial soil organic carbon for all locations was rated medium/moderate, 2.37 (Bako), 2.51 (Diga) and 2.13 (Gute). Medium initial total nitrogen was also recorded for all locations; 0.22, 0.24 and 0.19 for Bako, Diga and Gute respectively. Compared to initial content, soil organic carbon and total nitrogen increase was recorded for all locations and both years. However, there was no significant increase but remained in similar critical range category (Figure 2). Increasing organic carbon and total nitrogen trend was achieved improving by cereal legume intercropping, using organic fertilizer (vermicompost) and application of lime [20].

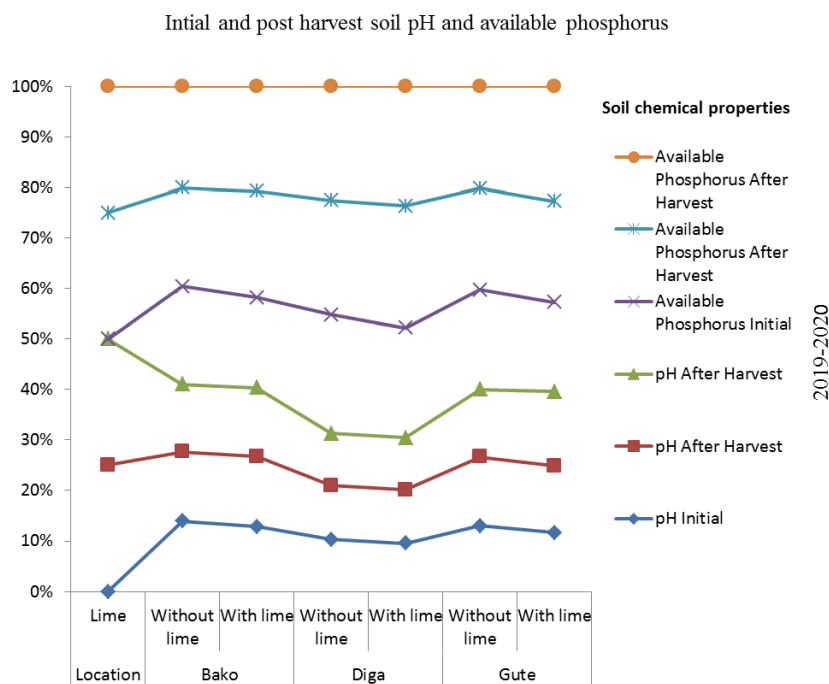


Figure 1. Soil pH and available P as influenced by lime application over three location and two growing seasons.

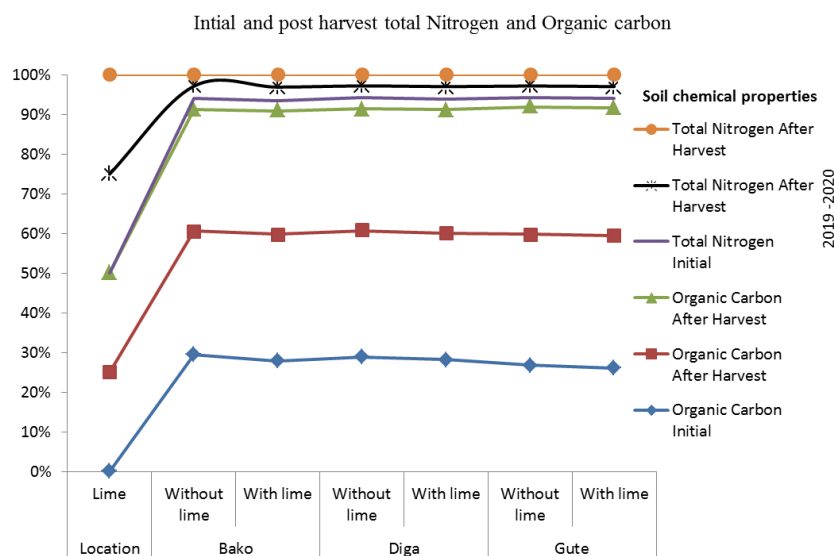


Figure 2. Soil OC and TN as influenced by lime application over three location and two growing seasons.

4. Conclusion and Recommendation

Varietal tolerance to low soil pH across locations was attained by Bako 09. The overall mean grain yield of two years and three locations for Bako 09 was the highest both under lime and un-limed treatments. Hence, Bako 09 is recommended across the three locations (Bako, Diga and Gute). As far as site specific recommendation is concerned, Kumsa, Bako 09 and Boneya produced the highest grain yields which were not significantly different from each other and recommended for strongly acidic soils of Bako area. Bako 09 is again produced the highest grain

yields and recommended for Diga and Gute areas (very strongly acidic to extremely acidic soils). Application of lime on acidic soils increased soil pH and increased finger millet yields. Hence, lime application is critical for soils with low pH (< 5.5).

Single technology, only lime application, might have temporary influence on soil reaction and soil chemical properties. Varietal selection for acid soils is the cheapest method and the technique to be considered at initial stage of screening. Cropping system managements, integrated use of organic and inorganic fertilizers and split application of fine particle lime require further research attention for sustainable crop and land productivity.

Abbreviations

Al	Aluminum
Av. P	Available Phosphorus
CEC	Cation Exchange Capacity
Mn	Manganese
N	Nitrogen
Oc	Organic Carbon
TN	Total Nitrogen

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Author Contributions

Mamo Mekonnen: Investigation, Supervision, Visualization, Writing – original draft

Temesgen Temena: Supervision, Visualization

Shiferaw Tadesse: Conceptualization, Formal Analysis, Investigation, Methodology, Software, Writing – review & editing

Bayisa Baye: Supervision

Data Availability Statement

The corresponding author can provide data used to support the study's conclusions upon request.

Conflicts of Interest

The authors declare no conflicts of interest.

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Research Fields

Mamo Mekonnen: Cereal and pulse crop Agronomy, Horticulture Managements, Soil Fertility improvement, crop design, Organic and inorganic fertilizer use

Temesgen Temena: soil science, Soil Chemistry, Soil improvements, Soil Analysis, crop managements'

Shiferaw Tadesse: Crop Agronomy, pulse and Cereal crop managements, soil fertility improvement, crop design

Bayisa Baye: Soil science, Agriculture chemistry, crop management, soil improvements, Soil Analysis