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EFFECT OF BLENDED FERTILIZER AND LIME APPLICATION ON YIELD OF FINGER MILLET, AND SOIL PROPERTIES OF ACIDIC SOILS IN WESTERN ETHIOPIA

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ABSTRACT

Finger millet (*Eleusine coracana L.*) is a small seeded cereal grown in low rainfall areas of Ethiopia. It is tolerant of drought. Nutritionally, the grains are a good source of quality protein and various minerals. However, production of finger millet is constrained by poor soil fertility and low input production systems. An experiment was carried out to evaluate the effect of different fertility management on yield of finger millet and soil physicochemical properties under limed and unlimed conditions of acidic soils in western Ethiopia. The treatments comprised of NP and different formula blended fertilizers under limed and unlimed conditions were laid in a randomized complete block design with three replicates. The result revealed that amelioration of soil acidity and application of N and P nutrients are a key intervention that should be sought in the study area. K, S, Zn and B are not limiting nutrients for the production of finger millet in the study area.

Contribution/Originality: This paper serves as the most recent study on the use of blend fertilizer in acid prone highlands of Ethiopia in giving sight whether it has a comparative advantage or not than the recommended N and P fertilizer.

1. INTRODUCTION

Finger millet (*Eleusine coracana L.*) also known as African millet is a cereal crop widely grown in low rainfall areas of Africa and Asia. In Ethiopia it is produced in almost all regions on about 1.6 million ha of land annually [1] with average yield of 2000 kg per ha. Being a hard and low input crop, it is often produced on marginal soils on which other crops fail to give reasonable yield [2]. Finger millet can be considered as a poor man's crop due to its wide range of adaptability, high nutritional value of the grain and excellent storage quality [3, 4]. Moreover; it is a source of income for rural households living in marginal areas in Ethiopia. Despite its importance as a low input crop, its productivity is highly variable and ranges between 400 and 2000kgha^{-1}. This is attributed to biophysical factors and management practices. Finger millet performs well in areas receiving an annual rainfall of 500-1000m, and soils with characteristics of fertile, well drained sandy to loams and slightly acidic to neutral pH levels [5]. Low soil fertility is one of the most limiting constraints to finger millet production in most areas of Ethiopia. Despite its significant role in dietary needs and income of smallholder farmers, this crop has been given less research attention and its agronomic requirement is not well studied in Ethiopia.

In addition to previously diagnosed ones (N and P), a recent study on Ethiopian soils revealed a depletion of many soil nutrients to a level limiting crop performance in most areas of Ethiopia [6]. Soil nutrients such as K, S, Zn, B are reported to affect food production in the country. Human induced perturbation of nutrient cycling through wide spread use of biomass for fuel, feed and construction materials, soil erosion and lack of amelioration in the form of fertilizer are blamed to cause their depletion [6-8]. This grabs research attention and few activities have been initiated to validate and/or calibrate macro-and micro-nutrients requirement on different test crops in the different parts of the country. Few studies indeed confirm the importance of including K in nutrient amendment for potato production [9-11]. This piece of work also presents the response of finger millet to different soil fertility management practices in western part of Ethiopia.

2. MATERIALS AND METHODS

2.1. Description of the Study Site

The experiment was conducted for three years (2015-2017) at Nedjo district of Welitate Gida Kebele/Peasant association (smallest unit of governmental administration) in western Ethiopia. The study site is located at 9^{0} 33' 07" N and 35^{0} 25'50" E, with an altitude of 1933 meters above sea level Figure 1. The area has a mean annual rainfall of about 1400 mm and experiences a weakly bimodal rainfall pattern extending from March to May and with the effective rain being from June to September. Mean annual temperature varies from a minimum of 18^{o}C and a maximum of 28 ^{o}C. The soil type is Nitisols with characteristics deep and good drainage conditions. Acidity and low fertility of soils, and termite infestation are critical constraints of crop production in western corridor of the Ethiopian highlands [12].The farming system is mixed-crop livestock production where teff, finger millet, triticale, maize, tuber crops are dominant crops produced while cattle, sheep, goat, donkey, mule and chicken are major animal species supporting the livelihood of the smallholder farmers.

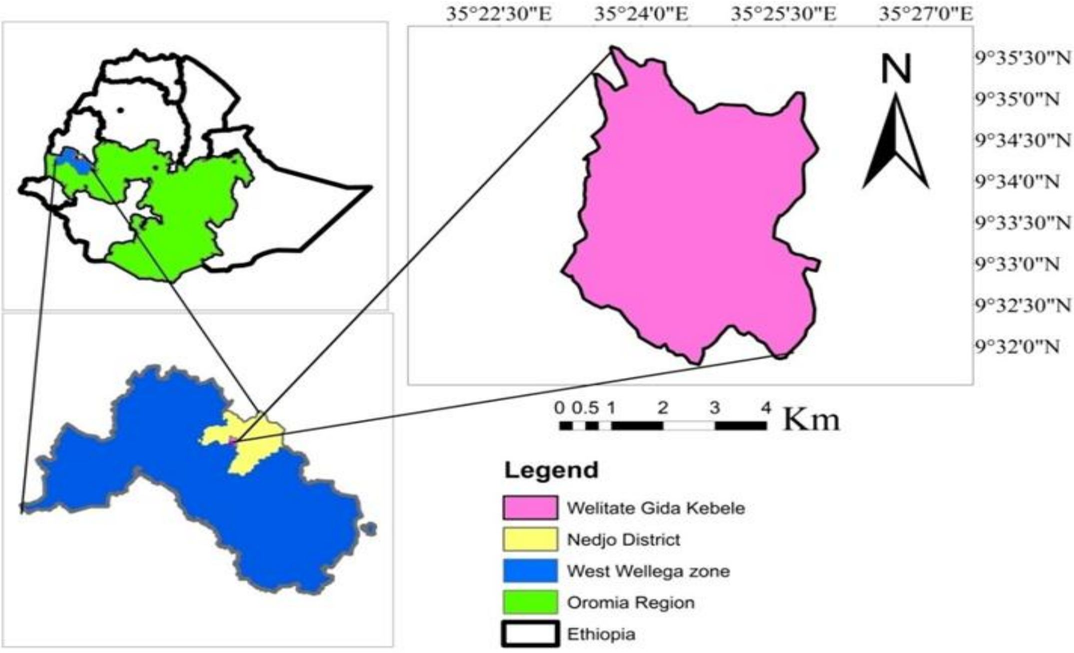

Figure-1. Map of the study area – Welitate Gida Kebele as done using Arc GIS version 10.3.

2.2. Experimental Design and Treatments

The experiment was laid-out in randomised complete block design (RCBD) with three replicates. A total of eleven treatments (fertility management practices) were included and each tested on a plot size of 12 m^{2}. Land preparation, planting, weeding and harvesting were undertaken according to the crop agronomic practices.

For liming treatments, the lime requirement was determined on the basis of the exchangeable acidity, bulk density and 15 cm depth of the soil using the equation below. One mole of exchangeable acidity would be neutralized by an equivalent mole of $CaCO_3$ Kamprath [13]. The required amount of lime was uniformly applied a month before planting.

$$LR, CaCO_3\ (kg/ha) = \frac{cmolEA/kg\ of\ soil * 0.15\ m * 10^4\ m^2 * B.D.(Mg/m^3) * 1000}{2000}$$

Where:

LR= Lime requirement; EA= Exchangeable acidity; BD= Bulk density

2.3. Treatments

1. Control
2. Recommended NP: 64.4 N and 69 P_2O_5
3. Formula 2 without lime: 64.4 N + 54 P_2O_5+ 10.1 S + 1.06 B
4. Formula 4 without lime: 69N + 51 P_2O_5 + 11 S + 3.34 Zn + 1.01 B
5. Formula 4 modified without lime: 57.5N + 70 P_2O_5 +15.2 S + 4.4 Zn + 0.5 B
6. Formula 5 modified without lime: 66.7 N + 52 P_2O_5 + 30 K_2O + 11.2 S + 3.44 Zn + 0.5 B
7. Recommended NP with lime: 64.4 N and 69 P_2O_5 + lime
8. Formula 2 with lime: 64.4 N + 54 P_2O_5 + 10.1 S + 1.06 B + lime)
9. Formula 4 with lime: 69N + 51 P_2O_5 + 11 S + 3.34 Zn + 1.01 B + lime
10. Formula 4 modified with lime: 57.5N + 70 P_2O_5 +15.2 S + 4.4 Zn + 0.5 B + lime
11. Formula 5 modified with lime: 66.7 N + 52 P_2O_5 + 30 K_2O + 11.2 S + 3.44 Zn + 0.5 B + lime

2.4. Soil Sampling and Analysis

Soil samples of the experimental site were collected before planting and after harvesting from a plough depth of 0-20 cm. Before planting representative soil samples collected from an experimental field were thoroughly mixed and form a composite sample which was used for chemical and texture analysis. Exchangeable acidity, pH, available P, TN, exchangeable bases (K, Ca, Mg, Na), and micro nutrients (Mn, Cu, Fe, Zn) were soil parameters considered in this study. For physiochemical analysis soils samples were ground to pass through a 2 mm sieve. The pH of the soil was determined following the potentiometer method (1:2.5 soils: water) as described by Chopra and Kanwar [14]. Available phosphorus was measured using Bray–II procedure [15]. Total nitrogen was measured following Kjeldhal method [16]. Titration method with 1N KCL leaching was used to measure exchangeable acidity [17]. Exchangeable Ca, Mg, K and Na were determined from 1N NH_4OAC extract using Atomic Absorption Spectrometry [18]. Available Mn, Cu, Fe and Zn were determined with DTPA as described by Lindsay and Norvell [19].

2.5. Data Collection and Analysis

Morphological parameters such as plant height and number of fingers per plant were measured from five plants randomly selected from middle rows of each plot at harvesting. Biomass and grain yields were measured from harvest of interior rows. Data on prices of inputs and products were collected for partial budget analysis that would augment the decision for recommendation of fertility management inputs for finger millet production in the study areas and other places with similar agro-ecologies.

All measured data were analyzed using general linear model (GLM) of Statistical Analysis System [20]. Least Significance Difference Test at 5% probability level was used for mean separation.

Model: $\gamma_i = \mu + F_i + \varepsilon_i$

Where γ_i is the response of the crop to different fertility management, μ= Overall mean, F_i = Effects of fertility management and ε_i is the residual error.

2.6. Partial Budget Analysis

Economic data was collected to assess the costs and benefits associated with different treatments, partial budget, dominance and marginal analysis following technique described by CIMMYT (International Maize and Wheat Research Centre) [21]. The three years (2015 – 2017) pooled grain yield data was used and this three years average price of finger millet was used to convert the grain yields into gross yield benefits.

3. RESULT AND DISCUSSION

3.1. Soil Physico Chemical Properties

3.1.1. Soil Texture

The soil is clay in texture with mean fractions 66.3%, 13% and 20.7% clay, sand and silt respectively Table 1. This implies that it needs huge amount of lime to reclaim the soil acidity, because soil higher in clay will have a higher cation exchange capacity (CEC) and will require more lime to raise the pH as supported by different literatures.

Table-1. Textural class of soil in the study site, Nedjo, western Ethiopia as done at Holeta soil Lab.

Fraction	%
Clay	66.3
Silt	13
Sand	20.7
USDA Textural class	Clay

3.2. Soil Chemical Properties

From the analysis result, soil pH before planting and after harvest fall in the same range. Both showed very strongly acidic level [22] but figuratively it has showed an increment from initial 4.53 to 4.96 with Formula 5 modified and lime Table 2. Treatments that had lime in addition (treatment no 7 up to 11) showed a slight pH increase. But these pH increments never correspond to the ideal pH range for most crops which is between 6.5 and 7.5 [23]. The soil exchangeable acidity has showed a sharp decline in soils treated with lime Table 2. Even though the experiment has showed the importance of liming the amount of lime determined by exchangeable acidity method for a hectare of land was not adequate to raise the pH to an ideal range for crop production.

Soil total nitrogen never showed a substantial difference due to applied fertility managements. This might be due to readily uptake by the crop. Available phosphorous of soil before planting and after harvest fall in the same category, and both showed very low range [24] but there was an increase from 4.79 to 6.34 ppm with the application of recommended NP + lime (treatment 7) Table 2. Fertility management that had lime additionally showed slight P and Ca increment Table 2. Ligeyo and Gudu [25] has also described the same phenomenon that lime increases P, Mg, Ca and Mo availability in acidic soils. Therefore, in P fixing acid soils, combined lime and P application is necessary to increase the availability of P for plant uptake.

The magnesium content of the soil has showed above critical level [24] with recommended NP + lime (treatment no 7), where as potassium and sodium content of the soil never showed a difference before planting and after harvest. Copper and Iron content of the experimental soil never showed a significant change among treatments whereas zinc content of the experimental soil showed inconsistence among treatments Table 2.

3.3. Yield and Yield Components

Combined analysis of variance of 3 years (2015-2017) indicated that most of the studied parameters showed significant difference at ($p < 0.05$) among treatments Table 3. The highest biomass (4475 kg ha^{-1}) and grain yield (872 kg ha^{-1}) were obtained from soils treated with lime and fertilized with formula 5 modified. This result clearly showed that around Nedjo area in addition to macronutrients (NPK) S, Zn, B nutrients were also limiting factors for finger millet production. Similar result was obtained by Weldegebriel, et al. [26] sorghum treated by fertilizer contained NPKSZnB (macronutrients in combination with micronutrient) gave higher yield.

Table-2. Soil physic chemical properties as affected by blended fertilizer under limed & unlimed condition at Nedjo, West Wollega as done at Holeta soil Lab.

Treatment	pH (1:2 H_2O)	TN (%)	AC	Ca	Mg	K	Na	AP	Mn	Cu	Fe	Zn
			---------- cmol(+)/ kg soil---------					------------ppm---------------				
Before planting (composite sample)	4.53	0.2	5.3	1.77	0.6	0.08	0	4.8	7	1	30.6	0.02
After harvest:												
1.Control	4.59	0.2	5.6	1.77	0.6	0.08	0	4.8	7	1	30.6	0.02
2. RNP	4.59	0.3	5.7	0.92	0.5	0.09	0.1	4.3	6.5	1.1	38	0.05
3. Formula 2	4.59	0.2	5.6	1.46	0.7	0.08	0	4.4	7	1.1	37.3	0.03
4. Formulae 4	4.67	0.2	5.2	1.54	0.9	0.07	0	4.8	5.5	1.1	32.7	0.14
5. Formula 4 modified	4.49	0.2	6.4	1.45	0.9	0.09	0	4.5	6.4	1.1	35.1	0.20
6. Formula5 modified	4.55	0.2	6.6	1.84	0.6	0.08	0	4.8	6	1	34.8	0.03
7. RNP + lime	4.70	0.2	3.7	2.32	1.3	0.09	0	6.3	6.7	1.2	36.9	0.03
8. Formula 2 + lime	4.84	0.2	4	2.3	0.7	0.08	0	5.2	5.8	1.1	36.8	0.01
9. Formula 4 + lime	4.72	0.2	4	2.1	0.6	0.08	0	5.2	6.7	1.2	36.8	0.10
10. Formula 4 modified + lime	4.80	0.2	3.2	2.13	0.4	0.08	0	5.6	7.1	1.1	31.5	0.23
11. Formula 5 modified + lime	4.96	0.2	1.9	2.81	0.6	0.11	0	5.2	7.4	1.2	29.5	0.05

AC = Exchangeable acidity.

The lowest plant height (31 cm) and harvest index (10) were recorded by control treatment. The second best biomass yields (3892 kg ha^{-1}) and grain yield (705 kg ha^{-1}) results of finger millet were recorded by recommended NP + lime. From this result, it is possible to conclude that recommended rate of NP with lime can gave a comparative biomass and grain yield with that of formula 5 modified + lime.

Table-3. Effects of different soil fertility management practices on morphological and yield performance of finger millet - over years analysis (2015-2017) – Nedjo, West Wellega

Treatment	PH (cm)	NF	BMY (kg ha^{-1})	GY (kg ha^{-1})	HI
1	31	2	234^{f}	25^{f}	10^{e}
2	49	4	2291^{e}	373^{e}	18^{abc}
3	50	4	2031^{e}	444^{de}	18^{abc}
4	49	4	2279^{e}	391^{e}	16^{cd}
5	49	4	2224^{e}	370^{e}	18^{abc}
6	53	5	3145^{c}	538^{c}	17^{bcd}
7	52	5	3892^{b}	705^{b}	19^{ab}
8	50	5	2900^{cd}	475^{cd}	16^{cd}
9	51	4	2694^{d}	485^{cd}	17^{bcd}
10	49	4	2909^{cd}	499^{cd}	16^{cd}
11	57	5	4475^{a}	872^{a}	20^{a}
Mean	49	4.26	2643	471	17
CV (%)	13.4	13.6	12.1	18.5	13.5
LSD	6	0.54	300	82	2

PLHT = plant height, BM = biomass, GY= grain yield, HI=harvest index
1= Control, 2=Recommended NP, 3=Formula 2, 4= Formula 4, 5=Formula 4 modified, 6= Formula 5 modified, 7= Recommended NP +Lime, 8= Formula 2 + lime, 9= Formula 4 + lime, 10= Formula 4 modified + lime, 11= Formula 5 modified + lime.

3.4. Partial Budget Analysis

In view of economic benefits, a shift in practice from RNP to other better option needs partial budget analysis was done to identify the rewarding treatments. Three years (2015-2017) average market prices of finger millet grain, farm gate price of N and P fertilizers were 7.5, 9.8 and 10.55 birr per kg respectively. The prices of different nutrients in blended fertilizers were 14.73 birr per kg. The price of $CaCO_3$ was 1.87 birr per kg, and labor demand was valued at 38 birr per person for 8 working hour. For a hectare of land seven personnel (labor force) were estimated to undertake fertilizer and lime application Table 4.

The economic analysis further revealed that the application of Formula 5 Modified + lime (i.e.,

NPKSZnB + lime provided the highest marginal rate of return (MRR) 739 % Table 4 suggesting for one birr invested in finger millet production, the producer would get birr 7.39 after recovering his investment. Since the MRR assumed in this study was 100%, the treatment Formula 5 Modified under limed condition gave an acceptable MRR. Similarly, the application of Recommended NP (RNP) with lime provided the second best marginal rate of return (MRR) of 733 % Table 4 suggesting for one birr invested in finger millet production, the producer would collect birr 7.33 after recovering his investment. Both treatments Formula 5 Modified with lime and RNP with lime gave nearly equal MRR, hence unless advantages of quality aspects of grain obtained from balanced fertilization (i.e., Formula 5 Modified + lime) was considered lime treatment and use of Recommended NP is feasible option for finger millet production by smallholder farmers of the study site, Nedjo, western Ethiopia.

Table-4. Partial budget and dominance analysis of blended fertilizers and lime application effect on yield of finger millet.

No	Treatment	Average Yield (kg/ha)	Gross benefits (birr/ha)	Variable costs (birr/ha)				Net Benefit	MRR (%)
				Fertilizer & Lime cost	Seed	Labor	Total cost		
1	Control	24.5	183.5	0	7.5	0.0	7.5	176.0	
2	Recommended NP	373.4	2800.2	2954.9	7.5	155.0	3117.5	-317.3 D	
3	Formula 2	444.2	3331.4	3617.6	7.5	155.0	3780.2	-448.7 D	
4	Formula 4	390.6	2929.3	3692.6	7.5	155.0	3855.2	-925.9 D	
5	Formula 4 modified	370.4	2778.2	4119.8	7.5	155.0	4282.4	-1504.1 D	
6	Formula 5 modified	537.8	4033.7	4307.5	7.5	155.0	4470.0	-436.3	13.3
7	Recommended NP + lime	704.9	5286.4	3142.4	7.5	266.0	3415.9	1870.5	733.0
8	Formula 2 + lime	475.4	3565.7	3805.1	7.5	266.0	4078.6	-512.9 D	
9	Formula 4 + lime	485.5	3641.2	3850.1	7.5	266.0	4123.6	-482.4 D	
10	Formula 4 modified + lime	499.5	3746.0	4307.3	7.5	266.0	4580.8	-834.8 D	
11	Formula 5 modified + lime	871.7	6538.0	4494.9	7.5	266.0	4768.5	1769.5	739.1

4. CONCLUSION AND RECOMMENDATION

In the study area, the use of fertilizer has focused mainly on the use of nitrogen and phosphorous fertilizers in the form of urea and di-ammonium phosphate (DAP) for almost all cultivated crops. The result of this experiment gave a clue on the importance of amending micronutrients in the study area if the soil is limed. However, from an economic point of view, marginal rate return (MRR) from fertility management with formula 5 and RNP under limed condition is nearly equal. Hence, unless advantages of quality aspects of grain obtained from balanced fertilization were considered it is not advisable to choice plant nutrients K, S, and micronutrients for finger millet production around Nedjo area. This would lead to the need of N and P nutrient use with lime on acid nitisol of the study area. From all treatment/fertility management the application of recommended NP + lime has improved the available phosphorous of the soil (6.3 ppm).

From yield response and economic analysis recommended NP with lime can be suggested as best option for finger millet production in the study area, however the amount of lime determined by exchangeable acidity method for a hectare of land was chosen at a relatively low level hence, not adequate to raise the pH to an ideal range for crop production. Therefore, further studies on different lime rate determination methods should be carried out to evaluate their applicability under extremely acidified field conditions.

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