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AGRONOMIC PRACTICES OF MAIZE AND FARM NUTRIENT STATUS IN BAKO TIBE DISTRICT, WEST SHOA ZONE, ETHIOPIA: LESSON FROM AGRONOMIC PANEL SURVEY

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ABSTRACT

Agronomic panel survey was conducted in Bako Tibe district to assess current farmers maize agronomic practices and associated actual maize grain yields. The survey was conducted using 100 households. Most of the maize farms (90%) were characterized as having strongly to strongly acidic soils, low to medium SOC, medium to high TN, very low to low av.P, high to very high exch. K, low to medium exch.Ca, and medium to high exch. Mg, high av. Zn and Fe and very high Mn contents. Most farmers (94%) grow improved maize varieties and 80% of them grew a pioneering hybrid Limu and Bako hybrids BH540 and BH543. Most farmers (97%) apply different inorganic fertilizers and of them >70% of them applied NPS+Urea or NPS alone. Farmers rarely retain crop residue. Most farmers (81%) maintain lower plant density at harvest than the recommended density and the density declined from vegetative to harvesting stage. About 99% of the farmers grow sole maize, 57% rotate maize with other. Percent weed cover of the farms were 25% on average but reached as high as 80%. About 87.5%, 86%, 75% of farmers harvested grain yield that was higher than the national, regional and zonal average, respectively. Since most maize farms (90%) were very strongly to strongly acidic, there is a need to apply lime to improve maize productivity and nutrient use efficiency in the area. The poor weed and crop residue management, sole cropping of maize and lower plant densities practiced by farmers were among the gaps observed that potentially reduce maize productivity in the study area unless the extension sector intervenes. However, the current trend improved maize varieties and inorganic fertilizers use is promising and needs to be encouraged for intensification of maize production in the study area.

Contribution/Originality: This paper serves as the most recent study on maize agronomy in Ethiopia in giving sight to the nutrient status of soils of the best maize growing district in the region. It also gives an insight into what the maize agronomic practices (cropping system, crop residue management fertilizer, and improved maize variety use) look like in the distinct.

1. INTRODUCTION

Maize is the second most widely cultivated crop in Ethiopia and is grown under diverse agro-ecologies and socioeconomic conditions typically under rain-fed condition (Abate *et al.*, 2015). Maize has expanded rapidly in terms of both area and production. Following the increasing trend of farmers' investment on required inputs, mainly in improved seeds and chemical fertilizers, maize productivity has also dramatically increased in Ethiopia.

As a result, maize has had a positive impact on poverty reduction in many parts of the country (Abate *et al*., 2015). In Ethiopia, maize has also expanded to new agro-ecologies such as the highlands of Ethiopia following the release of suitable highland varieties such as BH660, Jibat, Wonchi, etc. (Gudeta *et al*., 2011).

Before 1992, farmers in Ethiopia mainly grow local maize varieties that are low yielding, tall growing and hence were very susceptible to lodging (Abate *et al*., 2015) in spite of the availability of few improved maize varieties released already. Adoption of improved maize varieties was noticed from 1993 onwards (Abate *et al*., 2015) following the release of improved maize hybrids (BH140 in 1988) and BH660 in 1993 (Mosisa *et al*., 2001; Legesse *et al*., 2011). Maize agronomic research was initiated shortly, after the release of the new maize varieties. Consequently, several maize agronomic recommendations were developed for different locations including Bako Tibe (Tolessa *et al*., 2001; Dagne *et al*., 2011; Temesgen *et al*., 2011; Wakene *et al*., 2011). The various agronomic recommendations include optimum plant density (Tesfa *et al*., 2011) optimum fertilizer rate (Tolessa *et al*., 2001; Wakene *et al*., 2011) weed management (Temesgen *et al*., 2011) in maize and suitable maize-based cropping systems (Dagne *et al*., 2011).

Bako Tibe is one of the maize belt areas in Western Oromia, with the area under maize and total maize production of 32,562 hectare and 2,027,207 quintals, respectively (Bako Tibe District Bureau of Agriculture, data average of three years). The national maize program at Bako Agricultural Research Center has developed maize agronomic packages for Bako Tibe and adjacent districts for which the center has research mandate. Although these recommendations were promoted to farmers for use, there is no sufficient information on the actual amount and type of fertilizers that farmers currently apply for intensifying maize production. There is also no information on the type of maize varieties being grown by these farmers. The actual plant density used by farmers and the level of weed and crop residue management is also not well known. Yet the maize yield gap in the district is as high as 37% as calculated from the average farmers' actual yield reported in this paper (5004 kg ha^{-1}) and the average optimum maize grain yield recorded (7960 kg ha^{-1}; TAMASA unpublished data) from the researchers managed multi-location on farm experiments conducted in the same grid during the same season under non limiting fertilizer inputs (120-40-40; N-P-K). Thus, this study was aimed at 1. Assessing current farmers maize agronomic practices: (fertilizer *type* and *rate*, *type* and *name of maize variety used*, *farmers' plant density*, *weed* and *crop residue management etc)*. 2. Determining the actual farmers' maize grain yields in Bako Tibe district.

2. METHODOLOGY

2.1. Description of the Study Area

Location

Bako Tibe district was one of those districts with the highest maize production and largest area under maize in western Oromia (West Shoa Zone) with a total maize area of 32,562 hectare and production of 2,027,207 quintals (*source:* Bako Tibe District Bureau of Agriculture, data av. of three years). Thus, the district was selected as a priority district for conducting the agronomic panel survey under the Taking Maize Agronomy to Scale in Africa (TAMASA) Project. The district is located in Oromia Regional State at road distance of 250 km from the capital city of Ethiopia, Addis Ababa to the western direction Figure 1. Geographically the district is situated between 9°12'35" - 9°7'30"N and 37°58'25" - 37 °13'40"E. The altitudes of the studied farms ranged between 1593-1847 meter above sea level (m.a.s.l) with average altitude of 1670 m.a.s.l, which are all in the mid altitude. The dominant soil type is nitisol characterized as very strongly to strongly acidic.

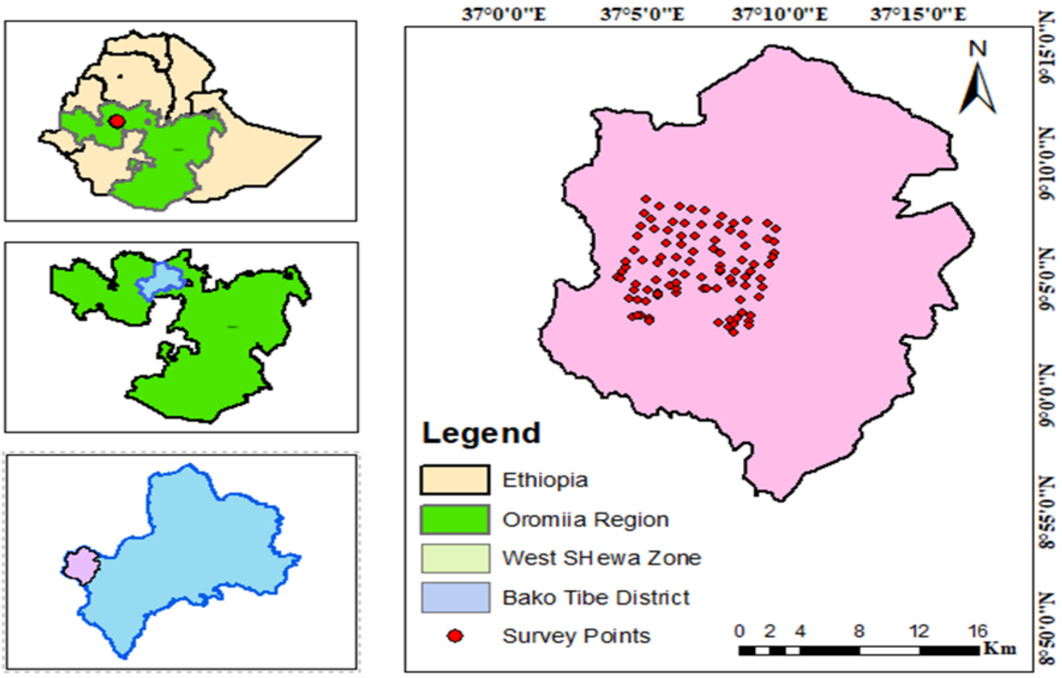
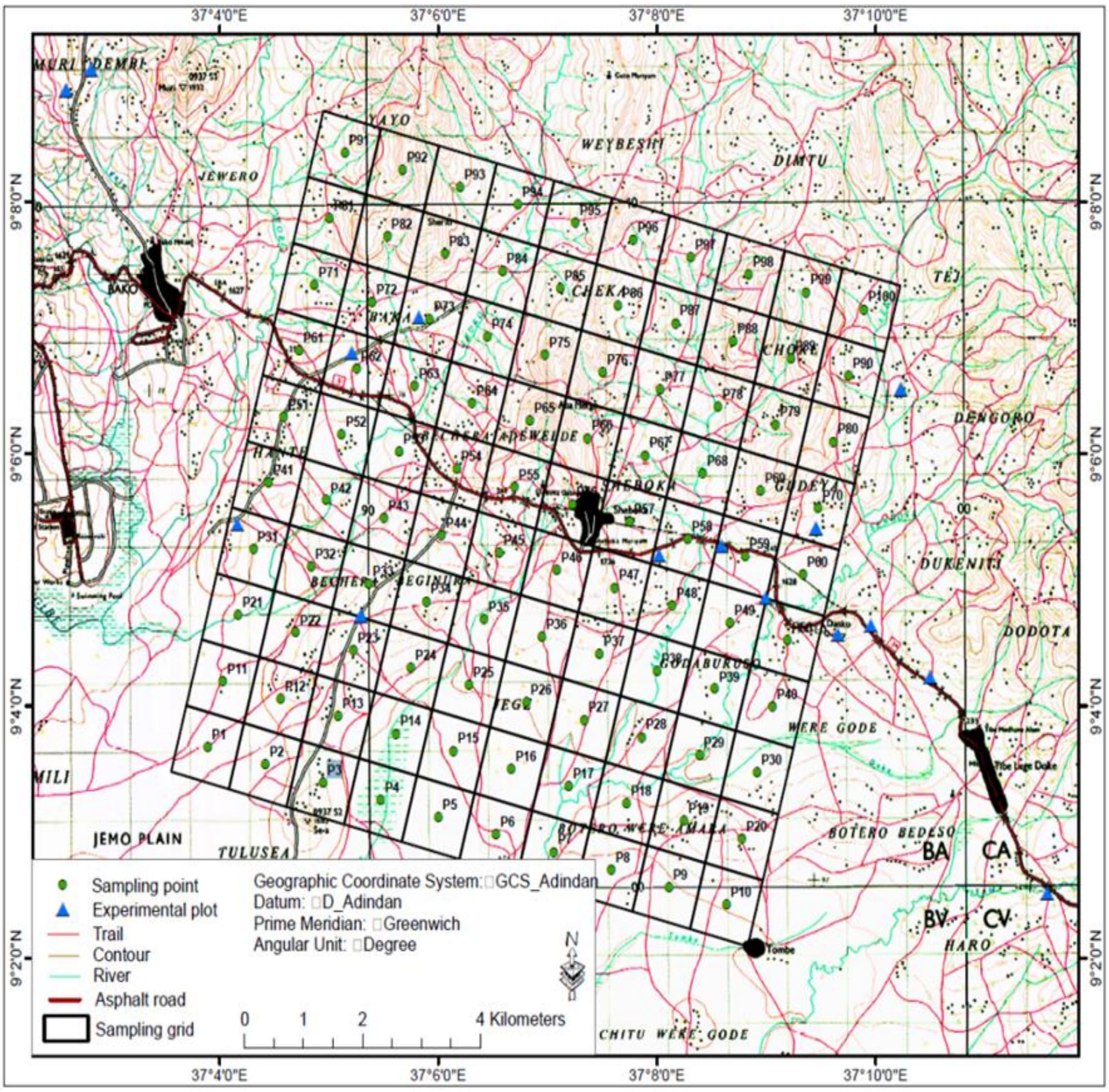


Figure-1. Location map of study Area (Bako Tibe District).

Source: The MAP was developed by GIS guys using coordinates of the study sites.



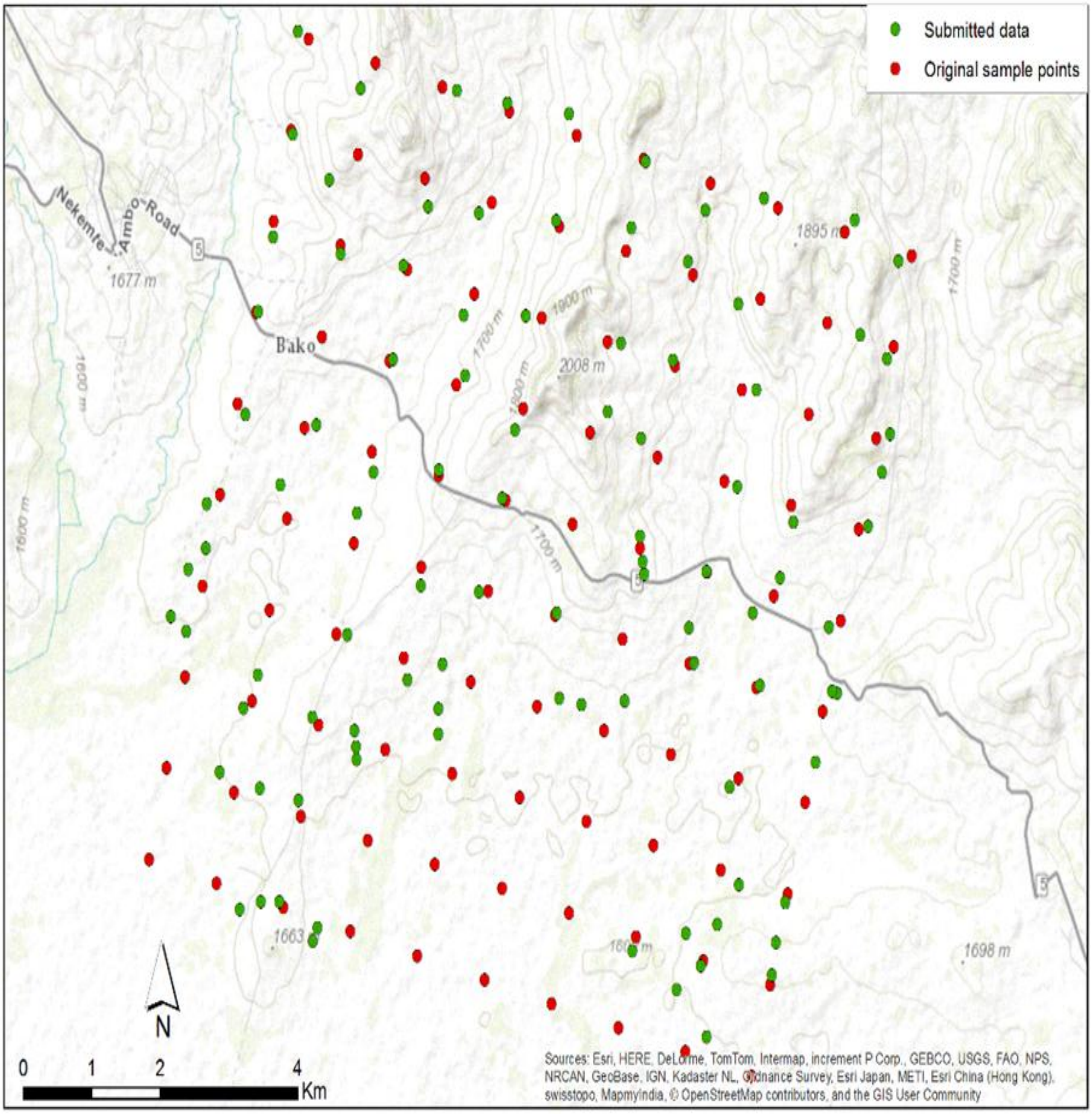


Figure-2. Maps showing the 100 1 km by 1 km sub-grids and the actual sampling points (left: green dots).

Source: The MAP was developed by GIS guys using coordinates of the study sites. NB: Red dots are central points of 1 km by 1km sub-grids, while green dots are actual sampling points.

Climate

Metrological data obtained from Bako Agricultural Research Center, the closest experimental sites to the survey area (1-2 km radius), indicated that the district has a uni-modal rainfall pattern with long term mean annual rainfall of 1247 mm. The rainy season stretches from February to November with maximum rainfall amount recorded in June, July and August. The long term mean annual temperature was 20.6^{O}C with mean (10 years) annual minimum and maximum temperatures of 13.2 and 28^{O}C, respectively.

Sampling Procedure

Farmers' Selection

A 10 km X 10 km grid was generated see Figure 2. The grid was further divided into one hundred 1 km x 1 km sub-grids with the central point of each sub-grid allocated a coordinate. During the survey, enumerators navigate to the central point of each sub-grid using GPS essential installed on the smart phones and select maize farm and a farmer close to the central point of the 1 km X 1 km.

Procedures of Data Collection and Analysis

Before conducting the survey, training was given to staff members from Ambo Agricultural Research Center, under the Ethiopian Institute of Agricultural Research (EIAR). The maize farm was surveyed at three different crop stages (vegetative stage, flowering stage, and harvesting stage). Data during each crop stage was collected using open data kits (ODK). For the two crop stages (vegetative and flowering stages) data was collected from farms of 100 households. However, during the harvesting stage crop data was collected only from farms of 73 households since some farmers have already harvested due to the untimely rain. All crop data was recorded and soil sampling was made from 4 m x 4 m quadrants from randomly selected three quadrants per farmer's field.

The parameters/variables recorded include: Gender and age of respondents, land tenure system, whether training on agronomic practices have been given, level of farmers' trust for extension service, types and names of maize varieties grown, types and rates of fertilizers applied, plant density (at each crop stage), crop residue management (% residue retained), %weed cover, disease and pest incidence (%), maize cropping system, grain yield and cob numbers harvested, plot level GPS coordinate, altitude and field area measures. In addition, soil samples at the depth of 0-20 cm were collected from three quadrants and were bulked to form representative of that farm. The soil samples were analyzed following appropriate laboratory procedures for each nutrient using wet chemistry. Descriptive statistics was used to analyze and present the results.

3. RESULTS AND DISCUSSIONS

3.1. Soil Fertility of the Surveyed Maize Farms

Table-1. Soil organic carbon (SOC), pH and some macro and micro nutrient contents of soils of the study farms and percentage of farms belonging in different soil nutrient content rating /category (N=100).

Soil parameters	Soil Test Result	Category					References
		Very high	High	Medium	Low	Very low	
SOC (%)	1.7 (0.9-2.9)	-	-	60%	40%	-	Tekalign, 1991
pH (water)	5.2 (4.6-5.9)	NA	NA	NA	NA	NA	
Total N (%)	0.18 (0.10-0.31)	6%	62%	32%	-	-	Murphy, 1968
Av. P (mg kg^{-1} soil)	6 (1-24)	-	2%	5%	35%	58%	Jones, 2003
Exch. K (mg kg^{-1} soil)	239 (123-485)	19%	80%	1%	-	-	Jones, 2003
EC.S (ds/m)	35 (15-63)	NA	NA	NA	NA	NA	
Ca (mg kg^{-1} soil)	1250 (325-4178)		14%	40%	46%	-	Jones, 2003
Mg (mg kg^{-1} soil)	336 (116-1196)	7%	25%	62%	6%	-	Jones, 2003
Zn (mg kg^{-1} soil)	8 (4-16)	10%	90%	-	-	-	Jones, 2003
Al (mg kg^{-1} soil)*	905 (444-1751)						
Fe (mg kg^{-1} soil)	130 (74-256)	1%	99%	-	-	-	Jones, 2003
Mn (mg kg^{-1} soil)	111 (43-266)	99%	1%	-	-	-	Jones, 2003

Values are means and those in parenthesis are ranges (Min & max)
*=No rating available

3.1.1. Soil Organic Carbon and pH

The soil organic carbon (SOC) content in the study area ranged from 0.9-2.9% with an average value of 1.7%. According to SOC rating by Tekalign (1991) 40% of the sampled maize farms had SOC content rated as low (0.5-

1.5%), while 60% had SOC content rated as medium/moderate Table 1. The results of the current study (av. OC of 1.7%) comply with the finding of Wakene and Heluf (2004) who also reported medium/moderate SOC content (1.95%) in the top 0-20 cm of nitisols of cultivated land in Bako Tibe district, while the adjacent virgin land had SOC content of 5.9% (very high). The relatively lower OC content of the soils of the maize farms in the current study compared to what (Wakene and Heluf, 2004) recorded for virgin lands in Bako Tibe district could probably be ascribed to limited or absence of organic fertilizer application, periodic removal of crop residues from the maize fields for different purposes and continuous cultivation which resulted in OM degradation. The lower percentage of crop residue maintenance observed in the current study Table 5 also supports this conclusion. In line with our observation (Eyasu, 2016) also reported moderate range SOC content (1.6- 2.5%) for Bako area confirming our observation.

Data presented in Table 1 indicated that the pH of the soils of the 100 maize farms varied from 4.6 to 5.9 with the mean value of 5.2. According to the classification of soil reaction classes suggested by both Murphy (1968) and Jones (2003) 25% of the surveyed maize farms were classified as very strongly acidic, 65% as strongly acidic and the rest 10% as moderately acidic. Although soil acidity can occur naturally, human activity can also aggravate the problem (Landon, 1991). This was confirmed by the finding of Wakene and Heluf (2004) and Heluf and Wakene (2006) who reported increased soil acidity for cultivated lands compared to adjacent virgin lands which enabled them to conclude that intensive cultivation and continuous use of acid-forming inorganic fertilizers aggravated soil acidity in Bako area. Thus, the continuous use of ammonium-based fertilizers such as DAP ($(NH4)_2HPO_4$) and other chemical fertilizers in the study area might have contributed to soil acidification as suggested by Abebe and Endalkachew (2012).

In the current study, the exchangeable aluminum content of the soils tended to show a negative correlation with soil pH Table 2, indicating that soil pH decreases with increasing exchangeable Al content of the soil. In the case of 90% of the maize fields, where the soils were strongly and very strongly acidic, the soils contain excess aluminum that is chemically active and reacts with soil phosphorus, rendering it unavailable due to insolubility. In strongly and very strongly acidic soils, there will also be higher P sorption due to oxides and hydroxides of Al and Fe in cultivated lands thus making phosphorus fertilizers to be tied up and become less available to crops (Landon, 1991). Thus, for those soils, it is recommended to raise the soil pH through liming to increase the availability of plant nutrients and to improve nutrient recovery efficiencies as well as crop productivity.

3.1.2. Primary Nutrients (NPK):

The total nitrogen (N) content of the soils under study ranged from 0.10-0.31% with an average value of 0.18% Table 1. According to Murphy (1968) of soil total N content rating, 32% of the maize farms had medium total nitrogen content while the remaining 62% had high total N content and the rest 6% had very high total N Table 1. Our observation is in agreement with the report of Eyasu (2016) who reported total N content in the high range (0.19-0.25%) for the nitisols in Bako areas. Most of the soil samples had medium to high range of total N content but low to medium category SOC content. Yet there was a strong significant positive correlation between SOC and total N $R^2 = 55^{**}$, Table 2 implying that the total N content of the soil could be related to the soil organic carbon content Table 1.

The available phosphorus (P) content varied from 1 to 24 mg kg^{-1} soil with a mean value of 6 mg kg^{-1} Table 1. According to soil available P rating by Jones (2003) 58% of the surveyed maize farms were rated as having very low, 35% as low, and only 5% as medium and 2% as high available P Table 1. This result is in agreement with the findings of Wakene and Heluf (2004) who also reported low available phosphorus (av. of 5.8 mg kg Olson P) in soils from cultivated lands in Bako Tibe district. However, our results contradict with the report of Eyasu (2016) who reported av. P content of 22-26 mg kg^{-1} soil, which belongs to the medium rating (if Bray) or very high rating (if

Olsen) method was used for the determination. Although soil acidity highly influences P availability, the soil pH and available P did not show any clear significant relationship in the present study Table 2.

Available potassium (K) in the soil ranged between 123 and 485 mg kg^{-1} with an average of 239 mg kg^{-1} Table 1. According to Jones (2003) only 1% of the surveyed field were rated as having medium K content (91-140 mg kg^{-1}), 80% as high (141-300 mg kg^{-1}) and 19% as vey high (>300 mg kg^{-1}) K content. Our result is in agreement with the finding of Eyasu (2016) who reported an exchangeable K content of 546 mg kg^{-1} (very high category) for nitisols of Bako areas but contradicts with the reports of Wakene and Heluf (2004) who observed average exchangeable K content of 101 mg kg^{-1} soil (rated as medium) in the same nitisols of Bako Tibe district. Our result also agrees with the report of Dagne (2016) who also reported high available K (180 mg kg^{-1} soil for Kejo and 197 mg kg^{-1} soil for Ongobo) in similar soils of Gobu Sayo, an adjacent district to Bako Tibe.

3.1.3. Secondary Nutrients (Ca and Mg)

The Exchangeable calcium (Ca) content of the soils ranged between 325-4178 mg kg^{-1} with a mean value of 1, 250 mg kg^{-1} soil. Exchangeable Ca content of soils of the study area was rated as low (251-1000 mg kg^{-1} soil) in 46% farms, as medium (1001-2000 mg kg^{-1} soil) in 40% farms and as high in 14% farms according to Jones (2003). Similarly, Wakene and Heluf (2004) and Dagne (2016) reported an av. Ca content of 918 mg kg^{-1} soil in Bako Tibe District and 600-936 mg kg^{-1} soil, in Gobu Sayo district, respectively both of which were in the low category, partly supporting our finding. However, our result highly contrasts with the finding of Eyasu (2016) who observed an Exchangeable Ca content of 4,400-5,800 mg kg^{-1} soil (high to very high category) in nitisols of Bako area.

The exchangeable magnesium (Mg) content of the soils ranged between 116-1196 mg kg^{-1} with the average value of 336 mg kg^{-1} soil. Most of the soil samples (62%) were in the medium range, 25% in a high range, while 7% and 6% were in the very high and low ranges, respectively according to Jones (2003) Mg rating. The result of the present study agrees with the reports of Wakene and Heluf (2004) and Dagne (2016) who also reported medium category (151-350 mg kg $soil^{-1}$) Mg content in soils of Bako Tibe (av. 209 mg kg soil) and Gobu Sayo districts (193-199 mg kg soil), respectively. However, our result contradicts with the observation of Eyasu (2016) who reported an Exchangeable Mg content of 960-1080 mg kg^{-1} soil (very high category) in nitisols of Bako area.

Table-2. Relationship between organic carbon, soil pH, Al, Mn, P and total N.

	Pearson correlation coefficient, N=98 (Probability level)					
	OC	**pH**	**Al**	**Mn**	**Av.P**	**TN**
OC	1	0.03674 (0.7195)	0.05339 (0.6016)	0.15740 (0.1217)	0.13715 (0.1781)	0.54600 (<.0001)
pH	-0.03674 (0.7195)	1	-0.16273 (0.1094)	-0.05336 (0.6018)	0.04930 (0.6297)	0.06046 (0.5543)
Al	0.05339 (0.6016)	-0.16273 0.1094	1	0.09056 (0.3752)	0.01706 (0.8676)	0.05156 (0.6141)
Mn	0.15740 (0.1217)	-0.05336 (0.6018)	0.09056 (0.3752)	1	-0.07788 (0.44459)	0.18222 (0.0725)
Av.P	0.13715 (0.1781)	0.04930 (0.6297)	0.01706 (0.8676)	-0.07788 (0.4459)	1	0.04268 (0.6765)
TN	0.54600 (<.0001)	0.06046 (0.6141)	0.05156 (0.6141)	0.18222 (0.0725)	0.04268 (0.6765)	1

Source: This is SAS statistical software output from row data.

3.1.4. Micronutrients (Zn, Mn, Fe)

The zinc (Zn) content of the farms ranged between 4 to 16 mg kg^{-1} soil with a mean value of 8 mg kg^{-1} soil. The available Zn content of soils of all the farms (100%) in the current study Table 1 was in the adequate range according to Jones (2003). The available Zn contents of soils of 90% the farms were in the high category while 10% of the farms were in the very high category according to Zn rating by Jones (2003). This result is in agreement with the report of Girma *et al.* (2016) who observed sufficient available Zn concentration (average of 2.96 mg kg^{-1} soil) in maize growing soils of central Mecha. Likewise, Eyasu (2016) reported Zn content that was in the high category in Nitisols of Bako areas supporting our finding. However, our results contradict with the report of Wakene and Heluf (2004) and Dagne (2016) who observed Zn deficiency in Nitisols of Bako Tibe and adjacent Gobu Sayo districts, in Western Oromia.

The manganese (Mn) content of the soils of the studied maize farms ranged from 43 to 266 mg kg^{-1} soil with a mean value of 111 mg kg^{-1} soil Table 1. The manganese contents of nearly all the soil samples (99%) was in a very high range (i.e. >50 mg kg^{-1} soil) according to Mn rating developed by Jones (2003). In agreement with our finding, Wakene and Heluf (2004) and Dagne (2016) also reported very high available Mn content in Nitisols of Bako Tibe district (56 mg kg^{-1} soil) and Gobu Sayo District (77-82 mg kg^{-1} soil), respectively, while Eyasu (2016) reported high Zn content (25-35 mg kg^{-1} soil) for the same area.

The Iron (Fe) content of the soils ranged between 74-256 mg kg^{-1} soil with a mean value of 130 mg kg^{-1} soil. About 99% of the farms had high Fe content according to Jones (2003) and our result is in conformity with the results of Wakene and Heluf (2004), Dagne (2016) and Eyasu (2016). Serious micronutrient deficiency is not expected in soils with lower pH, due to increased solubility and hence the Zn deficiency reported by Wakene and Heluf (2004) and Dagne (2016) unlike the present finding and the finding of Eyasu (2016) need to be further confirmed.

3.1.5. Characterization of the Farmers

Most of the surveyed farmers were male respondents (91%). Most of them belonged to the age group of 25 to 50 years old (75%) while very few (3%) were below the age of 25 years. Most of the respondents (81%) owe the land they use for the maize production while 19% of the respondents rented the land for maize production Table 3.

Table-3. Gender, age and land tenure of surveyed farmers.

Variables	Percent farmers
Gender	
Male	91%
Female	9%
Age	
<25	3%
25-50	75%
>50	22%
Land tenure	
Private	81%
Rented	19%

3.2. Maize Variety Use in the Study Area

The type of seed/ variety grown remarkably influence maize grain yield (Enujeke, 2013). The type of maize variety used can explain 35-40% of maize yield gap (Ghimire *et al.*, 2016) signifying that the use of appropriate variety is an option to close maize yield gaps. Adoption of improved maize varieties in Bako area like any other parts of Ethiopia was noticed from 1993 onwards following the release of improved maize hybrids (BH140 in 1988) and BH660 in 1993 at Bako Agricultural Research Center (Asfaw *et al.*, 1997; Abate *et al.*, 2015). This was mainly due to the government initiative/campaign for increased food production in collaboration with Sasakawa Global 2000 through the use of improved maize production packages (improved seeds and chemical fertilizers, DAP and UREA). Since then, a number of other improved maize varieties (both OPV and hybrids), have been released for different maize agro-ecologies of Ethiopia. Some of these varieties were released for highland agro-ecology (Gudeta *et al.*, 2011) some for mid-altitude agro-ecology (Legesse *et al.*, 2011) and others for low altitude and moisture stress areas (Gezahegn *et al.*, 2011).

The results of the current study (maize agronomic panel survey) showed that 94% of the surveyed farm households grew improved maize variety while only 6% grew local/recycled seeds of improved maize varieties Figure 3. From among those farmers who grow improved maize varieties, most of the respondents (80%) grew a pioneering hybrid Limu and Bako hybrids BH540 and BH543 in the study area during the survey period. The study showed that hybrid varieties such as BH661, BH660 and shone were grown by few households during the survey period Figure 3. The two Hybrids, BH661, BH660, are very high yielding and are most suitable for mid to higher altitude areas than the lower altitude areas as they lodge in the lower altitudes due to faster and tall growth (Legesse *et al.*, 2011). Consequently, only 11% of the farmers grew these two varieties in the study area Figure 3. The results of the current agronomic panel survey showed that the varieties grown by the respondents were all in the recommended agro-ecology for the varieties described by Legesse *et al.* (2011). Knowing the type of maize variety grown in a given region is quite important especially for the seed companies, as this will enable them to properly target seed production and distribution.

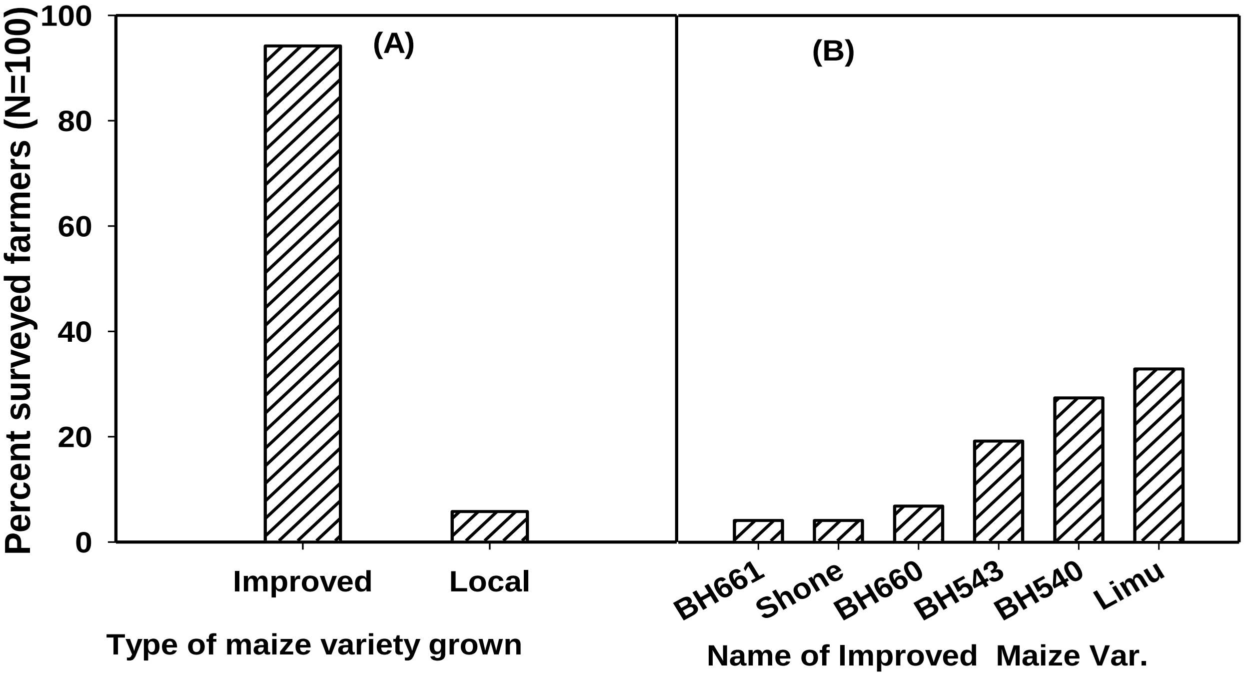


Figure-3. Type of maize variety (A) and name of the improved maize variety (B) used by farmers (data from agronomic panel survey in 10 km x10 km grid, in Bako Tibe district, 2015).

From the current study, it can be suggested that yield gap in the study areas cannot be related to the use of inappropriate varieties since almost all farmers (94%) used improved hybrid maize varieties that were recommended for that agro-ecology (mid-altitude).

From the current study, it can be suggested that yield gap in the study areas cannot be related to access to improved varieties since almost all farmers (94%) used improved hybrid maize varieties that were recommended for that agro-ecology (mid-altitude).

3.3. Soil Nutrient Management through Fertilizer Application

Low soil nutrient contents are the most yield-limiting factors in maize production (Tolessa *et al.*, 2001). In most maize growing regions, nitrogen was the most yields limiting nutrient followed by phosphorus (Tolessa *et al.*, 2001; Wakene *et al.*, 2011; Tesfaye *et al.*, 2019). The omission of nitrogen fertilizer (keeping both P and K fertilizers at non-limiting rates), for instance, resulted in average grain yield penalty of 2662 kg ha^{-1} in 2015 season and 4845 kg

ha^{-1} in 2016 season in Bako Tibe district (Tesfaye *et al.*, 2019). Progressive increase in maize grain yield with increasing levels of both N and P was observed (Tolessa *et al.*, 2001; Shiferaw, 2018).

The application of chemical fertilizers for maize production in Ethiopia is, however, a recent phenomenon that began in 1993, following the government campaign for increased food production in collaboration with Sasakawa Global 2000 (Abate *et al.*, 2015). Thus, the application of chemical fertilizers had the same lifetime as the use of improved maize varieties both of which emerged following the strong collaboration of the government of Ethiopia with SG2000 to achieve increased food production in the country (Abate *et al.*, 2015). Before that time farmers grow local maize without any chemical fertilizer or with the application of organic fertilizers alone such as manures (Abate *et al.*, 2015). As a consequence, the yield of maize was quite low about 1 t ha^{-1} (Abate *et al.*, 2015). Later on maize agronomy research recommended a blanket recommendation of 100 kg DAP and 200 kg Urea (20 kg P ha^{-1} and 110 kg N ha^{-1}). Later on each regional research institutes developed regional fertilizer recommendations for their own mandate regions, which was 30 kg P ha^{-1} and 119 kg N ha^{-1} for Bako area (Wakene *et al.*, 2011). As of 2015, soil test/ETHioSiS soil map based fertilizer recommendation emerged, which laid a base to decide the type of nutrients (blended fertilizer) that a given region and down to district level should apply, but still with no rate determined. Consequently, farmers are currently applying blended NPS (19-38-7) and Urea keeping the rates similar to the previous DAP (18-46) and urea (46%) recommendations since the blended fertilizer rate determination research is still underway.

Results of the agronomic panel survey conducted at Bako Tibe district showed that most farmers (95%) apply fertilizer in different forms while only 5% grow maize without any fertilizer application. Of those framers that apply fertilizer, 97% apply chemical fertilizer while only 3% apply organic fertilizers especially cattle manure Table 4. According to survey result 40% of the farmers apply Urea+NPS, 31% apply only NPS, 19% apply DAP and Urea, and the rest 9% and 1% apply DAP and urea alone, respectively. Most of the farmers (95%) apply inorganic fertilizer as basal (at planting) and also top dress urea at knee stage Figure 4. The amount of chemical fertilizer (regardless of type) that the farmers apply ranged from 90 kg ha^{-1} to 600 kg ha^{-1} with the average amount 318 kg ha^{-1} Table 5. Only, 7% of the farmers apply <200 kg ha^{-1} chemical fertilizers while the rest 93% apply >200 kg ha^{-1} (data not shown). In view of this observation, it can be suggested that low rate of chemical fertilizer application cannot be the reason for the high yield gap (37%) in the study area.

Table-4. Fertilizer use by farmers.

Variables	% farmers
Apply fertilizer	
Yes	95
No	5
Apply inorganic fertilizer	97
Apply organic fertilizer	3
Practice intercropping	
Yes	1
No	99
Practice crop rotation	
Yes	57
No	43

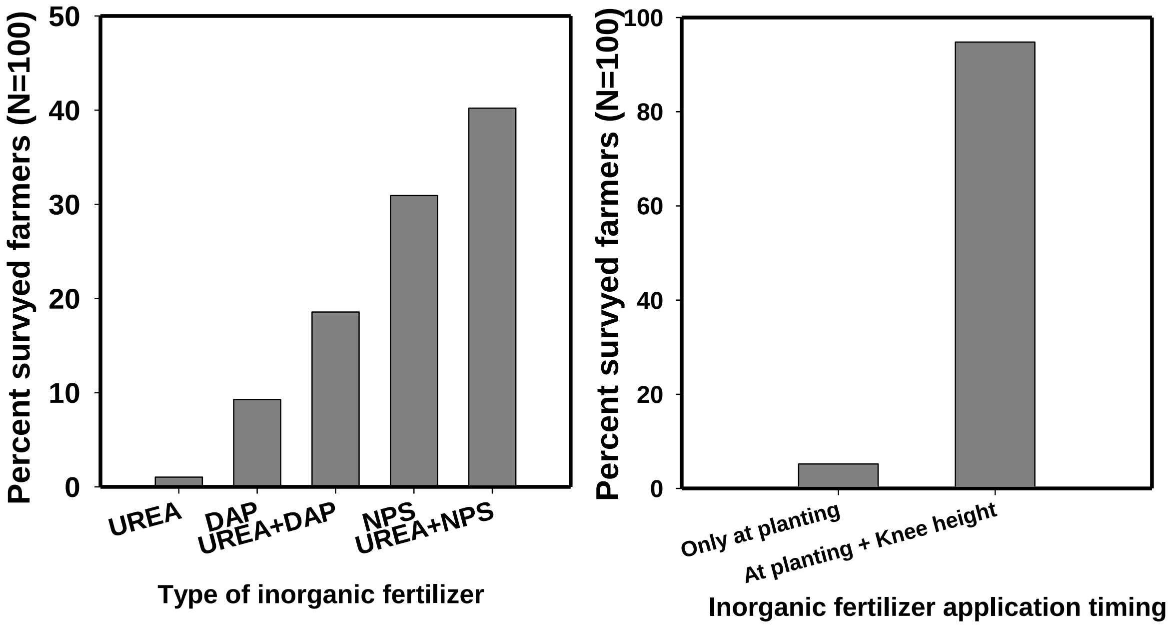


Figure-4. Type of inorganic fertilizer applied and application timing in the study area.

Crop Residue Management

The results of the agronomic panel survey conducted in Bako Tibe district revealed that farmers rarely retain crop residue (mean crop residue retained is 0.6%), with the maximum value of only 7.5% and the lower value of zero Table 3. Thus, nutrient recycling from crop residue is not expected in those farms. Farmers remove maize stovers primarily for use as fuel and as animal feed. Some farmers even burn the residue shortly before planting the next crop (Tolessa *et al.*, 2001) personal observation). Such trends result in the depletion of soil organic matter and ultimately the soil turns unproductive unless a huge amount of chemical fertilizers are applied to intensify maize production. In the current survey, the result revealed the existence of a weak positive relationship between grain yield and the amount of fertilizer applied (data not shown), indicating that fertilizer use/nutrient management could not explain the variation in maize grain yield among the 100 farms.

3.4. Plant Density

Plant density is one of the most important cultural practices determining grain yield, as well as other important agronomic attributes of maize crop (Sangoi, 2001; Tenaw *et al.*, 2001; Abuzar *et al.*, 2011). Nafziger (1994) reported that lower plant density can explain up to 33% of the maize grain yield variation. Many authors also reported that maize yields significantly varied with plant population (Gobeze *et al.*, 2012; Getahun *et al.*, 2018) and the same results were observed during our agronomic panel survey. Both extremes (very low and very high) of plant population reduced maize grain yield (Getahun *et al.*, 2018). Increasing plant population beyond the optimum results in reduced grain yield and Tokatlidis and Koutroubas (2004) ascribe such reduction in grain yield to increased barrenness of plants as a result of the adverse effect of high plant population on the interval of pollen shading and silking creating non synchronization and hence results in low yield.

Optimum plant population for higher grain yield varied with maize cultivar (Al-Naggar *et al.*, 2015) and also with the favorability of the rain, lower density tended to produce higher grain yield under erratic rain while higher density tended to produce higher grain yield under favourable rainfall (Workayehu, 2000). In Ethiopia the optimum maize plant density recommended by the research system varied from 44, 444 plant per hectare (75 cm X 30 cm single seed per hill) to 53,333 plants per hectare (75 cm X 25 cm single seed per hill) depending on cultivar. On the other hand, the government extension program in consultation with Agricultural Transformation Agency (ATA) recommended a plant population of 62,250 plants ha^{-1} (80 cm X 40 cm with two seeds placed 5 cm apart).

Our results showed that most of the farmers (81%) maintained plant density below the recommended density of 44,444 plants ha^{-1} Figure 5 at harvest and practicing such lower plant population by the farmers would obviously result in grain yield reduction and this can be confirmed from the significant positive relationship observed between plant density and grain yield Table 6. The Correlation analysis of crop stand count at harvest and grain yield as well as crop stand count and a number of harvested cobs showed a significant positive relationship (data not shown). This shows that at lower plant population, the number of harvestable cobs and hence grain yield was highly reduced. Getahun *et al.* (2018) reported that maize grain yield could be reduced by 18% due to reduction of plant density from 44,444 to 31,250 plants ha^{-1}. Results of the current agronomic panel survey showed that the number of crop stand got reduced from vegetative stage to harvesting stage Table 5. Farmers mentioned that an agronomic practice called "Shilshalo" as well as attack from stalk borer results in considerable reduction of crop stand count for a shift in growth stage from vegetative to harvesting stage. The percent incidence of stalk borer recorded during the agronomic panel survey, which was as high as 17% Table 5, also supports the farmers' suggestion.

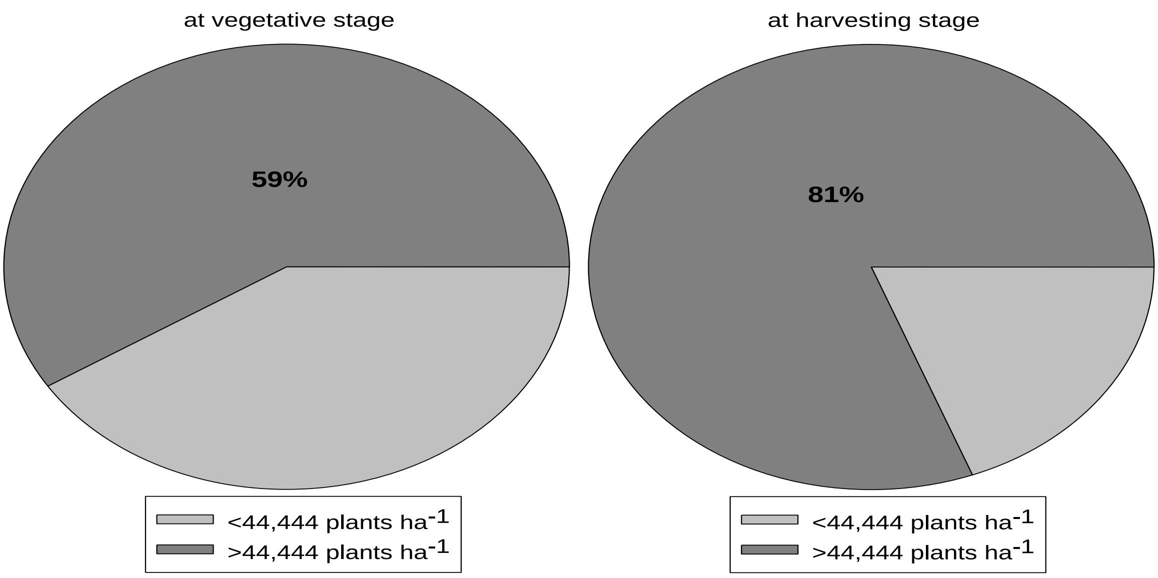


Figure-5. Percentage of farmers who maintained higher or lower plant density compared to the recommended density for the area.

3.5. Maize Cropping System

A number of field trials have been conducted on maize intercropping and rotation with beans and other suitable crops since such practices improve soil fertility and break the disease cycle from soil borne pathogens. Consequently, various maize intercropping and rotation recommendations were made for different maize growing areas. Intercropping maize with beans was recommended in the southern Ethiopia (Workayehu and Wortmann, 2011; Tamiru, 2014; Ashenafi, 2016; Ejigu *et al.*, 2017)and in Bako area (Tesfa *et al.*, 2011). Maize intercropping with faba bean was recommended at Adet as profitable cropping system (Tilahun *et al.*, 2012). Intercropping potato with maize was recommended for central highlands of Ethiopia such as Holeta (Temesgen and Wondimu, 2012) in Tigray region (Beyenesh *et al.*, 2017) in Wollo (Bantie, 2015). Rotation of maize with pulses (haricot bean, soyabean, pigeonpea), oil crops (noug), was also recommended as a best practice in Bako and similar area (Tesfa *et al.*, 2001). Double cropping of maize with cereals (tef), pulses (haricot bean), and root crops (irish and sweet potatoes) were recommended at Hawassa (Tesfa *et al.*, 2001).

Although intercropping and rotation of maize with other crops, has multiple benefits, the result the current maize agronomic panel survey, conducted in Bako Tibe district, showed that nearly no farmer practice the recommended intercropping. About 99% of the surveyed farmers grow sole maize while only one farmer intercropped maize with beans (data not shown). About 57% of the surveyed farmers rotate maize with other crops while the rest 43% does not practice rotating maize with other crops and grow maize after maize. Of those farmers practicing rotation, about 72% of them rotate maize with tef while 19% rotate with pepper and the rest 8% with vegetables and/or beans (data not shown).

3.6. Weed, Disease and Insect Pest Assessment

Weeds were reported as the most yield limiting variable in maize production than plant density resulting in up to 88% yield loss (Getahun *et al.*, 2018).The results of the agronomic panel survey in Bako Tibe district revealed that the average percent weed cover in the surveyed farms was 25% with maximum percent weed coverage being as high as 80% and the minimum being 1.5% Table 6. Results of the field experiment showed that reduction of grain yield due to lack of weed control in maize could reach up to 88% (Getahun *et al.*, 2018). The disease incidence ranged between 0-22%, with average disease incidence of only 1.8%. This is partly due to the use of improved disease resistant maize varieties by the majority of the farmers Figure 3. The incidence of insect pest also ranged between 0-17%, with the average pest incidence of only 2.5%. Stalk borer was the insect pests noticed during the survey. All the biotic factors (weed, disease and insect pest incidences) showed the tendency of having negative relationship with grain yield and cob numbers although the relationship was not significant in all cases. The reason for lack of clear relationship specially between weed incidence and grain yield could be attributed to the poor approach used to estimate weed infestation (visual observation, which is subjective to person estimating the weed coverage instead of considering weed biomass measurement).Thus, similar future studies on weed infestation should include measuring biomass to properly describe the relationship between weed and grain yield.

3.7. Maize Yields and Yield Components

Results of the crop cut during the agronomic panel survey showed that the grain yields varied considerably between maize farms. The minimum grain yield was 1822 kg ha^{-1} while the maximum was as high as 10881 kg ha^{-1} with average grain yield of 5004 kg ha^{-1} which is higher than the national, regional and zonal average of 3680, 3800, 4110 kg ha^{-1} reported by Central Statistical Agency (2016) respectively. The numbers of harvested maize cobs were also highly variable with the minimum of 15113 cobs ha^{-1} and the maximum of 64375 cobs ha^{-1} while the average number of cobs per ha^{-1} was 37166 cobs ha^{-1}. Cob number showed significant positive correlation with plant density (r^2=0.74) and grain yield (r^2=0.50) Table 6.

Table-5. Fertilizer rate, %crop residue and weed cover, disease and pest incidence, crop stand count, number of cobs and grain yield per hectare.

Parameters	Values recorded (N=100)
Fertilizer rate (kg ha^{-1})	318±105 (90-600)
Crop residue retention (%)	0.6±1.4 (0-7.5)
Weed cover (%)	25.5±21.1 (1.5-80)
Disease incidence (%)	1.8±3.3 (0-22)
Pest incidence (%)	2.5±3.1 (0-17)
Crop stand count (plants ha^{-1})	
Vegetative stage	43722±10519 (22663-75625)
Harvesting stage	37273±8152 (22500-61250)
Cob number (cobs ha^{-1})	37166±9541 (15313-64375)
Grain yield (kg ha^{-1})	5004±1440 (1822-10881)

Values in parenthesis are ranges, while those outside the parenthesis are mean and standard deviations.

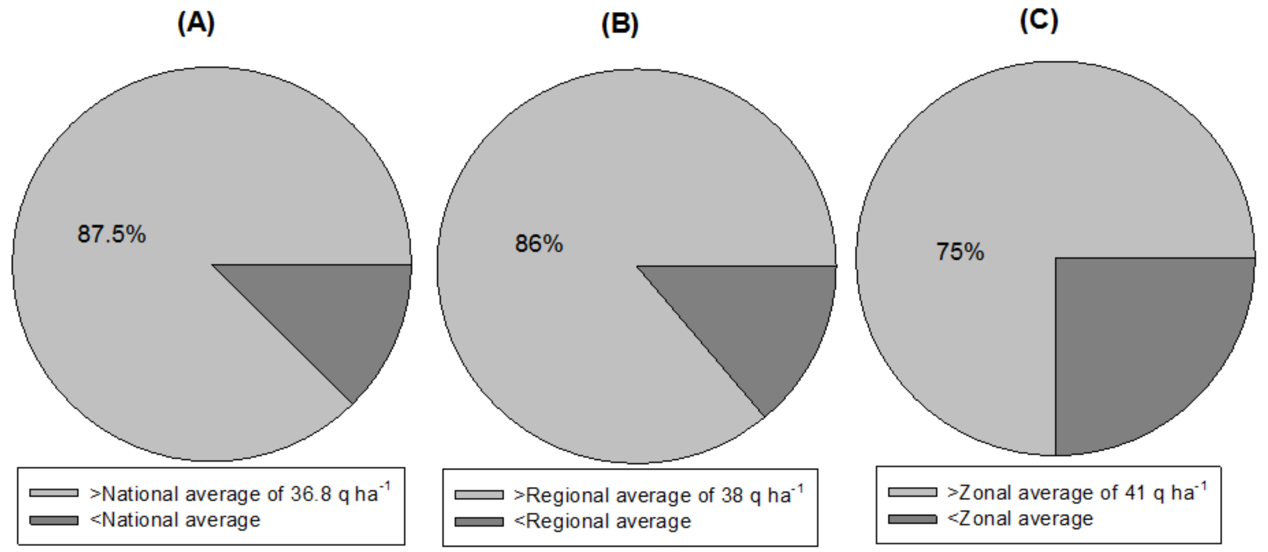


Figure-6. Percentage of famers who harvested above and below national, regional and zonal average (Note: *National regional and Zonal average data were adopted from CSA, 2016/17 data).*

About 87.5% of the farmers obtained grain yield greater than the national average and 86% of the farmers obtained grain yield higher than the regional average while 75% of the farmers harvested grain yield higher than the zonal average Figure 6. Since 25% of the farmers harvested less than the zonal average, they should be given due attention and support in terms of extension services by the district bureau of agriculture to enhance the maize productivity in the distinct.

Table-6. Relationship between grain yields, plant density, cob number, fertilizer rate, weed cover, disease and pest incidence.

	Pearson correlation coefficient, (N=70-73) (Probability level)						
	Grain yield	**Plant density**	**Cob number**	**Fertilizer rate**	**Weed cover**	**Disease incidence**	**Pest Incidence**
Grain yield	1	0.34966 (0.0024)	0.50026 (<.0001)	0.06860 (0.5726)	-0.03093 (0.7951)	-0.20543 (0.0812)	-0.17985 (0.1279)
Plant density	0.34966 (0.0024)	1	0.74254 (<.0001)	0.07410 (0.5421)	-0.20329 (0.0845)	(0.07054 (0.5531)	-0.12285 (0.3004)
Cob number	0.50026 (<.0001)	0.74254 (<0.001)	1	0.20925 (0.0821)	-0.03827 (0.7479)	-0.04830 (0.6849)	-0.15787 (0.1822)
Fertilizer rate	0.06860 (0.5726)	0.07410 (0.5421)	0.20925 (0.0821)	1	-0.00382 (0.9750)	-0.19896 (0.0987)	0.06535 (0.5909)
Weed cover	-0.03093 (0.7951)	-0.20329 (0.0845)	-0.03827 (0.7479)	-0.00382 (0.9750)	1	0.07390 (0.5343)	-0.22580 (0.0548)
Disease incidence	-0.20543 (0.0812)	0.07054 (0.5531)	-0.04830 (0.6849)	0.19896 (0.0987)	0.07390 (0.5343)	1	0.19256 (0.1026)
Pest Incidence	-0.17985 (0.1279)	-0.12285 (0.3004	-0.15787 (0.1822)	-0.06535 (0.5909)	-0.22580 (0.0548)	0.19256 (0.1926)	1

Source: This is SAS statistical software output from row data.

3.8. Extension Services

Maize growers like any other farmers benefit from the technical advice given by the extension/development agents. The number of DAs to farmers' ratio is currently 1:300 (source: personal communication; District BoA). About 42 and 12% of the surveyed farmers have very high and high trust on the extension service rendered through the government, while the rest 46% have medium (23%) and low (23%) trust for extension service Table 7. About 66% of the farmers received training on improved agronomic practices while the rest 34% did not. About 56% of the farmers obtain farm inputs (improved maize seeds and chemical fertilizers) through bureau of agriculture while 43% purchase from farmer cooperative unions Table 7.

Table-7. Percentage of farmers having trust for ES, receiving AGT, and sources of farm inputs

Variables	Percent farmers
Trust for extension service (ES)	
Very high	42%
High	12%
Medium	23%
Low	23%
Received maize agronomy training (AGT)	
Yes	66%
No	34%
Relevant input dealers	
BoA	56%
Coop union	43%
Private	1%

4. CONCLUSIONS

Most of the maize farms (90%) had *very strongly* to *strongly acidic* soil reaction classes indicating there is a serious soil acidity problem that can affect maize production unless lime is applied. Most of the maize farms had *low to medium SOC*, *medium to high TN*, *very low to low av.P*, *high to very high* K, *low to medium Ca*, and *medium to high Mg*, *high Zn& Fe and very high Mn contents*. Most farmers grow improved maize varieties. Most of the respondents (80%) grew a pioneer hybrid Limu and Bako hybrids BH540 and BH543 in the study area during the survey period. Most farmers apply different inorganic fertilizers for maize production and >70% of the respondents applied NPS + Urea or NPS alone. Farmers rarely retain crop residue and hence there is no expected nutrient recycling from crop residue in farmers' field. Most farmers (81%) maintain lower plant density at harvest than the recommended density for maize in the area and plant density declined as one move from vegetative to harvesting stage. About 99% of the surveyed farmers grow sole maize. 57% of the surveyed farmers rotate maize with other crops mainly with tef and some with pepper and vegetables and/or beans. Percent weed cover in the surveyed farms was 25% on average but could reach as high as 80%. About 87.5% of the farmers obtained grain yield greater than the national average and 86% of the farmers obtained grain yield higher than the regional average while 75% of the farmers harvested grain yield higher than the zonal average.

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