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Some maize agronomic practices in Ethiopia: A review of research experiences and lessons from agronomic panel survey in Oromia and Amhara regions

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There is a huge maize yield gap in Ethiopia. The use of improper maize agronomic practices could contribute to maize yield gaps. Agronomic panel survey (APS) and a baseline survey were carried out by EIAR and CSA, respectively in collaboration with CIMMYT for three years (2015-17) to assess the rates and types of inorganic fertilizers applied; maize varieties used and plant densities maintained by farmers in major maize growing areas of Ethiopia. The APS were conducted by EIAR in 3 to 4 grids of 10 km × 10 km size in five zones while the baseline survey was conducted by CSA in nine zones following their own protocol. Results showed that most of the surveyed farmers (95%) grow improved hybrid maize varieties and >85% of them grow the improved varieties within the agro-ecology they were recommended for. Maize variety BH661 was the commonest maize variety in Jimma zone, BH660 in West Gojam and West Shoa zones, Limu in West Shoa and East Wollega zones and BH540 in East Shoa zone. Most of the surveyed farmers (89.5%) apply fertilizer for maize production out of which 75% of them apply inorganic fertilizers, 20.5% only organic and 4.5% both types. In most maize growing areas, farmers apply fertilizer rates very close to the blanket recommended rate of 100 kg NPS and 200 kg UREA. However, a consistently higher inorganic fertilizer rate was applied in West Gojam and the lowest in East Shoa Zones. The plant density at harvest was lower than any of the recommended plant densities for most of the maize growing zones. As an average of all zones and years, about 87.5% farmers maintained plant density at harvest below the recommended. Mean grain yield was above the national average for most of the study areas, but exceptionally higher for Gojam and Wollega zones and lower for East Shoa zone. There was a positive relationship between cob number and plant density, plant density and grain yield, cob number and grain yield, implying using sub-optimal plant density could potentially affect grain yield.

Key words: Fertilizer rate, grain yield, maize varieties, plant density, *Zea mays.*

INTRODUCTION

Maize is the second most widely cultivated crop in Ethiopia and is grown under diverse agro-ecologies and socioeconomic conditions (Tsedeke et al., 2017). It is grown mainly during the main growing season known as *meher*, which relies on May-September rainfall (Dawit et al., 2014). Maize has expanded rapidly (in terms of both area and production) and yield has also shown an increasing trend. About 70% of maize production

concentrates in Oromia and Amhara regions (Dawit et al., 2014). Following the significant increase in maize productivity as a result of the good investment in improved seeds and chemical fertilizers to increase maize production and productivity, maize had a positive impact on poverty reduction in many parts of the country (Tsedeke et al., 2017). Maize has already expanded to new areas where maize production was not well known in the past (such as west and east Gojam), yet with better productivity. 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 and Wonchi (Gudeta et al., 2011).

Before 1992, farmers in Ethiopia mainly grow local maize varieties that are low yielding, tall growing and hence very susceptible to lodging (Tsedeke et al., 2017), in spite of the availability of few improved maize varieties released already and this accounts for low maize productivity during early 1990s (Srinivasan and Pandey, 2001). Adoption of improved maize varieties was noticed from 1993 onwards (Tsedeke et al., 2017) 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 also initiated shortly after the release of the new maize varieties. Several maize agronomic recommendations were developed for different locations. The recommendations include optimum plant density (Tesfa et al., 2011) and optimum fertilizer rates (Tolessa et al., 2001; Wakene et al., 2011), which are key determinants of maize productivity. However, the extent to which farmers are using these agronomic recommendations is not well known, since the maize yield gap is still high in Ethiopia.

For instance, although there are various fertilizer recommendations at different times such as blanket and regional recommendations in the past two decades or more and EthioSIS map/soil test based recommendations as of recently, there is no sufficient information on the actual amount of fertilizer rate that farmers currently apply to maize. Many studies showed that farmers grow improved maize varieties, but from the existing released maize varieties, there is no clear information on the type of maize varieties (OPV vs hybrids) that are being widely grown. Moreover, information with regards to the kinds/names of maize varieties dominantly grown in different maize growing zones of the country and whether these varieties are being grown in the appropriate ecology they are recommended for is scant. Appropriate plant spacing for different maize varieties have also been determined, however, there is no information on what proportion of maize growers have taken up these recommendations. Thus, the objectives of this study were: (i) To assess the types and rates of inorganic fertilizer used by farmers. (ii) To assess the types of improved maize varieties grown by farmers, and (iii) To assess the actual plant density and grain yield at harvest in different maize growing zones of Ethiopia.

METHODOLOGY

APS conducted by EIAR

Description of the study area

This APS was conducted by the Ethiopian Institute of Agricultural Research (EIAR) from five maize growing zones: EastWollega, West Shoa and Jimma Zones (in Western and South Western Oromia), East Shoa Zone (in Eastern Oromia), and West Gojam(in Amhara region). The Western and South Western Oromia as well as West Amhara regions are characterized by high rainfall sub-humid climate while East Shoa zone is characterized as a low moisture region with semi-arid climate (Figure 1).

Farmers' selection and sampling procedure

Three to four 10 km × 10 km main grids were generated in all the study sites. In each main grid, seven sub-grids of 1 km × 1 km size were randomly selected. In each sub-grid, 6 farmers were randomly selected for both HHs survey and crop cut to determine grain yield. Grain yield was determined by harvesting the crop (crop cut) at harvestable stage from three quadrants of 4 m × 4 m each.

Baseline survey by CSA

Description of the study area

The baseline survey was conducted by The Central Statistical Authority (CSA) from nine major maize growing zones of the country: East Shoa Zone (in eastern Oromia), West and South West ShoaZones, East and West Wollega Zones, Jimmaand Ilubabor Zones (in Western and South Western Oromia) and West and East Gojam zones (in Amhara regions).

Farmers' selection and sampling procedure

CSA used its own farmers' selection protocol unlike EIAR. In this case, grain yield was determined by harvesting from a single quadrant of 4 m × 4m plot size.

HHs data collection

Household and field parameters collected during both agronomic panel (by EIAR) and baseline surveys (by CSA) include: Type of maize variety, name of maize variety, fertilizer use, rate of organic

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Abbreviations: HHs, households; **APS,** Agronomic Panel Survey; **N,** nitrogen; **P,** phosphorus; **K,** potassium

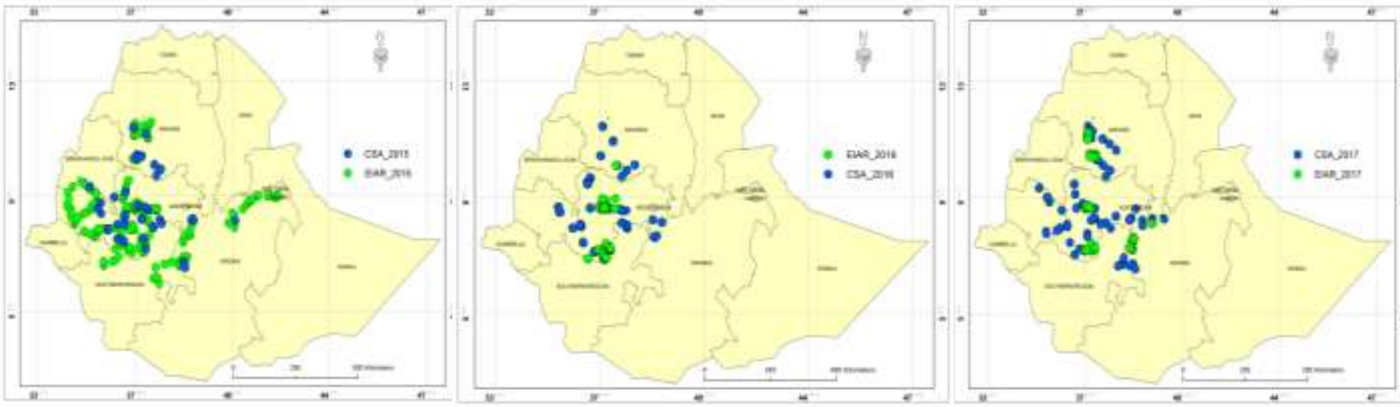

Figure 1. Maps of the survey area.

and inorganic fertilizer applied, number of crop stand per quadrant, number of cobs per quadrant, yield per quadrant, plot level GPS coordinate, altitude and field area.

Data analysis

Descriptive statistics was used to analyze and present the data

RESULTS AND DISCUSSION

Plant density

Plant density and maize productivity

Keeping plant density (PD) in optimum range is an important agronomic practice determining grain yields and yield components of maize crop (Tenaw et al., 2001; Sangoi, 2000; Abuzar et al., 2011). Lower plant density can explain up to 33% of the maize grain yield variation (Nafziger, 1994). Studies showed that maize yields significantly varied with plant population (Gobeze et al., 2012; Getahun et al., 2018) and the same results were observed during our survey as there was significant positive relationship between grain yield and plant density as well as number of cobs and plant density (Figures 2 and 3). Both very low and very high plant population, however, reduced maize grain yield (Getahun et al., 2018). Getahun et al. (2018) observed that low plant population resulted in 18% of the maize grain yield reduction at Assosa, in Ethiopia. Increasing plant population beyond the optimum resulted in reduced grain yield and Tokatlidis and Koutroubas (2004) ascribes 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 plants per hectare (75 cm × 30 cm single seed per hill) to 53,333 plants per hectare (75 cm × 25 cm single seed per hill) depending on cultivar. For varieties such as Melkasa-1, which is an extra-early maturing maize variety, the highest yield was obtained at plant population of 66,667 plants ha^{-1} in the central rift valley, while for ACV6, which is an early maturing maize variety and A511 (an intermediate maize variety) higher grain yields were obtained at a plant population of 53,333 plant ha^{-1}(Tesfa et al., 2011).The government extension program jointly with Agricultural Transformation Agency (ATA)recommended a plant population of 62,250 plants ha^{-1}(80 cm × 40 cm with two seeds placed 5 cm apart).

Current plant density in surveyed maize fields

The results of the APS conducted during the past three years (2015-17) revealed that the average plant population at harvest in most maize growing zones was much lower than what both the research system and the Ministry of Agriculture and Natural Resource through its extension program has recommended to farmers (Tables 1 and 2).

According to results of the APS, on average most farmers (87.5%) maintained plant density below the recommended amount of 44,444 plants ha^{-1} (Figure 2) at harvest and practicing such lower plant population by the farmers would results in grain yield reduction and this can be confirmed from the positive relationship observed between plant density and grain yield as well as plant density and number of harvested cobs (Figures 3 and 4). This shows that at lower plant population, the number of

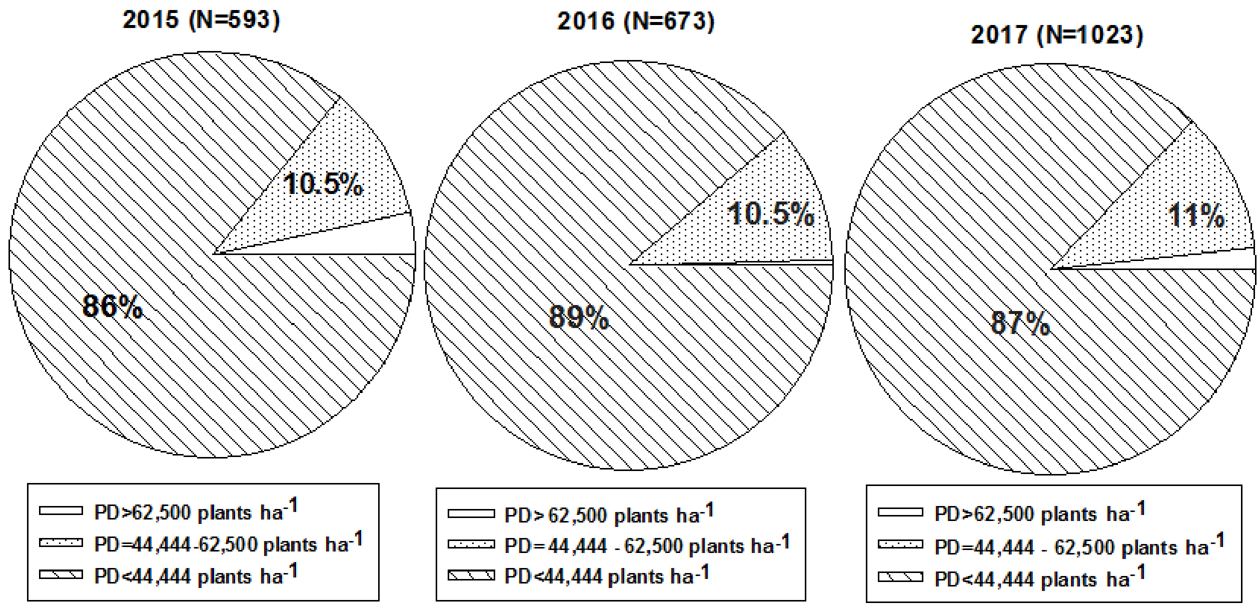

Figure 2. Percentage of famers practicing the different categories of plant density (the different survey data combined).

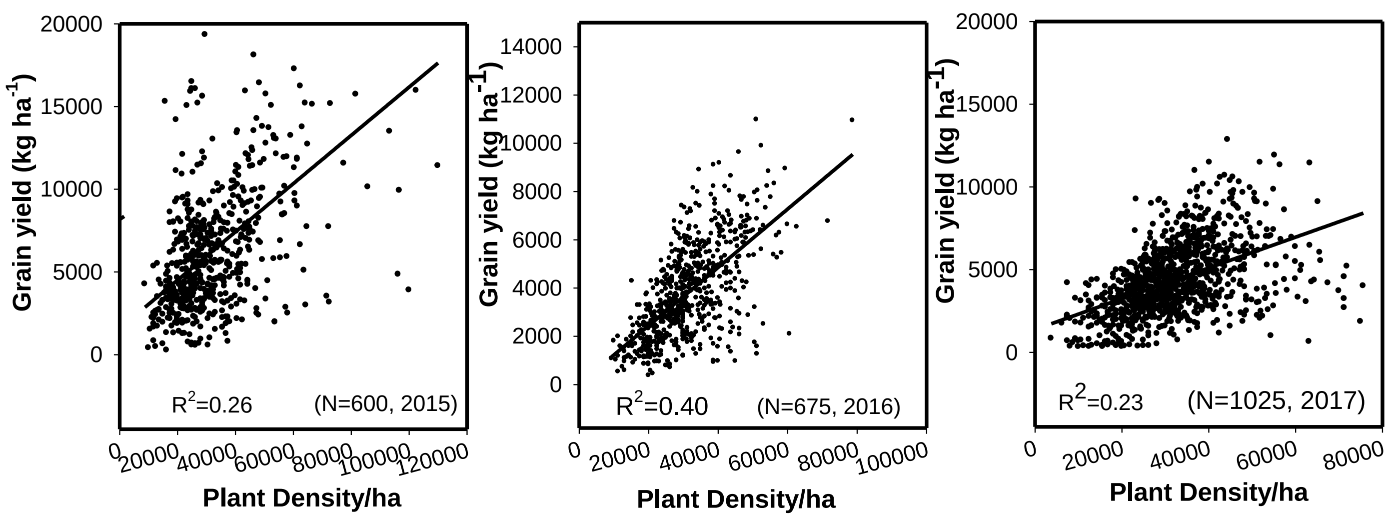

Figure 3. Relationship between plant density and maize grain yield (the different survey data combined).

Table 1. Plant density at harvest in different zones (Data from EIAR and CIMMYT joint survey).

Location	Plant density (Plants ha^{-1})								
	2015 (N=235)			2016 (N=336)			2017 (N=556)		
	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
East Shoa	-	-	-	-	-	-	34,751	16,667	65,833
Jimma	46,514	26,458	96,250	27,764	15,208	62,708	30,528	19,167	51,875
West Shoa	34,448	22,708	54,167	40,085	25,000	78,750	37,088	17,292	53,125
East Wollega	23,427	15,833	29,583	-	-	-	40,242	22,500	59,167
West Gojam	49,512	27,083	72,917	-	-	-	36,321	15,000	65,208

Table 2. Plant density at harvest at different maize growing zones in Ethiopia (Data from CSA and CIMMYT joint survey).

Location	Plant density (Plants ha^{-1})								
	2015 (N=382)			2016 (N=351)			2017 (N=469)		
	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
East Shoa	27,708	15,000	57,500	32,023	15,000	60,625	47,093	7,500	75,625
Jimma and Ilubabor	24,826	6,750	48,125	26,379	12,500	47,500	21,706	7,500	40,000
West and South east Shoa	27,183	10,000	50,625	27,358	9,375	53,125	24,265	8,125	60,000
East and West Wollega	30,906	11,875	64,375	31,054	11,250	59,375	28,984	7,500	55,000
West Gojam	28,992	11,875	48,750	30,333	15,625	43,750	30,389	12,500	65,625
East Gojam	-	-	-	30,813	10,000	50,625	32,742	10,000	60,000

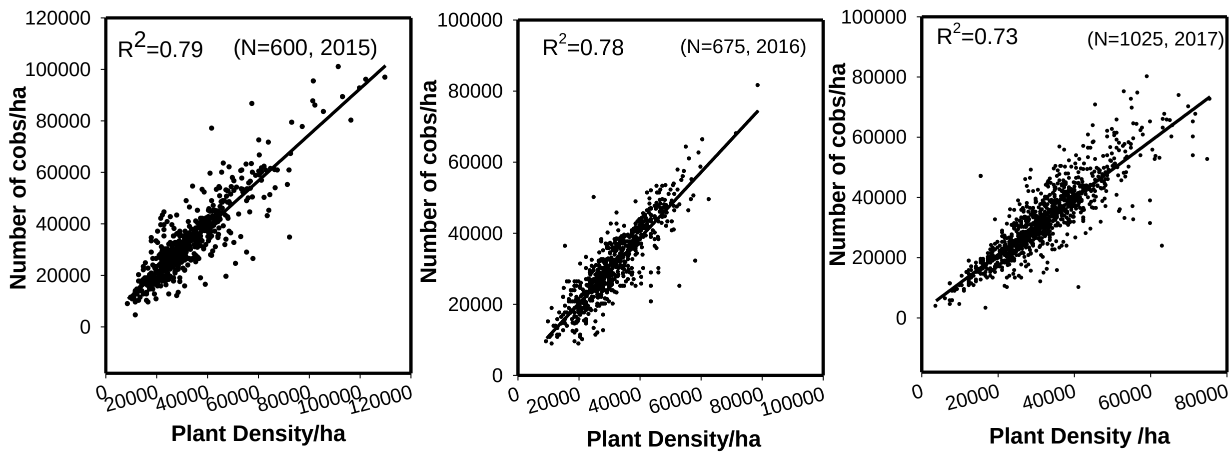

Figure 4. Relationship between plant density and number of harvested maize cobs (the different survey data combined).

harvestable cobs and hence grain yield was reduced. In agreement with our observation, Getahun et al. (2018) reported 18% grain yield reduction due to reducing plant density from 44,444 to 31,250 plants ha^{-1}.

Results of the APS (EIAR and CIMMYT survey data) (Table 1) showed that relatively higher average PD at harvest was maintained in West Gojam followed by Jimma during 2015 season, and in East Wollega during 2016 season. However, the trends of PD were not consistent in each zone throughout the three seasons. On the other hand, results of the CSA and CIMMYT survey data (Table 2) showed that the highest average PD in 2015 was recorded for East and West Wollega zones and in 2016 and 2017 for East Shoa zone. Except for East Shoa in 2017 season, in all cases, the average PD recorded in all other zones were lower than the research recommended PD of 44,444 plants ha^{-1} (Table 2).

The data presented in Figure 2 showed that across the three years, only 11% of the surveyed farmers maintained PD in the range of recommended rates (that is, between 44,444 to 62,500 plants ha^{-1}), while 86 to 89% of the surveyed farmers maintained PD below the recommended rate of 44,444 plants ha^{-1}. Data presented in Figure 3 showed that there is a positive relationship between PD and grain yield although the relationship is not as strong as that of PD and number of cobs (Figure 4). The strong and significant positive correlation between number of cobs and PD shows that maintaining higher PD ensures more number of harvestable cobs and perhaps also more cob and grain weights. Therefore, among other factors, low plant population could be one of the reasons for farmers to harvest less cobs and lower grain yield in the different parts of the country. Thus, farmers should be able to keep plant density as optimum as possible or at least closer to the recommended rates to minimize maize yield gap.

Maize variety

Significance of maize variety type used to closing yield gaps

The type of seed/variety grown remarkably influenced maize grain yield (Enujeke, 2013). The type of maize variety used can explain up to 20% of maize yield gap, signifying that the use of the appropriate variety is one

Table 3. Percentage of farmers growing improved maize varieties in different maize growing zones (data from EIAR and CIMMYT joint survey).

Location	Farmers using improved maize varieties (%)		
	2015 (N=235)	2016 (N=336)	2017 (N=772)
East Shoa	-	-	74
Jimma	71	92	93
West Shoa	96	100	96
East Wollega	74	-	98
West Gojam	100	-	99

Table 4. Percentage of farmers growing improved maize varieties in different maize growing zones (data from CSA and CIMMYT joint survey).

Location	Farmers using improved maize varieties (%)		
	2015 (N=382)	2016 (N=351)	2017 (N=469)
East Shoa	62	39.5	28
Jimma and Ilubabor	64	82.8	69
West and south west Shoa	63	90.7	53
West and East Wollega	41	64.3	82.5
West Gojam	74	96.7	88.7
East Gojam	-	47.5	92

way to improve maize grain yields (Ghimire et al., 2016) and thus close maize yield gaps.

Trend of maize variety development and use in Ethiopia

Before 1992, farmers in Ethiopia mainly grew local maize varieties that were low yielding, tall growing and hence very susceptible to lodging (Tsedeke et al., 2015) in spite of the availability of some improved maize varieties already released. As a consequence maize grain yield was quite low (<1.5 t ha^{-1}) during the early 1990's (Srinivasan and Pandey, 2001).Adoption of improved maize varieties 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; Tsedeke et al., 2017).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). Details of the characters of the released varieties can be found in the same references. So far no extensive study has been carried out with regards to the proportion of farmers growing improved and local maize varieties and whether the farmers grow those improved varieties within the agroecology they were recommended for or not. Moreover, there is no information regarding the extent to which each of these varieties are being grown in the nine different maize growing zones.

Current improved maize variety use in the survey areas

Results of the three years extensive survey conducted jointly by CIMMYT and EIAR showed that the proportion of farmers growing improved maize varieties ranged from 71 to 100% in 2015, from 92 to 100% in 2016 and from 74 to 99% in 2017 season (Table 3). West Gojam was the leading zone in terms of the proportion of farmers growing improved maize varieties followed by West Shoa. The results of the survey conducted jointly by CIMMYT and CSA during 2015-2017 seasons in major maize growing zones of Oromia and Amhara regions showed that the proportion of farmers growing improved maize varieties ranged from 41 to 74% in 2015, 40 to 97% in 2016 and from 28 to 92% in 2017 seasons (Table 4). West Gojam and East Gojam were the two leading zones in terms of the proportion of farmers growing improved maize varieties.

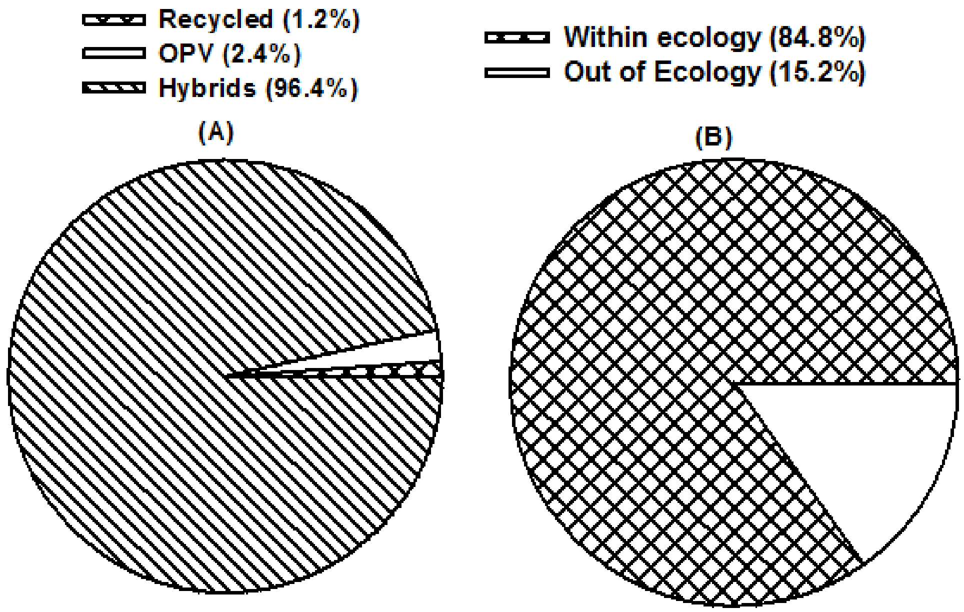

Figure 5. Type of maize varieties grown (A) and ecological suitability (B) during the 2015 survey (the different survey data combined).

Types of improved maize varieties used

Considering all the maize growing zones altogether, from among famers growing improved maize varieties, 96.4% of them grow hybrids, while only 2.4% grow open pollinated varieties (OPV) (Figure 5A). Most farmers (85%) grow the improved varieties within the agro-ecology they were recommended for but about 15% of them grow the improved varieties outside the agro-ecology they were recommended for (Figure 5B).

Oromia region

Results of the Agronomic panel survey jointly conducted by EIAR and CIMMYT showed that in East Shoa zone, in which most of the maize growing ecology is characterized by moisture stress, a range of improved maize varieties (BH540, BH543 and Melkasa 1,2 and 4) are grown by different farmers (Table 5). These varieties are relatively early maturing and Melkasa types in particular are moisture stress tolerant (Gezahegn et al., 2011). However, the commonest maize varieties grown by farmers were BH540 (48% respondents in 2017) and BH543 (50% respondents in 2015) (Table 5). In Jimma zone, which is characterized as having high rainfall and long growing season, Bako hybrids BH661 (47 and 59% respondents in 2016 and 2017, respectively) and BH660 (32% respondents in 2015) and BH661 (47 and 59% respondents in 2016 and 2017, respectively) were the commonest maize varieties grown by farmers. These varieties are long maturing types taking up to 160 days to reach physiological maturity (Legese et al., 2011). In WestShoa zone, farmers grow improved maize varieties such as Limu, BH661, BH660, BH540 etc. However, the results of our study showed that Limuand BH660 were the commonest maize varieties grown. In 2017 farmers drastically shifted almost to growing Limu than any other varieties. In East Wollega, Limu, followed by BH661, were the most widely grown maize varieties especially in 2016 and 2017.

On the other hand, the results of the survey jointly conducted by CIMMYT and Central Statistical Authority (CSA), showed that in East Shoa zone, BH660 (57% respondents) was the most widely grown maize variety in 2015 and BH540 (65%) in 2016 and Melkasa Types (42%) in 2017. Results of the same survey showed that BH661 (36 and 38% in 2015 and 2016 season, respectively) and shone (32% in 2017) were the most widely grown improved maize varieties in Jimma and Ilubabor Zones. Shone (35% respondents in 2015) and BH661 (37% respondents in 2016) and BH660 (40% respondents in 2017) were the commonest improved maize varieties in West and South West Shoa Zone. In East and West Wollega zones, Shone was the most commonly grown maize var. (54% in 2015) and (36% in 2016), while in 2017 Limu took the lead (40%) followed by BH661 (30%).

Amhara region

Results of the agronomic panel survey jointly conducted by EIARand CIMMYT showed that Limu and BH660 were

Table 5. Patterns of maize variety use in different maize growing zones of Oromia and Amhara regions (data from EIAR and CIMMYT joint survey).

Location/zone	Year	% Farmers growing maize variety								
		BH661	BH660	Limu	Shone	BH540	BH543	Melkasa-1-4	Pioneer3553	Others
East Shoa	2015	14				14	50	-		22
	2017	-				48	27	7		18
Jimma	2015	29	32		25					14
	2016	47	39	8						6
	2017	59	18	10						13
West Shoa	2015		29	29	13	17				12
	2016	23	52			16				9
	2017			82						18
East Wollega	2015			36	36					28
	2016	29		31		22				18
	2017	25		42		10				14
West Gojam	2015		32	27		17			24	
	2017	33	11	41						15

the commonest maize varieties grown (32 and 27%, respectively in 2015) and Limu and BH661 (41 and 33%, respectively in 2017) were the most commonly grown maize varieties. Accordingly to joint survey of CIMMYT and CSA, BH660 was the commonest maize variety (47 and 61%) in 2015 and 2016, respectively, while BH540 was the commonest maize variety in 2017.

According to the joint survey carried out by CSA and CIMMYT, the pioneer hybrids Limu and Shone were the most widely grown maize varieties in Wollega zones; the two varieties together making 96% of maize seed grown in 2015 (Table 6). However, during 2016 these two varieties were grown only by 65% of the farmers, perhaps due to the introduction of BH661 to the area, which was picked up by 22% of the farmers. In 2017 season, BH661 and Limu dominated the production (70%) and Shone was dropped. The two Bako hybrids (BH661 and BH660) and the Pioneer hybrids Limu and Shone were the four most widely grown maize varieties making altogether 100% of the seed grown by the farmers in Jimma and Ilubabor zones in 2015, while in 2016 farmers dropped Shone and three of the above hybrids were grown by 79% of the farmers, with BH661 being the most dominant. The Bako hybrids (BH661, BH660 and BH540) altogether makeup 95% of the improved maize varieties grown by the farmers in East and West Gojam zones during 2015. In 2016 season, however, 96% of the farmers grew only BH660 and BH540, perhaps due to lack of improved seeds of BH661 and the pioneer hybrids. The same trend was observed during 2017, where the two Bako hybrids BH660 and BH540 were grown by 72% of the farmers in the zones. In West and South West Shoa zones, the two Bako hybrids and pioneer hybrids were dominantly grown throughout the three years. The percentage of farmers growing these varieties altogether ranged from 81% in 2015 to 89% in 2016. In East Shoa, the two Bako hybrids (BH661 and BH660) and an open pollinated variety Melkassa-4altogether makes 80% of the improved maize varieties grown by the farmers. It is surprising that the popular stress tolerant maize varieties released for this region such as MH140 could not be reported for the area during 2015. It is also surprising that BH660, which is more adaptable to the mid and high altitude and high rainfall areas, is yet being commonly grown in East Shoa zone, which are dominated by moisture stress and lower altitude. However, in 2016, 84% of the farmers in East Shoa zone grew, BH540 and Melkasa types, which are more suitable for lower elevationagro-ecologies.

Fertilizer use

Significance of fertilizer management to close yield gaps

Low soil nutrient contents are the most yield limiting factors in maize production (Tolesa et al., 2001). In most maize growing regions, N is the most yield limiting nutrient followed by P (Wakene et al., 2011; Tolesa et al., 2001; Tesfaye et al., 2019). The omission of N fertilizer (while both P and K fertilizer are applied at non-limiting rates), resulted in a grain yield penalty of up to 5,400 kg ha^{-1}in Jimma area. The magnitude of yield response to N

Table 6. Patterns of maize variety use in different maize growing zones of Oromia and Amhara regions (data from CSA and CIMMYT joint survey).

Location/zone	Year	% Farmers growing maize variety							
		BH661	**BH660**	**Limu**	**Shone**	**BH540**	**BH543**	**Melkasa-1-4**	**Others**
	2015	18	57					25	
East Shoa	2016					65		19	16
	2017		17					42	42
	2015	36	11	19	34				
Jimma and Ilubabor	2016	38	24	17					22
	2017	17	23		32				28
	2015	8	27	19	35	11			
West and South west Shoa	2016	37		31	21				12
	2017	25	40	19					17
	2015		4	42	54				
East & West Wollega	2016	22		29	36				13
	2017	30	15	40					15
	2015	31	47	2		17			
West Gojam	2016	4	61			35			
	2017		25	15		47			13

application depended on the favorability of rainfall as well as with maize variety, with more response to N application under favourable rainfall condition than unfavourable conditions (Workayehu, 2000; Tesfaye et al., 2019) and with hybrids than with local varieties (Tolesa et al., 2001). Progressive increase in maize grain yield with increasing levels of N and P was observed in many parts of the country (Tolesa et al., 2001).

Contrary to N and P fertilizers, farmers do not apply K fertilizer to maize as well as to other crops nor did the research system so far recommend using potassium fertilizer for maize production. To see if maize responds to K application in major maize growing areas of Ethiopia, multi-location (150) nutrient omission trials were conducted during 2015 and 2016 seasons. Results of the omission trials in those major maize growing areas (Jimma, West Shoa, East Wollega East Shoa and Sidama zones) revealed that the application of K did not give any yield advantage in most locations (Tesfaye et al., 2019) except in Gobu Sayo district of East Wollega zone. Likewise, the application of secondary nutrients such as calcium, magnesium and micronutrients such as zinc and boron also did not improve maize grain yields in all locations except at Adami Tullu in East Shoa zone (Tesfaye et al., 2019). The application of balanced nutrient is quite important to sustainably increase maize grain yield and to avoid nutrient mining (negative nutrient balance) (Magen, 2008). Knowing which nutrient to include in the balanced fertilization, however, needs further investigating the soil nutrient content, crop response to the nutrient and tissue nutrient concentration status (Zia et al., 2003). In view of this, it would be worthwhile to carefully examine the current fertilizer recommendations which relies more on soil test results, with less focus on crop response or tissue nutrient testing.

Trend of fertilizer application in maize production

The application of chemical fertilizer in maize production is a recent phenomenon as it began in 1993, following the government campaign for increased food production in collaboration with Sasakawa Global 2000 (Tsedeke et al., 2017). Thus, the application of chemical fertilizer 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 in addressing food security through enhancing food production in the country. Before that time farmers grow local maize without any chemical fertilizer or with the application of organic fertilizers alone such as manures (Tsedeke et al., 2017). As a consequence maize yield was quite low (about 1 t ha^{-1}) (Tsedeke et al., 2017). Later on agronomic research recommended a blanket recommendation of 100 kg DAP and 200 kg Urea (20 kg P ha^{-1} and 110 kg N ha^{-1}) to be used at country level. After that each regional research institute started to

Table 7. Amount of fertilizer applied by farmers to maize crop (data from EIAR and CIMMYT joint survey).

Location	Amount of fertilizer applied (kg ha^{-1})				
	2015 (N=197)	2016 (N=336)		2017 (N=678)	
	DAP + Urea	NPS	Urea	NPS	Urea
East Shoa	50-500 (179)	-	-	7-200 (84)	7-500 (64)
Jimma	10-400 (186)	35-704 (182)	16-562 (141)	16-476 (127)	8-400 (99.6)
West Shoa	51-404 (200)	17-612 (136)	29-564 (211)	37-200 (117)	64-600 (229)
East Wollega	50-400 (140)	-	-	24-600 (132)	24-450 (198)
West Gojam	200-875 (425)	-	-	24-800 (242)	24-800 (232)

Values in parenthesis are mean values.

develop regional fertilizer recommendations for their own mandate regions, which ranged between 20 kg P ha^{-1} for most regions to 61 kg P ha^{-1} for Achefer areas and between 41 kg N ha^{-1} for Melkasa to 180 kg N ha^{-1} for Achefer areas (Wakene et al., 2011). As of 2015, soil test (EthioSIS soil map) based fertilizer recommendation emerged with the support of Agricultural Transformation Agency (ATA). So far soil maps were developed and officially released for Tigray, Amhara and SNNP and very lately for Oromia region as well. Soil maps based blended chemical fertilizers are now a day being used by farmers and a shift has already been made from using DAP (18-46) to NPS (19-38-7), which has sulphur blended to it or other blends such as NPSB/NPSBZn.

Current farmers' fertilizer management in maize production

The results of the 2015 survey showed that 89.5% of the surveyed farmers applied fertilizer, while only 10.5% do did not apply any fertilizer. About 75% of the fertilizer input users apply inorganic alone, 20.5% organic alone and only 4.5% use integrated organic and inorganic fertilizers (Figure 5). In view of the declining trend of soil organic matter content in the country, the use of organic fertilizer or at least integrated organic and inorganic fertilizers should be promoted to safeguard the agricultural soils from turning unproductive.

In the current surveys, results revealed existence of weak positive relationship between grain yield and fertilizer rate applied (data not shown), indicating that fertilizer use/nutrient management could not explain the variation in maize grain yield. This might further indicate that farmers are applying fertilizer blindly without considering the soil nutrient requirement to sustain maize production. This could be true since regional/ blanket recommendations cannot properly address individual farmer's requirement of fertilizer amount to be applied. Our observation may also suggest the need to use decision support tools such as nutrient expert tool to make location/farm specific fertilizer recommendation, which generates the recommendation based on farm specific information.

According to the survey results jointly conducted by CSA and CIMMYT, across all zones 83 to 99% of the farmers apply fertilizer for maize production in 2015 (Table 9). In 2016, only 50% of the farmers applied fertilizer in East Shoa, while in the other zones 92 to 100% of the farmers applied fertilizers for maize production (Table 9). On the other hand, according to EIAR and CIMMYT joint 2015 survey data,75.5% (East Wollega) to 100% (West Gojam) of the farmers applied fertilizers for maize production (Table 9).

Farmers apply either organic or inorganic fertilizer or both (Table 9). In 2015, almost in all zones, farmers applied either organic or inorganic or both although the proportion of farmers applying both organic and inorganic is very little or even nil as in the case of East Shoa and West Wollega (Table 9). Unlike during 2015, in 2016 about 24 to 33% of farmers in East and West Gojam, respectively applied both inorganic and organic fertilizer in an integrated manner (Table 9). Such a nutrients management approach is suitable to increase yield and also enhance soil organic matter content and needs to be encouraged to sustain maize productivity.

The average amount of DAP/NPS and UREA applied for maize production during 2015 is less than the blanket recommendation rate used in the country (300 kg ha^{-1} DAP+UREA), except for west Gojam, where the average amount applied is higher than the recommended rate by 42% (Table 7). However, during 2016, the average amounts of NPS+UREA applied in both Jimma and West Shoa zones were very much close, but slightly higher than the blanket recommendation that was being used for maize production (Table 7) implying that farmers follow the extension advise. On the other hand, during 2017, except in East Shoa and Jimma Zones, where the applied fertilizer is lower than the blanket recommend rate, the amount of fertilizers (NPS+UREA) farmers apply is remarkably higher than the recommend rate especially, in West Gojam (Table 8).

On the other hand, according to CSA-CIMMYT joint survey data, except in West and East Gojam during 2016, where the applied amount of fertilizer is slightly higher than the blanket recommendation rate, the amount

Table 8. Amount of fertilizer applied by farmers to maize crop (data from CSA and CIMMYT joint survey).

Location	Amount of Inorganic fertilizer (UREA+DAP/NPS) applied (kg ha^{-1})	
	2015 (N=218)	2016 (N=247)
East Shoa	67-458 (187)	50-365 (133)
Jimma and Ilubabor	20-625 (208)	14-797 (203)
West and south west Shoa	33-688 (206)	41-500 (215)
East and West Wollega	11-625 (202)	35-750 (276)
West and East Gojam	12-648 (238)	29-722 (325)

Values in parenthesis are mean values.

Table 9. Percentage of famers using different fertilizer types (data from CSA and CIMMYT joint survey).

Location	Percentage of farmers using fertilizer (%)		Farmers applying *Inorganic-organic-both fertilizers* (%)	
	2015 (N=382)	2016 (N=351)	2015 (N=330)	2016 (N=310)
East Shoa	95	50	52-48-0	37-63-0
Jimma and Ilubabor	87	92	90-9-1	100-0-0
West and south west Shoa	85	97	50-47-3	80-9-11
West and East Wollega	83	90	62-38-0	57-35-8
West Gojam	**99**	**100**	43-41-16	33-33-33
East Gojam	-	93	-	43-32-24

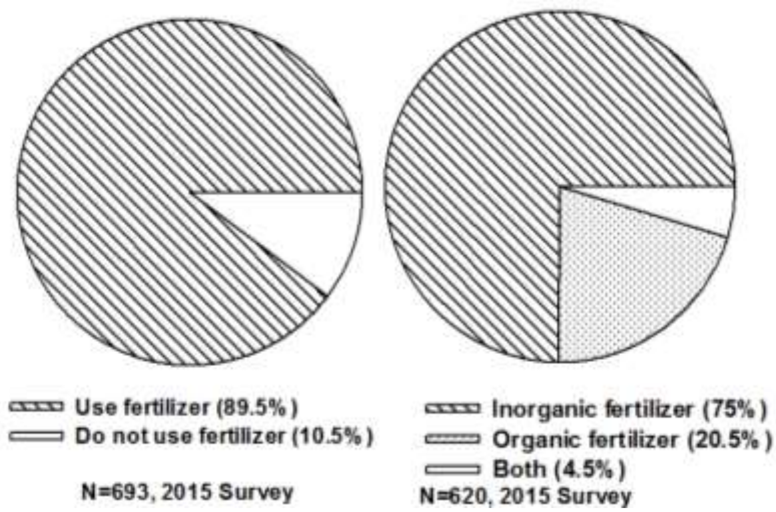

Figure 6. The percentage of farmers using or not using the different types of fertilizers (different survey data combined).

of applied fertilizer in all the other zones were lower than the blanket recommendation on average by 66%.

Maize grain yield

Maize grain yield is steadily increasing in Ethiopia and the current average national maize grain yield is 3.8 t ha^{-1} (CSA, 2017). This is by far higher compared to other African countries, but still low compared to the potential of the crop. Variability in maize crop performance and in grain yield is very common in different regions and zones, owing to difference in farmers' crop management practices and also due to soil and climatic variability within smaller areas.

Data presented in Figure 6 show that in 2016 and 2017 seasons, 54 and 44% of the surveyed farmers, respectively harvested maize grain yield that was less

Table 10. Maize grain yield in different maize growing areas (data from EIAR and CIMMYT joint survey).

Location	Grain yield (kg ha^{-1})								
	2015 (N=235)			2016 (N=336)			2017 (N=556)		
	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
East Shoa	-	-	-	-	-	-	3670	730	11478
Jimma	5428	1897	11335	3979	1117	9173	4482	1323	8980
West Shoa	4367	1952	7064	5913	2721	10973	4683	1361	9759
East Wollega	5763	2670	11721	-	-	-	5305	2471	8943
West Gojam	6740	1959	13443	-	-	-	6735	1916	11907

Table 11. Grain yield in different maize growing areas (data from CSA and CIMMYT joint survey).

Location	Grain yield (kg ha^{-1})								
	2015 (N=382)			2016 (N=351)			2017 (N=469)		
	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
East Shoa	3355	1644	5188	1679	822	4367	2858	644	5219
Jimma and Ilubabor	4335	1275	9275	2434	372	5270	3316	575	6156
West and south west Shoa	4051	1000	9831	3023	524	6814	3053	625	5781
East and West Wollega	5633	825	17049	2958	1015	8939	3926	1003	10366
West Gojam	4673	563	11563	3404	1453	6304	4763	1156	12847
East Gojam	-	-	-	2895	1245	5537	4405	1838	9600

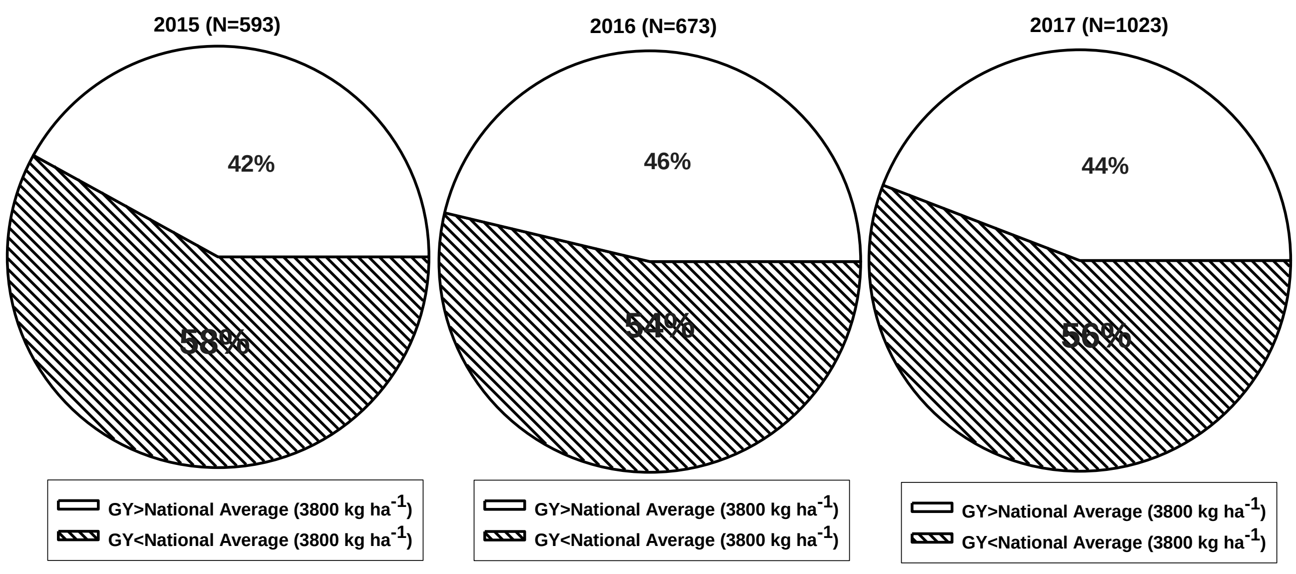

Figure 7. Percentage of surveyed farmers with grain yield above or below the national average (CSA and EIAR survey data).

than the national average of 3.8 t ha^{-1}. In 2015 cropping season, even more proportion (58%) of the surveyed farmers harvested maize grain yield that was less than the national average (Figure 7). Data presented in Table 10 showed that the mean grain yield in different maize growing zones were all above the average national maize grain yield except for East Shoa Zone, where the mean grain yield in 2017 was lower than the national average. In 2015 and 2017 seasons, mean grain yield was higher in West Gojam and East Wollega Zones compared to other zones (Figure 8). According to the data presented in Table 11, the mean grain yield in 2015 was above the national average in all zones except in East Shoa. In 2016 season, the mean grain yields were all below the

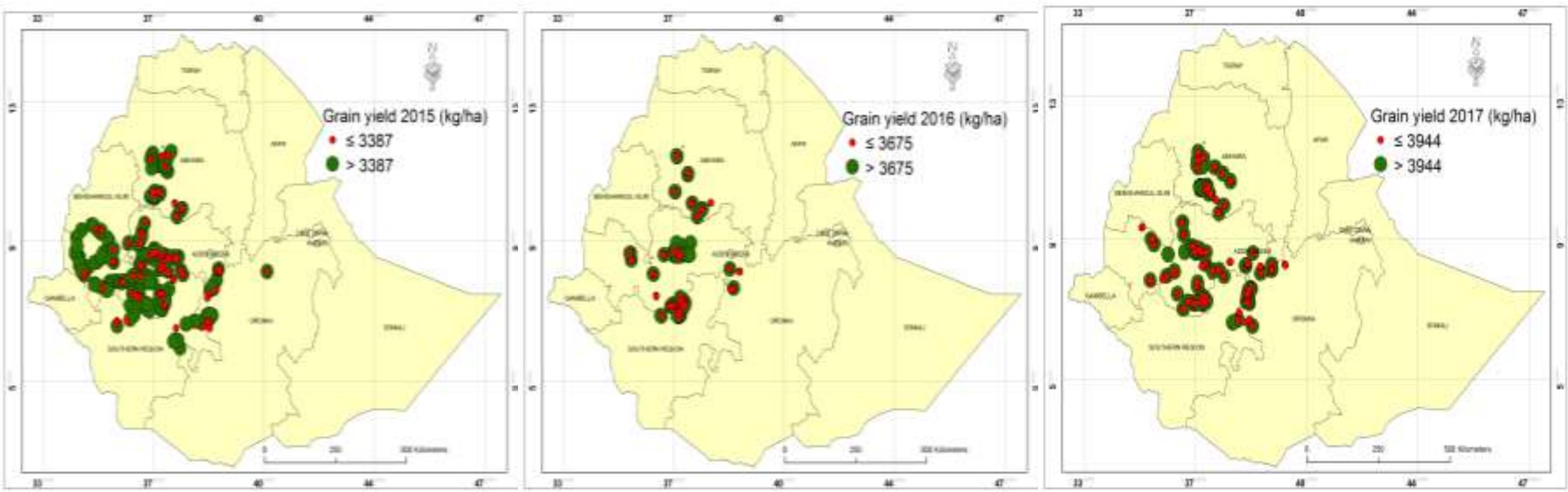

Figure 8. Map showing grain yield in different maize growing areas of Ethiopia.

national average in all the zones. In 2017, the mean grain yields were greater than the national average for two zones (East and West Gojam Zones), similar to the national average in East and West Wollega zones, while for the rest of the zones, the mean grain yield was lower than the national average.

Conclusion

In most maize growing areas plant densities were lower than any of the recommended plant densities and the fact that plant density correlated positively with grain yield thus implies maize yield gap could potentially be due to lower plant density practiced by farmers. More than 95% of surveyed farmers grow F1 hybrids. About 85% of the farmers grow improved maize var. within the ecologies they were recommended for. The proportion of farmers using improved maize variety varied with zones (higher proportion in the case of West Gojam and West Shoa). The kind of maize variety grown differed with growing areas with BH661being the commonest maize variety in Jimma zone, BH660 in West Gojam and West Shoa, Limu in West Shoa and East Wollega, and BH540 was the commonest maize variety in East Shoa zone.

Most farmers (89.5%) use fertilizer for maize production. About 75% of them use inorganic fertilizer but few farmers (4.5%) use both organic and inorganic forms in an integrated manner. Thus, much work needs to be done to bring Integrated Nutrient Management (INM) into farmers' attention. In some maize growing areas such as East Shoa and Jimma zones in particular, the integrated use of organic and inorganic fertilizers is given no/little attention which may aggravate the declining of soil OM content resulting in the subsequent declining of maize productivity. In most maize growing areas, farmers apply fertilizer rates very close to 100 kg NPS and 200 kg UREA which is the blanket recommended rate used some years ago. However, consistently higher inorganic fertilizer rate was applied in West Gojam and the lowest in East Shoa Zones. Grain yield was higher than the national average for all/most of the maize growing areas; however, it was exceptionally higher in Gojam and Wollega zones and lower in East Shoa zone although it lacks consistent across the years. There is a positive relationship between grain yield and plant density, grain yield and cob number, cob number and plant density. The positive relationship between cob number and plant density was, however, highly significant. In the future, weed management needs to be included in such studies since it is among the most important practices affecting grain yields and yet not addressed in the current study.

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CONFLICT OF INTEREST

The authors state that they have no conflict of interest.

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