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International Maize and Wheat Improvement Center

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Rust Resistant Wheat Varieties in Ethiopia from 2009/10 to 2013/14

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CIMMYT
International Maize and Wheat Improvement Center

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Summary

This study tracks wheat varietal adoption by farmers in Ethiopia from 2009/10 to 2013/14 and was based on two nearly identical national wheat variety adoption studies undertaken by EIAR and the International Maize and Wheat Improvement Center (CIMMYT) over a four-year period. A total of 2,096 households were surveyed in 2009/10 and 1,921 (all from the preceding survey) in 2013/14. Three potentially significant factors influenced Ethiopian wheat farmers during the four-year period between surveys. First, in 2010/11 one of the most devastating stripe (yellow) rust epidemics in recent times hit many of Ethiopia's wheat growing regions. Second, on-going investments by national and international organizations helped to develop, promote, and popularize improved rust resistant wheat varieties. Third, a new stem rust race (race TKTTF) was detected in Ethiopia for the first time in 2012.

Forty-two percent of the surveyed households were affected by the 2010/11 stripe rust epidemic, and 40% of the affected households discontinued using the old wheat varieties and replaced them with alternative varieties in the next production season. Survey results showed a substantial shift in varietal use over the four-year period. Previously dominant cultivars 'Kubsa' and 'Galema' became highly susceptible to stripe rust in 2010/11 and declined in area share. These two varieties alone accounted for 29.5% of the total wheat area surveyed in 2009/10. By 2013/14, they only accounted for 18% of the total wheat area surveyed (with 'Galema' accounting for only 1.4%). Varieties considered rust resistant (namely; 'Digalu', 'Kakaba', 'Danda'a', 'ET-13', 'Pavon-76' and 'Mada Walabu') occupied 47% of the total wheat area surveyed in 2013/14. The biggest area increases were recorded for the new rust resistant varieties 'Digalu', 'Kakaba', and 'Danda'a'. Most notable was the increase in the area planted to 'Digalu', which alone covered 27.1% of the wheat area surveyed in 2013/14 (vs. only 2.1% in 2009/10). The shift to growing 'Digalu' was most pronounced in the central and southern regions of Oromia and the Southern Nations, Nationalities, and Peoples' Region (SNNPR), but increased cultivation was also recorded in the northern regions of Amhara and Tigray. The main reason for expanding cultivation of 'Digalu' was its resistance to stripe rust. Most of the overall change in varieties' area coverage was observed in hot to warm sub-humid lowland (SH1) agro-ecologies, followed by tepid to cool humid mid-highland (H2) agro-ecologies; both are conducive environments for rust development and occurrence.

Reported total average wheat yields showed a modest and non-significant increase of 3% in 2013/14 (1.75 t/ha) compared to 2009/10 (1.70 t/ha). However, despite rising input costs over the four-year period, wheat production significantly increased the average net income of the surveyed farmers: 5,339 Birr/ha in 2013/14, compared with 4,320 birr/ha in 2009/10.

The current comparative study illustrates the widespread and rapid turnover of wheat varieties within the four-year period. A major stripe rust epidemic in 2010/11 was undoubtedly a key driver of change, but effective promotion and widespread availability of seed of alternative rust resistant varieties were also important. Recent investments to support varietal development and the promotion of rust resistant varieties undoubtedly played a role in making rapid varietal change possible. Wheat farmers in Ethiopia benefited from the varietal changes with productivity gains and increasing incomes. However, the risk of over-relying on a mega variety protected by single major gene resistance --'Digalu' in this instance-- in the

rust prone Ethiopian farming system was clearly revealed. While maintaining good resistance against the prevailing stripe rust and Ug99 stem rust races, 'Digalu' is now highly susceptible to TKTTF, the latest stem rust race to be detected in Ethiopia. As a result, replacement of 'Digalu' is a high priority.

Rust epidemics are a driving force for the replacement of susceptible varieties. The current study shows that rapid varietal replacement is possible in Ethiopia; however, it must be done in a concerted, coordinated, and strategic manner. Emphasis should be placed on ensuring that a genetically diverse range of varieties is popularized and put in the hands of farmers. As much as possible, a range of durable, race-nonspecific rust resistant varieties should continue to be developed and deployed, while avoiding single major gene-based resistance. These rust resistant varieties should be targeted to the highest rust prone agro-ecologies. Continuous monitoring of the rust populations in Ethiopia and the surrounding region is essential to ensure that new disease threats are detected as soon as possible and important races are used for screening by breeding programs to enable testing and development of new, improved, resistant varieties.

Acronyms

AEZ	Agroecological zone
CSA	Central Statistical Agency
DIIVA	Diffusion and impacts of improved varieties in Africa
FAO	Food and Agriculture Organization of the United Nations
GoE	Government of Ethiopia
HH	Household
IFPRI	International Food Policy Research Institute
masl	Meter above sea level
PA	Peasant Association
RRV	Rust Resistant Varieties
SNNPR	Southern Nations, Nationalities, and Peoples' Region
SSA	Sub-Saharan Africa

Abstract

Based on two comparable surveys of more than 2,000 Ethiopian wheat farmers during 2009-14 by the Ethiopian Institute of Agricultural Research (EIAR) and the International Maize and Wheat Improvement Center (CIMMYT), there was rapid and substantial varietal turnover involving the replacement of older, popular wheat varieties that became susceptible to emerging and evolving races of stem rust (*Puccinia graminis* f. sp*. tritici*) and stripe rust (*Puccinia striiformis* f. sp. *tritici*) with newer, resistant wheat varieties. This has resulted from (i) a devastating outbreak of stripe rust in 2010-11, (ii) the first appearance in Ethiopia of stem rust race TKTTF, (iii) heightened awareness among farmers about the need to adopt newer improved and disease resistant varieties, and (iv) considerable investments by national and International organizations to develop and spread improved, disease resistant wheat varieties. Finally, the study pointed up the need to ensure that a genetically diverse range of wheat varieties is popularized, that varieties featuring durable, race-nonspecific rust resistance---rather than resistance base on major, single genes---are developed and deployed, and that monitoring of rust populations in Ethiopia and the surrounding region continues, so that new races can be detected quickly and used for screening as part of resistance breeding.

1. Introduction

Wheat in Ethiopia is grown predominantly by smallholder farmers under rainfed conditions. Smallholder farmers have about 92% of the area allocated to wheat (USDA, 2013), with the remainder cultivated by a few government-owned, large-scale (state) farms and commercial farms. Wheat is the fourth most important cereal crop by area in the country, after tef, maize, and sorghum (CSA, 2014). Most wheat grown in Ethiopia is bread wheat (more than 80% of the wheat area), but tetraploid wheat (durum wheat and landraces) are grown in some areas (Shiferaw et al., 2014).

Wheat production and area in Ethiopia have increased over 2007-2013. The production of 4.0 million tons in 2013, a record output, made Ethiopia the leading producer of wheat in Sub-Saharan Africa and third on the continent, after Egypt and Morocco (FAOSTAT, 2013). However, in terms of production per unit area, Ethiopia is lagging behind other major producers in Africa, with an average wheat yield of 2.37 tons per ha in 2013, compared to 2.76 t/ha in Kenya and 3.61 t/ha in South Africa (FAOSTAT 2013). Despite the recent expansion, Ethiopia falls short of being self-sufficient in wheat production, and remains a net importer.

Wheat rust diseases are the major biotic threats to wheat production and productivity in Ethiopia. Over the last two decades, stem (black) rust caused by *Puccinia graminis* f. sp. *tritici* and stripe (yellow) rust caused by *P. striiformis* f. sp. *tritici* have been responsible for devastating epidemics (Singh et al., 2016). In 2010/11, one of the most severe stripe rust epidemics in recent history occurred in Ethiopia, affecting an estimated 600,000 ha of wheat (>30% of the total area). Popular cultivars such as *'Kubsa'* and *'Galema'* were highly susceptible to an aggressive new stripe rust race with virulence to the resistance gene *Yr27*. Also significant was the emergence of new, highly-virulent stem rust races in eastern Africa (i.e., the Ug99 race group) and, more recently, of non-Ug99 stem rust race TKTTF ("*Digalu*" race) in Ethiopia (Singh et al., 2015). The latter caused severe localized epidemics on the variety *'Digalu'* in 2013/14 and 2014/15 (Olivera et al., 2015). These emerging rust threats have driven the Government of Ethiopia (GoE), and national and international partners to develop or promote and popularize rust resistant varieties. This study monitored wheat varietal change and the adoption of rust resistant wheat varieties in Ethiopia between the 2009/10 and 2013/14 production seasons and determined the response of farmers to rust outbreaks.

1.1. Objectives of the report

The study was conducted to track wheat varietal changes by farmers from 2009/10 to 2013/14. A comprehensive national wheat variety adoption study was undertaken in Ethiopia during the 2009/10 production season by EIAR and CIMMYT under the auspices of the Diffusion and Impacts of Improved Varieties in Africa (DIIVA) project (Yirga *et al.,* 2013); it provided the baseline for the current study. Using a near-identical methodology and survey coverage in the 2013/14 production season, the present study investigated the adoption, presence, and diversity of varieties considered to be rust resistant, as well as changes in seed and input use, shifts in area under different varieties, and associated socio-economic factors, following the 2010/11 stripe rust epidemic.

The 2013/14 survey was designed to be directly comparable with the 2009/10 DIIVA survey in terms of sampling frame, household, and sample size. Although slightly different survey instruments were used in the two surveys, common key variables were extracted in both.

2. Methodology

2.1. Wheat agro-ecologies in Ethiopia

There are 16 well-defined agro-ecological zones in Ethiopia (MoA, 1998). Wheat is grown largely in tepid to cool moist mid-highlands (M2) and tepid to cool sub-moist mid-highland (SM2) agro-ecologies. These two zones account for approximately 53% of national wheat area. From the 2009/10 and 2013/14 surveys, 683 ha and 612 ha of wheat area, respectively, were found in these two agro-ecologies.

The four major wheat growing regions in Ethiopia are Oromia, Amhara, SNNPR, and Tigray, accounting for 99.5% of national wheat area and 99.6% of national wheat production (CSA, 2014; Table A2). Locations of selected survey districts across regions and major agro-ecological zones are shown in Figure 1.

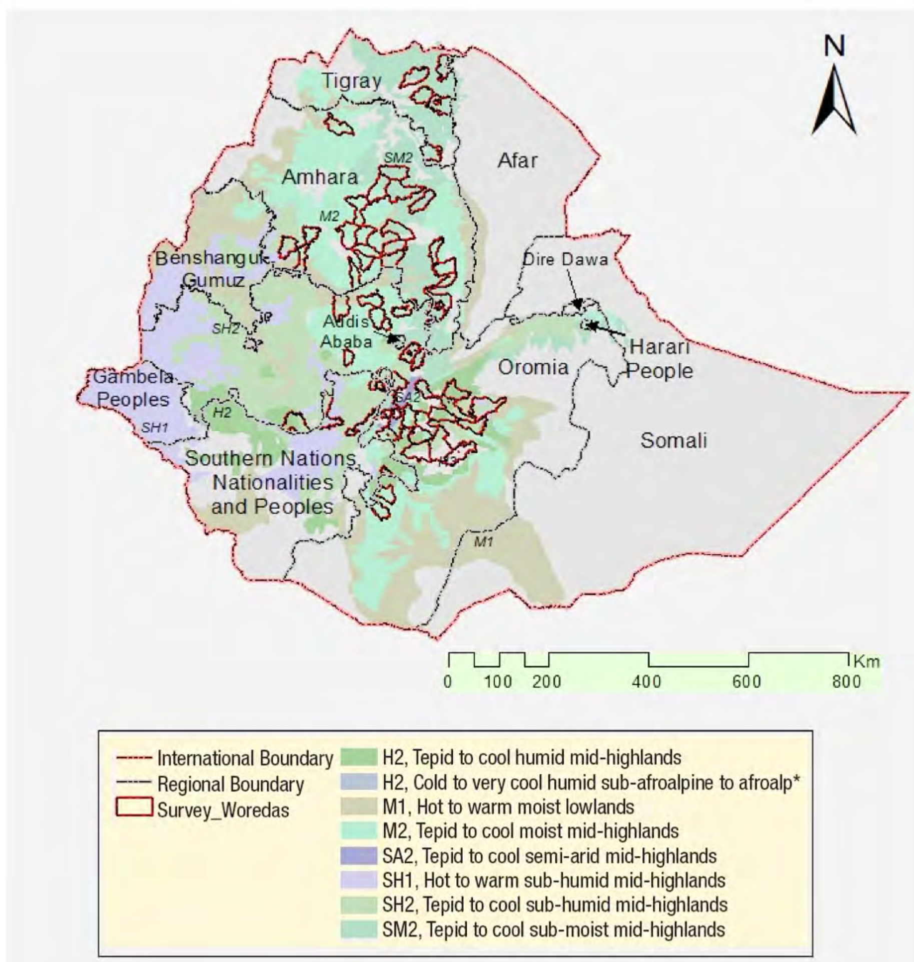

Figure 1. Districts surveyed in the selected major wheat producing agro-ecological zones.

2.2. Sampling procedure

Sampling procedure baseline survey 2009/10

During the 2009/10 national wheat survey under the DIIVA project, a stratified two-stage random sampling technique was employed. Stratification was done both by agro-ecological zone (AEZ) and region (Amhara, Oromia, SNNPR, and Tigray). Randomization took place at the kebele* and household levels. Details of the sampling procedure used are as follows.

- A list of 353 wheat producing districts with their respective areas under wheat production was obtained from CSA/IFPRI 2002 data. From the 353 wheat producing districts, 148 districts with more than 2,000 ha of wheat area were selected. These selected districts constituted about 85% of the total wheat area in the country in 2002; i.e., 854,446 ha of the total 1,003,667 ha national wheat area (source: CSA/IFPRI 2002). When the 148 main wheat producing districts were categorized by their major AEZ, they encompassed 8 AEZs[1].
- A list of 4047 kebeles in the 148 main wheat producing districts was obtained with their geographical area and major AEZ (data source: CSA 2007). In total, these kebeles fall under 15 AEZs, though 91.8% of them are in just 8 AEZs. The distribution varies by region (see Table 1). Since the kebele data do not include the wheat area, a rough estimate of the wheat area for the 4047 kebeles was obtained using the Spatial Production Allocation Model (SPAM) dataset (Harvest Choice, 2014). The percentage share of wheat area by AEZ follows almost the same pattern as the proportion of kebeles distributed by AEZ (see Table 1). The proportion of these kebeles and respective total wheat area in the major wheat growing regions (Oromia, Amhara, SNNPR and Tigray) were also identified by their proportion of AEZ (Table 1).
- Based on the proportion indicated above, 8 important AEZs that have ≥3% of the wheat areas (from 854,446 ha) were selected. Then, the maximum targeted 120 kebeles were distributed to these 8 AEZs by their proportion of each region (Table 2). Finally, the 120 sample kebeles were selected randomly, based on the proportionate distribution by AEZ and region (Table 3).

For each kebele sampled, supervisors randomly selected 15-18 (on average, 16) sample households from the kebele household list to secure all 2,000 targeted sample households. Using a fairly equal number of sample households per kebele ensured the proportionate distribution of sample households by the importance of AEZ for wheat area/production. A final total of 2,096 households were included in the 2009/10 baseline survey.

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* The smallest administrative unit of Ethiopia, similar to a ward or a municipality.

[2] These AEZs are: (1) tepid to cool moist mid highlands, (2) tepid to cool sub-moist mid highlands, (3) tepid to cool sub-humid mid highlands, (4) tepid to cool humid mid highlands, (5) cold to very cold humid sub-Afro-Alpines, (6) hot to warm moist lowlands, (7) hot to warm sub-humid lowlands, and (8) tepid to cool semi-arid mid highlands.

Table 1. Distribution of kebeles by region and AEZ, and proportion of wheat area in each AEZ.

AEZ	Number of *Kebeles* Oromia	Amhara	SNNP	Tigray	Total	Kebele share (%)	Wheat area share of each AEZ *	Average (AEZ and *Kebele* share)	Decision for sampling	Sample share (% of N=2,000)	% share of the selected AEZs	Proportionate distribution of the 120 sample *Kebeles*
A1	5	0	0	0	5	0.1	0.1	0.1	Dropped			
A2							0.44	0.22	Dropped			
H1	5	0	0	0	5	0.1	0	0.05	Dropped			
H2	542	0	47	0	589	**14.6**	14.1	**14.35**	Selected	14%	15.4	18
H3	23	0	0	0	23	0.6	5.49	**3.05**	Selected	3%	3.3	4
M1	86	139	0	0	225	**5.6**	3.01	**4.31**	Selected	4%	4.4	5
M2	692	635	23	0	1350	**33.4**	26.89	**30.15**	Selected	30%	33	40
M3	5	66	0	0	71	1.8	2.33	2.07	Dropped			
SA1	12	0	0	0	12	0.3	0.13	0.23	Dropped			
SA2	79	0	0	0	79	2	3.69	**2.85**	Selected			
SH1	103	10	73	0	186	**4.6**	2.59	**3.595**	Selected	4%	4.4	5
SH2	283	19	281	4	587	**14.5**	17.45	**15.98**	Selected	16%	17.6	21
SH3	5	0	0	0	5	0.1	2.09	1.095	Dropped			
SM1	2	29	0	28	59	1.5	1.33	1.415	Dropped			
SM2	195	445	6	191	837	**20.7**	20.02	**20.36**	Selected	20%	22	27
SM3	0	14	0	0	14	0.3	0.34	0.32	Dropped			
Total	**2037**	**1357**	**430**	**223**	**4047**	**100.1**	**100**	**100.05**	**91.78%**	**91%**	**100%**	**120**

* *Wheat area share of each AEZ as proportionate to the wheat area in 148 major wheat growing districts (>2,000 ha wheat area/district).*

Table 2. Distribution of sample Kebeles by AEZ and region (for selected AEZs).

AEZ	Oromia		Amhara		SNNP		Tigray		Total	
	No. of *Kebeles*	***Sample***	**No. of *Kebeles***	***Sample***	**No. of *Kebeles***	***Sample***	**No. of *Kebeles***	***Sample***	**No. of *Kebeles***	***Sample***
H2	542	17	0	0	47	1	0	0	589	18
H3	23	4	0	0	0	0	0	0		4
M1	86	2	139	3	0	0	0	0	225	5
M2	692	21	635	19	23	1	0	0	1,350	41
SH1	103	3	10	0	73	2	0	0	186	5
SA2	79	2	0	0	0	0	0	0	79	2
SH2	283	10	19	1	281	10	0	0	583	21
SM2	195	6	445	14	6	0	191	6	837	26
Total	**2,003**	**65**	1,248	37	430	14	191	6	3,849	122

Note: H2=tepid to cool humid mid-highlands, H3=cold to very cold humid sub-Afro-Alpine, M1=hot to warm moist lowlands, M2=tepid to cool moist mid-highlands, SH1=hot to warm sub-humid lowlands, SA2=tepid to cool semi-arid mid highlands, SH2=tepid to cool sub-humid mid highlands, and SM2=tepid to cool sub-moist mid highlands.

Table 3. Summary of sample Kebeles for the baseline survey (DIIVA project).

Region	Sample distribution				
	No. of zones	**No. of districts**	**No. of *Kebeles***	**No. of AEZs selected in each region**	**List of AEZs sampled in each region**
Amhara	8	22	**37**	4	M1, M2, SH1, SM2
Oromia	10	27	**65**	8	H2, H3, M1, M2, SA2, SH1, SH2, SM2
SNNPR	6	7	**14**	4	H2, M2, SH1, SH2
Tigray	4	5	**6**	1	SM2
Total	**28**	**61**	**122**		

Sampling procedure for the 2013/14 survey

During the 2013/14 wheat survey, all sample households selected during the 2009/10 baseline survey were revisited and, if present, the household heads were interviewed using the same questionnaire with a slight modification of contents. An overall attrition rate of 8.3% was encountered in the follow-up survey of 2013/14 (Table 4), most likely due to the unavailability of the sample household head (respondent) during the specific survey week, families moving away, or possibly the death of the occupying farmer. As a result, 1,921 sample households were covered during the 2013/14 survey. No replacement households were selected; hence all 2013/14 household survey participants had participated in the 2009/10 baseline survey. The surveys were conducted from April to June 2011 and March to May 2014, to capture the production data of the 2009/10 and 2013/14 seasons, respectively.

The surveys gathered household and plot level data, interviewing farmers to document crop production, wheat varieties used, agronomic practices, and utilization. A limited number of village, household, and welfare characteristics were also documented.

Table 4. Distribution of sample households (HH) interviewed in the baseline and the follow-up wheat surveys.

Region	Sample HHs in the baseline survey (2009/10)	Sample HHs in the follow-up survey (2013/14)	Attrition	
			No. of HHs	%
Tigray	105	93	12	11.4
Amhara	636	596	40	6.3
Oromia	1,109	1,003	106	9.6
SNNPR*	246	229	17	6.9
Total	2,096	1,921	175	8.3

** SNNPR is Southern Nations, Nationalities, and Peoples' Region.*

3. Results and Discussion

This section presents descriptive and qualitative statistics as a comparative analysis between the 2009/10 baseline survey and the 2013/14 follow-up survey. Wherever relevant, mean equality tests of selected variables using Student's t-test were conducted and reported based on the two rounds of survey data.

3.1. Village and household characteristics

A summary of average physical characteristics for all households sampled in 2009/10 and 2013/14 is given in Table 5. Two characteristics—distance to the nearest village and distance to main markets—remained relatively constant between the two survey periods. Conversely, distance to cooperative center and distance to agricultural office both showed significant ($P<0.05$) respective reductions of 1.02 and 0.76 km, which may reflect increased public support for the construction of offices (e.g., Farmer Training Centers, FTC) and village-based cooperative development which could enhance farmers' access to inputs and extension services in their vicinities.

Table 5. Village characteristics for the sampled households.

Village Characteristics	2009/10			2013/14			Difference	
	Obs	Mean	Std. Err.	Obs	Mean	Std. Err.	Mean	Std. Err.
Distance to Village Market *(km)* [a]	492	2.89	0.26	535	2.76	0.12	-0.14	0.28
Distance to Main Market *(km)*	1,874	9.20	0.29	1,877	9.04	0.14	-0.15	0.32
Distance to Coop Center *(km)*	1,809	6.09	0.32	1,881	5.08	0.12	1.02**	0.33
Distance to agricultural extension office *(km)*	1,886	3.74	0.28	1,866	2.99	0.06	0.76**	0.29

[a] Most households didn't have village markets and rely on main markets. That is the reason that we have a low number of observations reported on distance to village markets.

A summary of average socioeconomic characteristics for all sampled households in 2009/10 and 2013/14 is given in Table 6. Experience in growing wheat, educational levels of the household head and spouse, and number of family members engaged in agriculture all remained constant between surveys. Size of the active labor force showed a highly significant (P<0.001) decrease between 2009/10 and 2013/14, with a corresponding highly significant (P<0.001) increase in the dependency rate. These differences may be related to increasing off-farm opportunities, rising labor costs and declining interest in agricultural work.

Table 6. Descriptive statistics of household characteristics.

	2009/10			2013/14			
Household characteristics	**Obs.**	**Mean**	**Std. Err.**	**Obs.**	**Mean**	**Std. Err.**	**Mean difference**
Experience wheat growing *(years)*	2,035	16.75	0.25	1,875	16.86	0.26	0.13
Sex of HH head *(Male=1; Female=0)*	2,090	0.94	0.01	1,919	0.93	0.01	-0.01
Education of HH head *(years of schooling)*	2,090	2.98	0.07	1,918	2.97	0.08	-0.01
Education of spouse *(years of schooling)*	2,035	1.23	0.05	1,815	1.33	0.06	0.10
Age of HH head *(years)*	2,091	43.56	0.28	1,918	46.51	0.29	2.95***
Total family size *(persons)*	2,096	6.65	0.05	1,921	6.52	0.05	-0.13*
Family members mainly engaged in agriculture *(persons)*	2,065	1.39	0.02	1,883	1.39	0.02	-0.01
Active labor force *(persons)*	2,093	4.18	0.04	1,916	3.35	0.03	-0.83***
Dependency rate *(ratio)*	2,096	0.35	0.004	1,921	0.47	0.004	0.12***

3.2. Social capital and networking

Social capital and networking are means to access information, secure a job, obtain credit, protect against unforeseen events, exchange price information, reduce information asymmetries, and enforce contracts (Barrett, 2005). In the survey areas, on average, sampled households appeared to have slightly less connection to traders in the follow-up survey (approximately 5 traders known in 2009/10 vs. approximately 4 in 2013/14, P<0.05). In contrast, sampled households reported a higher number of known relatives that could provide support during critical times in the 2013/14 survey (20 in 2013/14 vs. 13 in 2009/10, P<0.0001) (Table 7). Such support might include labor exchange and providing financial support in the form of credit, which contribute positively to technology adoption. In a similar manner, if the household knows someone (relatives/friends) in a leadership position in the village or district, the probability of getting technological information that facilitates technology adoption could be enhanced. This latter metric was also reported to be higher in 2013/14.

Table 7. Social capital and networking.

Social capital and networking	2009/10 Obs	Mean	Std. Err.	2013/14 Obs	Mean	Std. Err.	Mean difference
Number of traders the respondent knows	2,050	4.82	0.13	1,916	4.29	0.11	0.53**
Number of reliable relatives the respondent has in and outside village	2,001	13.15	0.46	1,921	20.07	.80	6.92***
The respondent has relative/friend in leadership position *(1=Yes; 0=No)*	2,090	0.61	0.01	1,921	0.67	0.01	0.60***

3.3. Household assets

Asset ownership is usually taken as measure of wealth and (particularly in the case of articles such as a TV or radio) helps to access decision-supporting information. On average, the reported value of assets (physical assets, farm equipment and household furniture, but not livestock) was 14,840 and 27,660 birr per household in 2009/10 and 2013/14, respectively, a significant increase between the two periods (P<0.001). Household livestock ownership showed an average, non-significant decrease, going from 5 to 3 livestock units measured in TLU between the two surveys.

Table 8. Value of non-livestock assets and number of livestock owned.

Asset type	2009/10 Obs.	Mean	Std.Err.	2013/14 Obs.	Mean	Std.Err.	Mean difference
Asset value (non-livestock)	2,096	14,839.99	447.75	1,921	27,659.52	1,413.17	12,819.53***
Livestock ownership (TLU)	2,093	4.8	0.13	1,921	3.29	0.12	-1.51

3.4. Farm size and land use

The average landholding of the sampled households went from 1.84 to 1.81 ha between the two surveys, a non-significant reduction (Table 9) that could be a result of land allocations from parents to children establishing new families. In 2009/10, the percentage shares of wheat area relative to the land under cereals and to the total area cultivated in the specific season were 39 and 29%, respectively. These percentage shares did not differ significantly in 2013/14, with proportions of 41 and 30%, respectively (Table 10). Even after the stripe rust epidemic, the proportion of farmland allocated to wheat remained high, indicating the crop is important for household consumption, incomes, and livelihoods in the surveyed districts.

Table 9. Landholding of the households.

	2009/10			2013/14			Mean difference
	Obs	**Mean**	**Std. Err.**	**Obs**	**Mean**	**Std. Err.**	
Farm size (ha)	2,090	1.84	0.04	1,920	1.81	0.04	-0.03
Land owned before five years (ha)	2,016	1.98	0.04	1,878	1.95	0.045	-0.03

Table 10. Proportion of area covered by wheat.

Percentage share of wheat area relative to	Year		Mean difference
	2009/10	**2013/14**	
Land sown to cereals	39	41	2
Total cultivated land	29	30	1

3.5. Wheat varietal use and area change

The baseline survey covering the 2009/10 production season revealed that farmers were predominantly growing a very limited number of improved wheat varieties. Of the many improved varieties recorded in the baseline survey (see Table A8), only 12 were widely grown and just two ('*Kubsa*' and '*Galema*') occupied the largest area shares (Table 11 and Figure 2).

Table 11. Area share of popular improved wheat varieties in the surveyed areas, Ethiopia.

	2009/10				20013/14			
	Not including the year of seed recycling		Improved variety defined as freshly purchased improved seed and not recycled for more than 5 years		Not including the year of seed recycling		Improved variety defined as freshly purchased improved seed and not recycled for more than 5 years	
Major varieties	**(ha)**	**%**	**(ha)**	**%**	**(ha)**	**%**	**(ha)**	**%**
Kubsa	395.09	30.9	279.73	21.9	212.84	18.4	191.74	16.6
Galema	119.70	9.4	96.58	7.6	19.71	1.7	16.72	1.4
Tusie	117.64	9.2	96.20	7.5	30.07	2.6	28.57	2.5
Dashen	87.99	6.9	70.31	5.5	37.7	3.3	31.44	2.7
Mada Walabu	64.44	5.0	53.68	4.2	16.16	1.4	15.06	1.3
Pavon-76	42.94	3.4	36.73	2.9	47.69	4.1	46.69	4.0
Digelu	31.30	2.4	26.42	2.1	324.45	28.0	313.16	27.1
ET-13	23.94	1.9	18.31	1.4	26.84	2.3	23.45	2.0
Enkoy	20.16	1.6	14.00	1.1	0	0.0	0	0.0
Millennium	4.63	0.4	2.63	0.2	2.32	0.2	2.32	0.2
Danda'a		0.0		0.0	67.73	5.9	65.85	5.7
Kakaba		0.0		0.0	62.02	5.4	60.08	5.2
Other known improved varieties	85.38	6.7	71.19	5.6	39.45	3.4	36.18	3.1
Known improved varieties but recycled for >5 seasons			227.43	17.8			63.99	5.5
Total area under improved varieties	993.21	77.7	765.78	59.9	886.98	76.7	831.26	71.8
Local and unknown varieties		22.3	285.13	22.3	261.89	22.6	261.89	22.6
Total wheat area (ha)	1,278.34	100.0	1,278.34	100.0	1,157.14	100.0	1,157.14	100.0

If improved wheat variety use is defined conservatively (i.e., only freshly purchased improved seed and/or seed recycled for ≤ 5 seasons), *'Kubsa'* and *'Galema'* alone covered 29.5% of the total surveyed wheat area in the 2009/10 production season. This proportion was reduced to 18% of the total wheat area surveyed during 2013/14 production season. This shows a substantial reduction in the use of these two popular improved varieties, most likely due to their susceptibility to stripe rust in 2010/11.

The latest survey covering the 2013/14 production season also recorded many improved wheat varieties (see Table A8), with farmers continuing to grow only a limited number of improved varieties on a large scale. However, a substantial shift in the varieties being widely grown was observed in 2013/14 compared to 2009/10. Of the various improved wheat varieties recorded in the follow-up survey, only 12 were widely grown, with '*Digalu*' and '*Kubsa*' occupying the largest shares, both in terms of area and the proportion of households that grew them (Figure 2, Table 12).

From the total 1,157.14 ha of wheat grown by the households covered during the follow-up survey in 2013/14, *'Digalu'* covered 313.2 ha (27.1% of total surveyed wheat area), whereas the area covered by '*Kubsa*' and '*Galema*' declined to 208.5 ha (18% of the total surveyed wheat area) (Table 11 and Figure 2).

A comparison of the varieties sown by the survey households revealed major changes between 2009/10 and 2013/14. The proportions of the surveyed wheat area allocated to different wheat varieties (both local and improved) across the surveyed regions in 2009/10 and 2013/14 are illustrated in Figures 3-6.

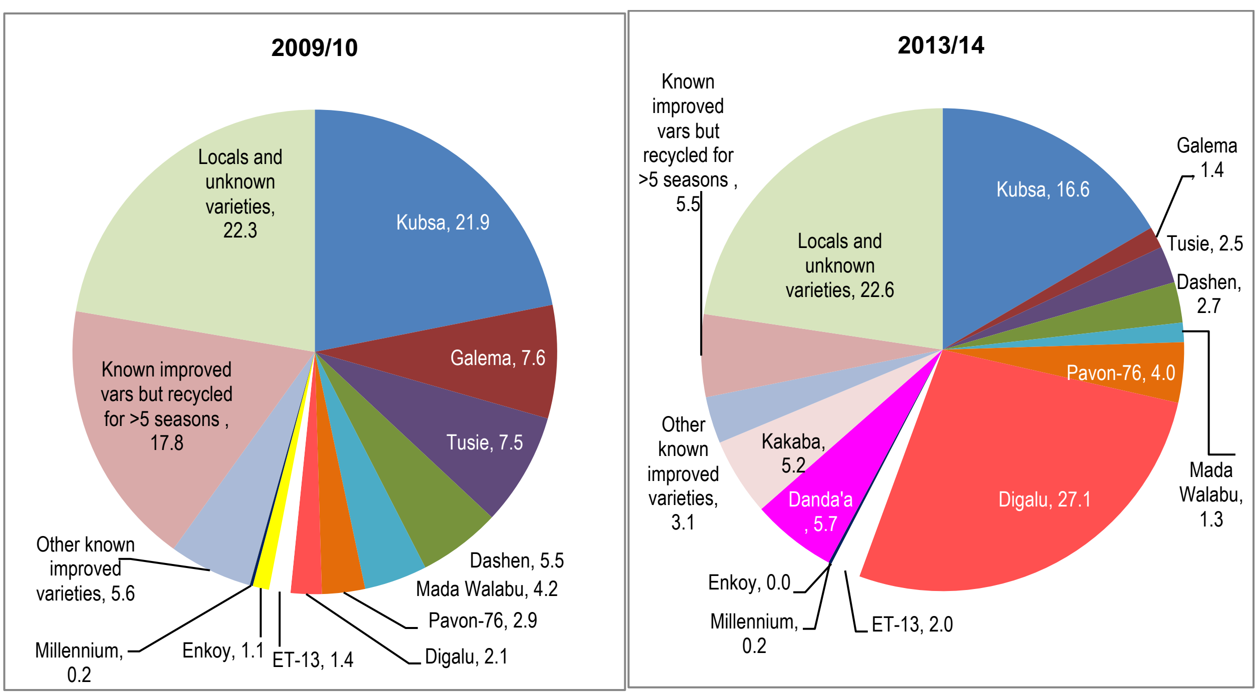

Figure 2. Percentage share of improved wheat varieties in the total wheat area surveyed in 2009/10 and 2013/14.

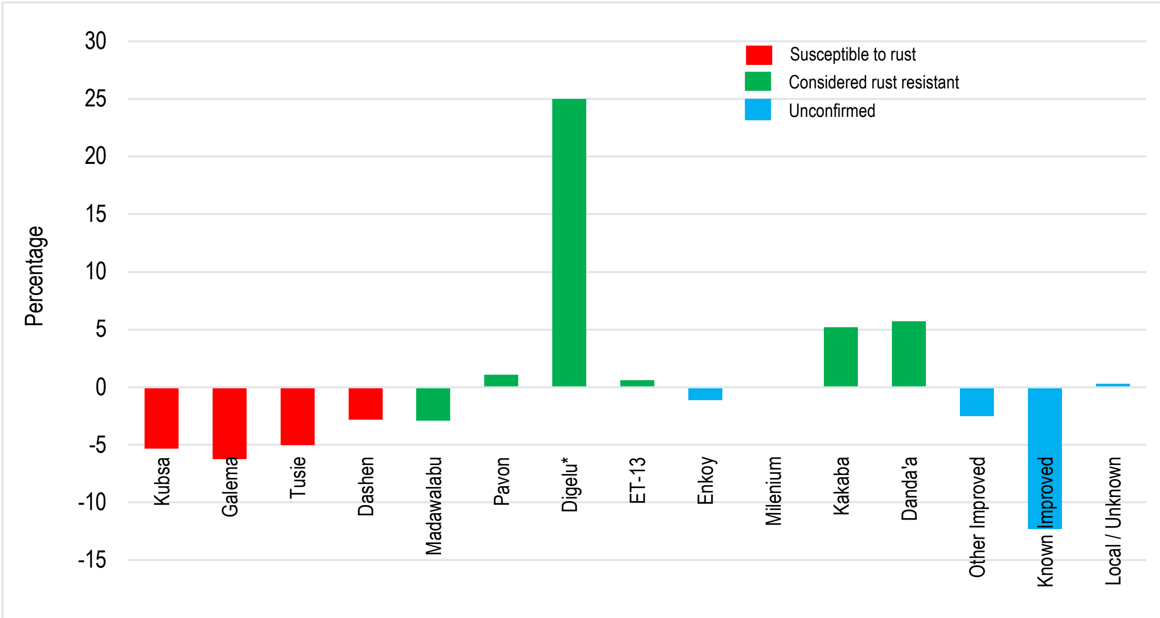

Figure 3. Change in area share of major wheat varieties between 2013/14 and 2009/10.

Most striking was the increase in the number of households growing '*Digalu*' and the area covered by that variety in 2013/14, as well as the decline in the use of '*Galema*' and of '*Kubsa*', although '*Kubsa*' remained in widespread use (Figures 2 and 3). '*Digalu*' was a resistant variety until 2013, the year it was affected by stem rust race TKTTF. It is also noteworthy that (i) older varieties with durable rust resistance (i.e., 'ET-13' and 'Pavon-76') were increasingly used in 2013/14, and (ii) new varieties with minor gene resistance or adult plant resistance (APR) to stem rust (i.e., "*Danda'a*" and '*Kakaba*') showed increasing use in 2013/14 (Figures 2 and 3).

We observed similar trends at the regional level but with some marked differences in varietal use and change. The proportions (area share) of the 12 most widely grown varieties by region in 2009/10 and 2013/14 are illustrated in Figures 4-6. The shift to growing '*Digalu*' was most pronounced in the central / southern regions of Oromia and SNNPR, but increased cultivation was also recorded in the northern regions of Amhara and Tigray. The decline in the cultivation of '*Galema*' was apparent across all three regions (SNNPR, Oromia, and Amhara) where the variety was grown. By 2013/14 '*Galema*' only covered a significant proportion of area in SNNPR. '*Kubsa*' remained an important variety, especially in Amhara, but major declines in its cultivation were recorded in 2013/4 in Oromia and, to a lesser extent, in Amhara. '*Kubsa*' was not reported to be grown by survey households in Tigray in either 2009/10 or 2013/14. Newly released rust resistant varieties '*Kakaba*' and '*Danda'a*' showed increasing cultivation in 2013/14 in Oromia, SNNPR, Amhara and, to a limited extent, in Tigray ('*Kakaba*' only). Both of these varieties were released in 2010, and so were absent from the 2009/10 survey.

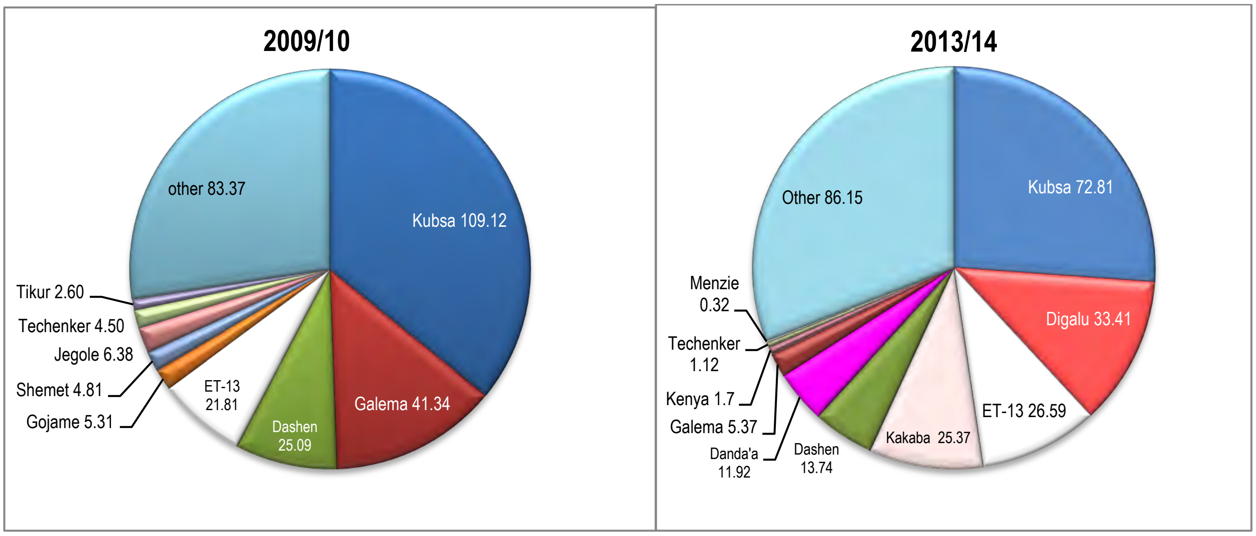

Figure 4. Proportion of the area (ha) in the Amhara region covered by wheat varieties in 2009/10 and 2013/14.

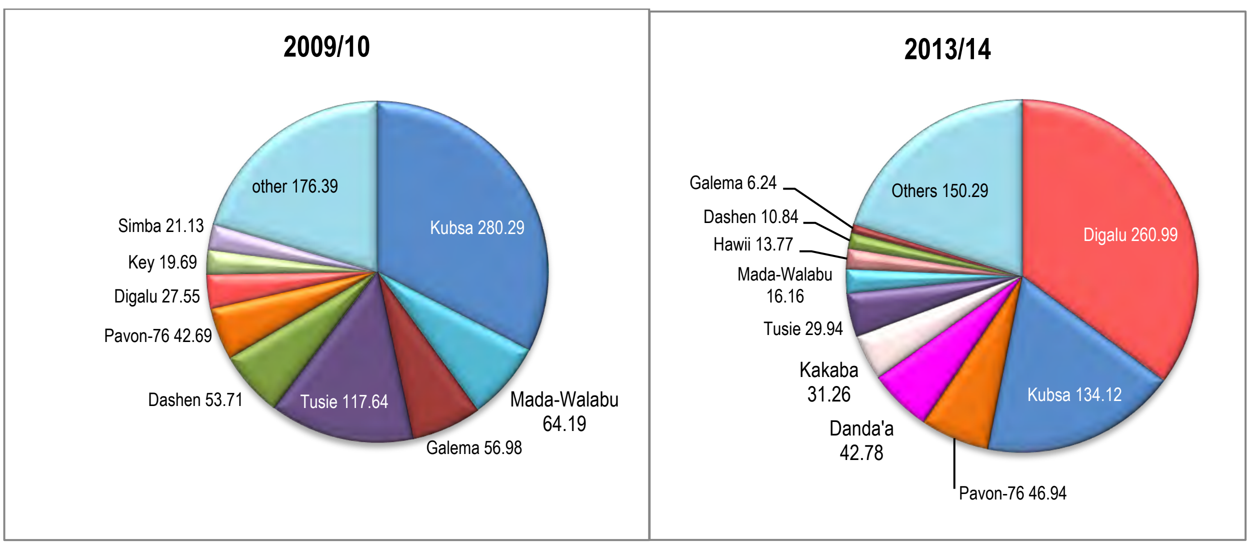

Figure 5. Proportion of the area (ha) in the Oromia region covered by wheat varieties in 2009/10 and 2013/14.

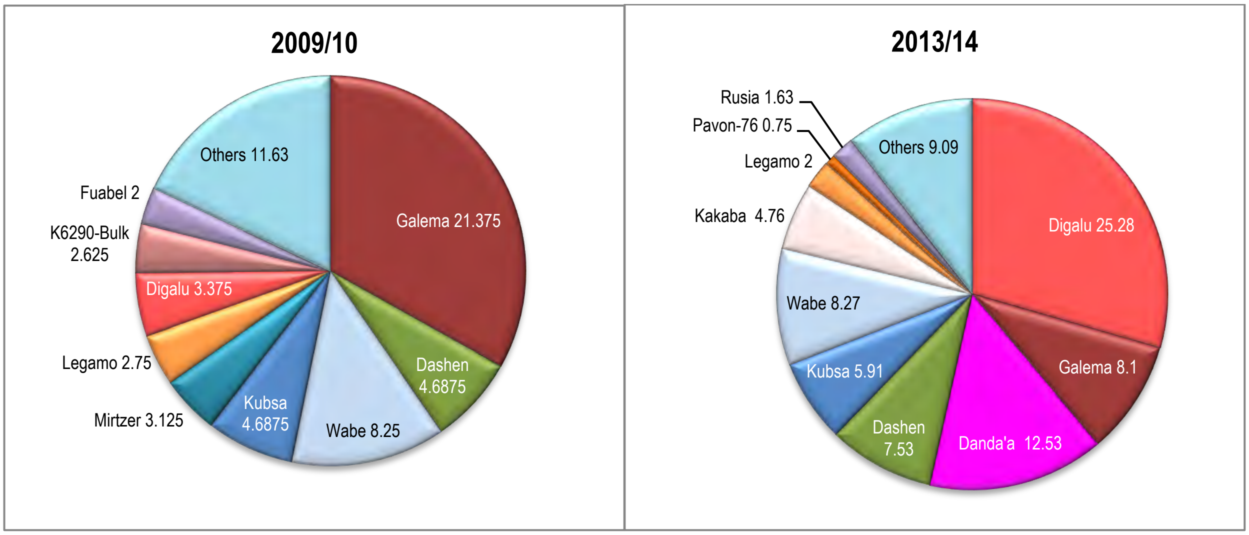

Figure 6. Proportion of the area in the SNNP region covered by wheat varieties in 2009/10 and 2013/14.

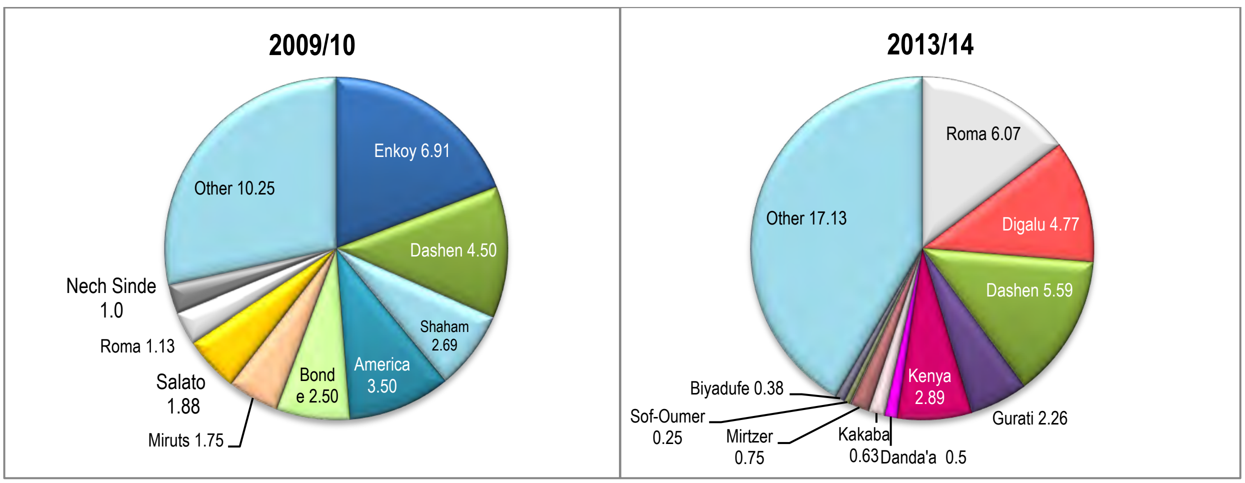

Figure 7. Proportion of the area of the Tigray region covered by wheat varieties in 2009/10 and 2013/14.

Changes in the spatial distribution of the major wheat varieties were mapped based on an intensity metric; i.e., the percentage of reported wheat area grown to a particular variety within a district (see Annex, Figures A1-A10). The spatial distribution maps support the regional trends, but give additional insights into areas of spread or decline of specific varieties. Key observations from the spatial distribution maps are as follows:

- *Danda'a.* A recently released variety featuring APR rust resistance. It spread rapidly since its release in 2010 and is being grown across all areas and just edging into Tigray.
- *Dashen.* An old variety (released in 1984) that became highly susceptible to stripe rust in 1988 (*Yr9* virulence). Its area of cultivation is declining, but it is still widely grown. In 2013/14, it was not grown in large parts of Oromia and entirely absent from Arsi/West Arsi/Bale zones. Its distribution is limited.

- *Digalu.* Released in 2005, it is high yielding and has good resistance to prevailing stripe rust races and the Ug99 race group of stem rust. Susceptible to new stem rust race TKTTF since 2013. Restricted and limited distribution in 2009/10, predominantly in Arsi/West Arsi/Bale zones. It spread rapidly and was very widely distributed in 2013/14 and grown by many farmers; it was probably the most widely grown variety especially in Oromia and SNNPR.
- *ET-13.* An old variety (released in 1981) but has durable resistance to both stem and stripe rust. Although still grown, its area is decreasing most notably in Oromia. In 2013/14, it was mainly grown in Amhara, with highest intensity in North Shewa.
- *Galema.* A relatively old variety (released in 1995) that was highly susceptible to stripe rust in 2010/11 (*Yr27* virulence). Its cultivation declined greatly across all areas, with very limited cultivation in 2013/14.
- *Kakaba.* A recently released APR rust resistant variety, it shows some susceptibility to stem rust race TKTTF under high disease pressure and is also susceptible to yellow rust. It spread rapidly since its release in 2010 and is now being grown across all areas, with highest intensity in Amhara and some cultivation in Tigray.
- *Kubsa.* Released in 1995, it was the most widely grown variety in 2009/10. Highly susceptible to stripe rust in 2010/11 (*Yr27* virulence). It was still widely distributed in 2013/14, but its use is declining, especially in Oromia.
- *Mada Walabu.* A release from Sinana ARC in 2000, it remains resistant to stem and stripe rusts. Distribution was limited to Arsi/West Arsi/Bale in both 2009/10 and 2013/14, but there were indications of increasing intensity of cultivation in 2013/14.
- *Pavon-76.* An old variety (released in 1982) that continues to show durable rust resistance. Its distribution was very restricted in both 2009/10 and 2013/14. It is adapted to lowland agro-ecologies and mainly grown in SNNPR and Oromia in the Rift Valley.
- *Tusie.* A relatively old variety (released in 1997), it still has some rust resistance, but shows susceptibility to Ug99. Restricted to Arsi/West Arsi and Bale zones of the Oromia Region.

The increasing tendency of households to adopt and grow rust resistant varieties across all the wheat growing AEZs was readily apparent. Table 13 summarizes the changes between 2009/10 and 2013/14 for key varieties considered to exhibit resistance to stem and/or stripe rust. Major changes in percent area and number of growers were observed in SH1 *(hot to warm sub-humid lowlands)* followed by H2 (*tepid to cool humid mid-highlands*). Varieties considered to be rust resistant were *'Digalu'*, '*Danda'a'*, '*Kakaba'*, '*ET-13'*, '*Pavon-76'* and '*Mada Walabu'*[2]. The corresponding disadoption of key varieties ('*Kubsa'* and '*Galema'*) rendered susceptible by an aggressive *Yr27* virulent race in the 2010/11 stripe rust epidemic was also apparent (Table 14). Disadoption of these two stripe rust susceptible varieties occurred across all AEZs in which wheat is grown.

[2] This sub-set of varieties is somewhat subjective, but aims to highlight varieties showing resistance to key prevailing stem and/or stripe rust races.

After the severe stripe rust epidemic of 2010/11, farmers' demand, especially for stripe rust resistant varieties, was high and the GoE, and national and international institutions began popularizing resistant varieties such as '*Digalu*', '*Danda'a*', and '*Kakaba*'. The willingness of farmers to adopt rust resistant varieties, coupled with successful varietal promotion and distribution, were considered key drivers of the major changes in area under what had been widely grown varieties ('*Kubsa*' and '*Galema*') to resistant varieties (Tables 12 and 13). In 2013/14, the total area covered by these resistant varieties had increased to 545 ha (47% of the total surveyed wheat area in 2013/14) (Table 13). In the four-year period between surveys, there is little doubt that substantial shifts occurred in Ethiopian wheat farmers' varietal use and adoption (Figure 8).

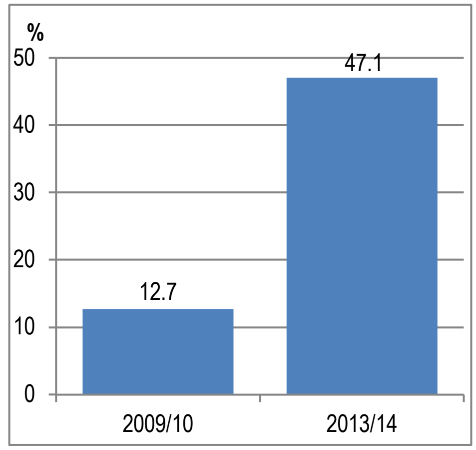

Figure 8. Proportion of wheat area under rust resistant varieties in 2009/10 and 2013/14.

The severe stripe rust epidemic of 2010/11 was considered to be a key driver of the rapid varietal change observed. However, there are considerable risks in replacing one set of mega-cultivars ('Kubsa' / 'Galema') whose resistance is based on major, single genes, with another ('Digalu') of the same type, in the rust-prone environments of Ethiopia. 'Digalu' is high yielding, possesses good resistance against prevailing races of stripe rust, and had good resistance to prevailing Ug99 stem rust races based on the major gene SrTmp. However, the SrTmp gene broke down following the incursion of stem rust race TKTTF in 2012 and Digalu is now highly susceptible to stem rust. Ensuing stem rust epidemics have affected tens of thousands of hectares in 2013/14 and 2014/15 (Olivera et al., 2015) and TKTTF has spread to all wheat growing areas of Ethiopia in the last two years, driven by the large-scale cultivation of 'Digalu'. The highly dynamic rust populations present in Ethiopia are likely to drive further rapid changes in varietal adoption in the future.

Table 12. Proportion of wheat area sown to rust resistant varieties by AEZ and year.

	2009/10						2013/14						Change in sample HH and wheat area under RRVs			
	Sample households			Wheat area			Sample households			Wheat area			Sample HHs		Wheat area	
AEZ[b]	growing wheat	growing RRVs [a]	% growing RRVs	Total (ha)	Under RRVs (ha)	% under RRVs	growing wheat	growing RRVs	% growing RRVs	Total (ha)	Under RRVs (ha)	% under RRVs	HH	%	ha	%
H2	254	99	39	261.38	55.94	21	270	211	78	247.00	152.48	62	112	39	96.54	40
H3	35	23	66	26.13	14.25	55	32	26	81	24.80	19.05	77	3	16	4.80	22
M1	56	1	2	61.44	0.25	0	56	18	32	35.30	5.75	16	17	30	5.50	16
M2	544	53	10	401.13	24.50	6	524	227	43	347.85	144.80	42	174	34	120.30	36
SA2	21	4	19	21.75	1.80	8	20	7	35	18.40	5.50	30	3	16	3.70	22
SH1	76	24	32	52.63	10.88	21	82	59	72	45.10	30.41	67	35	40	19.54	47
SH2	265	69	26	171.71	39.36	23	283	148	52	174.40	97.14	56	79	26	57.78	33
SM2	418	33	8	282.20	15.69	6	396	176	44	264.48	89.80	34	143	37	74.11	28

[a] *RRVs=Rust Resistant Varieties considered in this analysis were Digalu, Kakaba, Danda'a, Pavon-76, ET-13 and Mada Walabu.*

[b] *H2=tepid to cool humid mid-highlands; H3=cold to very cold humid sub-Afro-Alpine; M1=hot to warm moist lowlands; M2=tepid to cool moist mid-highlands; SH1=hot to warm sub-humid lowlands; SA2=tepid to cool semi-arid mid highlands; SH2=tepid to cool sub-humid mid highlands; SH2=tepid to cool sub-humid mid highlands, and SM2=tepid to cool sub-moist mid-highlands.*

Table 13. Proportion of wheat area sown to rust resistant varieties by year.

2009/10						2013/14						Area difference (ha)
Sample households			Wheat area			Sample households			Wheat area			
Growing wheat	Growing RRVs	% growing RRVs	Total (ha)	Under RRVs (ha)	% under RRVs	Growing wheat	Growing RRVs	% growing RRVs	Total (ha)	Under RRVs (ha)	% under RRVs	
1669	306	18	1,278.34	162.61	13	1663	872	52	1,157.14	544.89	47	382.28

Table 14. Area (ha) covered by widely grown wheat varieties by AEZ and year other than rust resistant varieties (RRVs).

	2009 (N=1669)									2013 (N=1663)									
	AEZ								Total area (ha)	AEZ								Total area (ha)	Area difference (ha)
Wheat varieties	**H2**	**H3**	**M1**	**M2**	**SA2**	**SH1**	**SH2**	**SM2**		**H2**	**H3**	**M1**	**M2**	**SA2**	**SH1**	**SH2**	**SM2**		
Kubsa	41.72	1.50	16.38	79.71	9.63	10.63	25.25	94.92		42.52		5.46	25.9	12.38	7.28	12.29	83.91		
Galema	30.25	3.50	0.50	17.34	0.75	7.75	16.42	20.06		2.81	0.67	0.25	4.51		1.88	6.10	0.50		
Kubsa and Galema (K&G)	71.97	5.00	16.88	97.06	10.38	18.38	41.67	114.98	**376.30**	45.33	0.67	5.71	30.41	12.38	9.16	18.39	84.41	206.46	**-169.8**
Millennium [3]	0.25			0.75			1.00	0.63		1.25	0.38	0.5	0.13			0.06			
Shina	3.75				0.25		0.75									0.25			
Wabe	0.25			2.25		3.88	4.38	0.50							1.13	5.51			
Tusie	34.5	1.25		50.95		0.5	8.88	0.13		12.9	0.88		9.41			5.38			
Simba	5.19	1.50			2.88	5.63	2.94	2.38		0.38					1.63	0.50	1.31		
Hawii	0.75			1.25			5.25	3.31								13.27	0.50		
Sof-omur	1.63	0.63				1.56	0.13						0.5			1.13			
Dashen	5.63		0.25	39.31			15.31	9.81		1.63			13.87	0.25		8.53	7.16		
Enkoy	0.63		0.75	5.00		0.25	1.50	5.88											
Total area under AEZ	**128.16**	**8.38**	**17.88**	**196.56**	**13.5**	**30.19**	**81.80**	**138.11**	**1278.34**	62.24	1.93	6.21	56.32	12.63	11.92	53.02	93.88	1157.14	
Share of K& G (%)	56	60	94	49	77	61	51	83	29	73	35	92	54	98	77	35	90	18	**-12**

H2=tepid to cool humid mid-highlands; H3=cold to very cold humid sub-Afro-Alpine; M1=hot to warm moist lowlands; M2=tepid to cool moist mid-highlands; SH1=hot to warm sub-humid lowlands; SA2=tepid to cool semi-arid mid highlands; SH2=tepid to cool sub-humid mid highlands; SH2=tepid to cool sub-humid mid highlands, and SM2=tepid to cool sub-moist mid-highlands. K & G= Kubsa and Galema varieties.

[3] Millennium is a stem rust resistant variety released in 2007. Due to its single major gene resistance based on *Sr24*, it was not aggressively promoted, as virulence against this resistance gene was acquired by the Ug99 race group in neighboring Kenya.

3.6. Input use in wheat production

A functioning input supply system and better input use are important to boost the production and productivity of the wheat sub-sector. Higher wheat yield depends on various factors like the availability and adoption of improved seed, proper application of recommended fertilizer, and other optimum agronomic practices. In the surveys conducted, farmers were asked about the different inputs they use in wheat production. Sources of improved seed, input use intensity, and level of seed recycling are discussed below.

3.6.1. Sources of wheat seed

The major sources of wheat seed (both improved and local) sown in the 2009/10 and 2013/14 production seasons are summarized in Table 15. In both survey years, the four major sources of seed reported by a large number of farmers were own saved seed, seed purchased from local traders, farmer-to-farmer seed exchange, and seed purchased from farmer organizations such as cooperatives.

Table 15. Major sources of wheat seed sown on plots surveyed in 2009/10 and 2013/14.

Main source of seed	2009/10 (Total area=1,278.4 ha)	2013/14 (Total area=1,157.1 ha)
Own saved seed	880.57	750.84
Local traders	81.62	71.07
Farmer-to-farmer seed exchange	77.65	58.55
Farmer groups / cooperatives	77.63	162.68
Local seed producers	34.44	44.96
District trade	13.69	0
Provided free by NGOs/government	9.81	3.39
Extension demonstration plots	6.38	2.63
Bought from the government	5.86	0
Government subsidy program	5.19	0.13
Gift from family/neighbor	3.5	1.19
On-farm trials	2.13	2.1
Seed company	1.63	0.5
Ministry of Agriculture	1.38	0
Own nursery	0.13	0
Gift from the government	0.13	0
Agro-dealers/agro-vets	0	5.14
Other sources	0	19.53

3.6.2. Input use intensity

On average, wheat farmers growing improved wheat seed used a seeding rate of 183.72 and 192.45 kg/ha in 2009/10 and 2013/14, respectively (Table 16). These figures slightly exceed national recommendations on seeding rates for improved wheat seed (150-175 kg/ha) (Teshome and Abate, 2013) and the seeding rates were significantly ($P<0.05$) higher in 2013/14 than in 2009/10. Fertilizer rates did not change significantly between the two survey periods. DAP use was 101 and 104 kg/ha and Urea use was 89 and 82 kg/ha, respectively, during the 2009/10 and 2013/14 production seasons. On average, at 2.31 l/ha herbicide use was significantly (P<0.05) higher in 2009/10 than in 2013/14, when farmers applied 0.93 l/ha (Table 16).

Table 16. Wheat input use intensity by type of user.

	Wheat input use intensity (input users only)			Wheat input use intensity (input users and non-users)		
Input type	**2009 Mean (SE)**	**2013 Mean (SE)**	**Difference Mean (SE)**	**2009 Mean (SE)**	**2013 Mean (SE)**	**Difference Mean (SE)**
Fertilizer DAP (kg/ha)	117.59 (3.01)	114.97 (2.54)	-2.09 (3.94)	66.93 (1.27)	85.75 (1.18)	18.82 (1.73)***
Fertilizer urea (kg/ha)	83.48 (2.47)	77.88 (5.60)	7.16 (3.04)*	34.05 (1.01)	44.49 (0.99)	10.44 (1.42)***
Seed use rate (kg/ha)				113.00 (1.99)	170.07 (1.62)	57.07 (2.58)***
Improved seed use (kg/ha)	180.99 (2.62)	187.32 (1.82)	6.33 (3.09)**			
Herbicide use (kg/ha)	0.79 (0.03)	0.83 (0.02)	0.04 (0.04)	0.38 (0.01)	0.48 (0.01)	0.10 (0.02)***
Pesticide use (kg/ha)	1.36 (0.19)	0.69 (0.05)	-0.67 (0.18)***	0.03 (0.01)	0.02 (0.01)	0.01 (0.01)
Family labor (person days/ha)	77.73 (0.85)	75.16 (0.83)	-2.58 (1.19)**	73.16 (0.87)	72.67 (1.76)	-0.49 (1.21)

Note: The figures in parentheses are standard errors.

3.6.3. Improved seed recycling practices

Looking at improved wheat varieties in a more conservative way (where only freshly purchased improved seeds and improved seeds recycled for a maximum of five seasons are considered improved seed use), the share of wheat area under improved varieties goes down substantially. However, the use of freshly purchased seed and seeds recycled for ≤ 5 seasons has increased over time (Table 17). For recycled seeds used for more than 5 seasons, the average number of recycling seasons remains at 11 in both surveys.

Table 17. Wheat seed recycling.

Wheat area	**2009/10**	**2013/14**	**Difference**
Total wheat area surveyed (ha)	1,278.34	1,157.14	-121.30
Total wheat area under improved seed (without considering recycled seed use) (ha)	993.21	886.98	-106.23
Total wheat area under improved seed (fresh seed or seed recycled for only ≤ 5 seasons) (ha)	765.78	831.26	65.48
Average number of seasons wheat seed was recycled (if recycled for 5 seasons or less)	2.95	2.55	-0.40
Average seasons unimproved seed was recycled (if recycled for more than 5 seasons)	11.16	11.21	0.05

3.7. Wheat production and productivity

Among the sampled households, about 80 and 87% of the respondents were producing wheat in 2009/10 and 2013/14, respectively. According to CSA (2014), the national average wheat yield increased from 1.83 to 2.45 t/ha over the four years between surveys. Farmers reporting results in this survey show that yield increased from 1.70 to 1.75 t/ha. The number of farmers reporting yield increases from 2009/10 to 2013/14 was not significant (Table 18). In 2013/14, the official average national wheat yield was 2.45 t/ha, with the minimum regional average in Tigray (1.8 t/ha) and the maximum regional average in Oromia (2.75 t/ha) (CSA, 2014). The reasons why the reported survey yields were lower than the official national statistics are unknown, but it should be noted that different methodologies were used; i.e., crop cuts vs. farmer reports.

Table 18. Wheat production and productivity (by year).

	2009/10 (N=2096)	2013/14 (N=1921)	Difference
Wheat producers (No.)	1,669	1,663	
Percentage of wheat producers	80	87	7
Farmer reported yield (t/ha)	1.70	1.75	0.05

3.8. Economic return on wheat production

Normally farmers engage in the production of a crop only if the net returns (i.e., gross returns minus the costs of variable inputs) are higher than those for alternative crops. Crops often compete for limited resources (land, labor) and a rational farmer allocates resources to a certain crop only if it remains relatively competitive (Asfaw et al., 2010). Gross income from wheat is measured as the monetary value of wheat obtained in a particular production season. The variable costs considered include fertilizers, seed (own saved and purchased), chemicals (herbicides and pesticides), labor (hired and family), oxen (hired and own), and the cost of hiring machines like tractors and combine harvesters. Based on the actual reported costs and returns in each survey year, the average gross margin obtained from wheat production was 5,004 birr/ha in 2009/10 and 8,936.71 birr/ha in 2013/14 (Table 19), a highly significant increase ($P<0.001$). Rising input costs were offset by the increased value of wheat and stable labor costs; hence, the return from wheat investments appears to be increasing mainly due to an increase in wheat prices (Table 19).

Table 19. Economic return on wheat production.

Variables	2009 Mean (SE)	2013 Mean (SE)	Mean diff (SE)
Average wheat price (Birr/kg)	4.66 (0.03)	7.02 (0.05)	2.36 (0.06)***
Average yield (kg/ha)	1,701.59 (21.26)	1,752.05 (21.06)	50.46 (29.92)
Gross value (Birr/ha)	9,115.13 (141.52)	14,941.75 (259.03)	5,826.62 (275.48)***
Variable costs			
Seed cost (Birr/kg)	1,040.48 (12.47)	1,276.29 (14.72)	235.81 (19.28)***
Machine cost (Birr/ha)	58.68 (4.28)	185.06 (10.58)	126.38 (11.27)***
Labor cost (Birr/ha)	2,120.44 (42.33)	2,134.29 (36.80)	13.85 (56.12)
Fertilizer cost (Birr/ha)	691.65 (16.60)	1,890.23 (33.22)	1,198.58 (36.76)***
Oxen power cost (Birr/ha)	775.19 (23.58)	787.77 (9.82	12.58 (25.61)
Pesticide cost (Birr/ha)	2.82 (0.48)	6.53 (0.84)	3.70 (0.96)***
Herbicide cost (Birr/ha)	32.62 (1.60)	70.68 (3.17)	38.05 (3.51)***
Total variable cost (Birr/ha)	4,193.25 (40.52)	5,860.15 (48.65)	1,666.90 (63.33)***
Gross margin (Birr/ha)	5,004.06 (137.66)	8,936.71 (250.62)	3,932.65 (266.69)***
Return on investment (B/C ratio)	2.17	2.55	0.38

Note: The figures in parentheses are standard errors.

3.9. Rust epidemics: Occurrence, varietal change and wheat yield

Wheat yields are affected by various abiotic and biotic stresses. Of the biotic stresses, wheat rusts are definitely the most important diseases that reduce wheat yields at the global level (FAO, 2014). The most important wheat rusts, a group of diseases caused by fungal pathogens (*Puccinia* spp.), are stem rust (also called black rust), stripe rust (also called yellow rust) and leaf rust (also called brown rust). Stem and stripe rusts are the major biotic constraints to wheat production in Ethiopia, with frequently recurring epidemics.

In the 2013/14 survey, wheat farmers were asked whether their wheat production was affected by the stripe rust epidemic of 2010/11, and survey results show that 42% of wheat producers were affected (Table 20). Forty percent of the affected households discontinued using (changed) the old wheat varieties and replaced them with alternative wheat varieties in the next production season (Table 20).

Table 20. Percentage of wheat producers affected by rust epidemics (N=1,921).

Were you affected by wheat rust?	Frequency	Percent
No	1,108	57.68
Yes	813	42.32
Total	1921	100
If affected, did you continue to use the same variety the next season?		
No	322	39.61
Yes	491	60.39
Total	813	100

In the 2013/14 survey, famers were asked to recall the actual and expected yield during the rust epidemics (2010/11). Table 21 below shows that the average wheat yield obtained during the stripe rust epidemic was 1.3 t/ha. However, the average expected yield reported by wheat producers under normal conditions was 2.6 t/ha. This implies that the average wheat yield obtained under the stripe rust outbreak was 50% lower than the average expected yield in a normal season.

Table 21. Average actual and expected yield during the wheat rust outbreak of 2010/11.

Yield scenario	Obs	Mean	Std. Dev.	Min	Max
Average expected yield under normal conditions (t/ha)	793	2.57	1.35	0.2	8.1
Average actual yield obtained (t/ha)	793	1.28	0.95	0.0	7.0
Difference (t/ha)		1.28			

4. Conclusions and Implications

The survey results indicate that epidemics caused by new races of rust were a major driver for farmers to change the wheat varieties they grew over the four-year period. Widely grown and productive wheat varieties '*Kubsa*' and '*Galema*' were highly susceptible to the stripe rust races that caused the 2010/11 outbreak. Due to this susceptibility and the promotion of other improved varieties, in the 2013/14 production season a significant area share of wheat was sown with '*Digalu*' and other wheat varieties that were less susceptible to stripe rust or the stem rust races prevailing in 2010. This rapid varietal change conferred immediate advances against rusts and provided significant gains for farmers, but large-scale cultivation of '*Digalu*', whose stem rust resistance is based on the single major gene *SrTmp,* created vulnerability to the stem rust race TKTTF that appeared in 2012 and resulted in localized but severe stem rust outbreaks on '*Digalu*' in 2013/14 and 2014/15. This dynamic disease situation highlights the challenges faced by Ethiopian wheat growers and emphasizes the need for diverse wheat systems that include cultivars whose resistance is race-non-specific and therefore more durable. Among the eight AEZs surveyed, SH1 (hot to warm sub-humid lowlands) and H2 (tepid to cool humid mid-highlands) were the two where major shifts to rust resistant varieties were observed. Both AEZs have environments that are highly suitable for wheat rust development, with stem rust favoring the warmer lowland environment and stripe rust the cooler highland environment.

The current comparative study found widespread and rapid turnover of wheat varieties within a four-year period. A major stripe rust epidemic in 2010/11 was undoubtedly a key driver of change, but effective promotion and widespread availability of seed of alternative rust resistant varieties were also important. Recent investments to support varietal development and promote resistant varieties undoubtedly played a role in making the observed, rapid varietal changes possible. Wheat farmers in Ethiopia benefited from the varietal changes, which resulted in productivity gains and increasing incomes. However, the risks of over-reliance on a widely sown variety protected by a single, major resistance gene – *'Digalu'* in this instance – in the rust prone Ethiopian farming system are clearly apparent. While maintaining good resistance against prevailing stripe rust races, '*Digalu*' is now highly susceptible to stem rust race TKTTF, and considerable efforts are underway to replace it with a new variety whose resistance is more genetically complex and durable.

A limitation of the current study is that it relied solely on farmer recall for both varieties grown and yields obtained. For both attributes it was impossible to estimate the accuracy of the information recalled by farmers. There were indications that yields reported by farmers were much lower than official statistics derived from crop cuts. DNA fingerprinting studies are planned to better document varietal use and turnover.

In terms of policy to improve wheat production, the current study shows that rapid varietal replacement is possible in Ethiopia, but it must be done in a concerted, coordinated, and strategic manner. Emphasis should be placed on ensuring that a genetically diverse range of varieties are made available farmers. As much as possible, a range of varieties whose rust resistance is race-nonspecific should be deployed and single major gene-based resistance should be avoided. Durable rust resistant varieties should be targeted to the most rust-prone agro-ecologies. Continuous monitoring of the rust populations in Ethiopia and the surrounding region is essential to detect emerging threats as soon as possible and ensure that important races are used for screening by breeding programs to test and develop new improved resistant varieties.

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Annexes

Tables

Table A1. Key to 18 AEZ classifications.

Code1	Code2	Legend
A1	5	Hot to warm arid lowland plains
A2	12	Tepid to cool arid mid highlands
H1	6	Hot to warm humid lowlands
H2	13	Tepid to cool humid mid highlands
H3	1	Hot to very cold humid Sub-AfroAlpine
M1	7	Hot to warm moist lowlands
M2	14	Tepid to cool moist mid highlands
M3	2	Cold to very cold moist Sub-AfroAlpine
SA1	9	Hot to warm semi-arid lowlands
SA2	16	Tepid to cool semi-arid mid highlands
SH1	10	Hot to warm sub-humid lowlands
SH2	17	Tepid to cool sub-humid mid highlands
SH3	3	Cold to very cold sub-humid sub-AfroAlpine
SM1	11	Hot to warm sub-moist lowlands
SM2	18	Tepid to cool sub-moist mid highlands
SM3	4	Cold to very cold sub-moist sub-AfroAlpine

Table A2. National wheat area and production and share of the major wheat producing regions.

Region	Producer	Area (ha)	Production (t)	Yield (t/ha)
National	4,746,231	1,605,654	392,5174.1	2.45
Tigray	399,300	112,819	205,033.3	1.82
Amhara	1,741,886	529,649	1,119,991.3	2.12
Oromia	1,948,739	837,000	2,302,851.4	2.75
SNNP	635,958	118,349	2,816,85.6	2.38
Total of the four regions	4,725,883	1,597,817	3,909,561.7	2.45
Share of the four regions (%)	99.57	99.51	99.60	

Source: CSA (2014) data.

Table A3. Average wheat productivity by AEZ (kg/ha).

AEZ	2009/10	2013/14
H2	1,986.85(1161.94)	2,049.47 (1179.35)
H3	1,916.50 (1221.19)	2,078.37 (1073.98)
M1	982.76 (581.55)	1,707.73 (1459.85)
M2	1,550.73(1065.97)	1,593.47 (1002.90)
SA2	2,190.83 (1284.55)	2,000.66 (743.11)
SH1	1,581.31(1241.60)	1,490.96 (978.80)
SH2	1,608.20 (917.00)	1,671.67 (932.69)
SM2	1,770.88(1224.75)	1,775.05 (1268.70)
Total	**1,690.02** (1131.56)	1,750.01(1136.15)

Note: The figures in parentheses are standard deviations. For the AEZ codes, refer to Table A1.

Table A4. Average wheat productivity by zone for CSA and own survey data (kg/ha).

	2009/10		2013/14	
Zone	**CSA**	**Own survey**	**CSA**	**Own survey**
Central Tigray	2,006	2,110.9	1,875	1,653.0
Eastern Tigray	1,961	1,741.3	1,454	1,249.4
Southern Tigray	1,854	2,290.5	2,021	2,521.3
South Eastern Tigray	*na*	1,289.1	*na*	1,479.5
Awi	1,367	1,311.6	2,134	1,475.0
East Gojjam	1,695	1,906.8	2,266	1,721.6
North Wollo	1,341	1,353.5	1,814	1,453.3
North Gondar	1,949	1,338.1	2,400	975.9
North Shoa	1,763	1,656.8	2,335	1,891.6
South Gondar	1,714	1,617.5	1,754	1,350.7
South Wollo	1,414	1,226.4	1,942	1,200.7
West Gojjam	1,710	2,219.0	2,332	1,724.7
Arsi	2,194	1,920.8	3,030	2,155.2
Bale	2,319	1,511.1	2,923	2,438.7
East Shoa	1,777	2,021.0	3,070	2,122.0
Finfine Zuria	*na*	1,254.0	*na*	1,067.0
Guji	1,201	1,056.4	2,508	780.5
Jimma	1,421	1,498.6	1,703	1,379.6
North Shoa	1,325	1,013.0	2,349	1,765.1
South West Shoa	1,960	1,464.7	2,639	1,240.1
West Arsi	2,146	2,200.3	3,313	2,178.6
West Shoa	1,826	1,594.4	2,418	1,508.0
Gurage	2,126	1,678.7	*na*	1,832.7
Hadiya	1,874	2,072.2	2,486	1,928.0
Halaba	2,324	1,263.5	2,721	1,941.7
Kambata Tembaro	1,738	1,487.1	2,606	1,132.8
Sidama	1,824	1,351.7	*na*	1,291.2
Yem	1,381	1,220.7	1,756	1,202.3

na=data not available.

Table A5. Comparing average wheat yield (kg/ha) for CSA and survey data (2009/10).

Variable	Obs.	Mean	Std. Err.	Std. Dev.
CSA	26	1,777.3*	62.3	317.5
Own survey	26	1,620.3	72.9	371.9
Difference	26	157.0	70.5	359.6

*T-value=2.22; * significant at 5%.*

Table A6. Comparing average wheat yield (kg/ha) for CSA and survey data (2013/14).

Variable	Obs.	Mean	Std. Err.	Std. Dev.
CSA	24	2327.0*	98.3	481.5
Own survey	24	1624.6	93.5	458.2
Difference	24	702.5	99.5	487.3

*T-value=7.06; * significant at 1%.*

Table A7. Comparing mean yield of each surveyed zone with mean yield of CSA data (2013/14).

Zone	CSA	Own survey	Difference	t-value
Arsi	3,030	2,155.2	874.8	15.92
Awi	2,134	1,475.2	659.0	5.39
Bale	2,923	2,438.7	484.3	3.29
Centeral Tigray	1,875	1,653.0	222.0	1.19
East Gojam	2,266	1,721.6	544.4	6.22
East Shoa	3,070	2,122.0	948.0	11.92
Eatern Tigray	1,454	1,249.5	204.5	2.17
Finfine Zuria	*na*	1,176.3		
Guji	2,508	780.5	1,727.5	22.94
Hadiya	2,486	1,928.0	558.0	4.03
Halaba	2,721	1,941.7	779.3	2.91
Jimma	1,703	1,379.6	323.4	2.95
Kambata Tembaro	2,606	1,132.8	1,473.2	8.69
North Gonder	2,400	975.9	1,424.1	13.24
North Wollo	1,814	1,453.3	360.7	3.43
Northsh_Amhara	2,335	1,891.6	443.4	3.79
Northsh_Oromo	2,349	1,765.1	583.9	3.79
Sidama	*na*	1,322.2		
South Est Tigray	*na*	1,415.0		
South Gonder	1,754	1,350.7	403.3	5.17
South West Shoa	2,639	1,240.1	1,398.9	14.46
South Wollo	1,942	1,200.7	741.3	19.30
Southern Tigray	2,021	2,521.3	-500.3	2.52
West Shoa	2,418	1,507.97	910.0	11.70
West Arsi	3,313	2,178.58	1,134.4	19.36
West Gojam	2,332	1,724.74	607.3	2.43
Yem	1,756	1,202.34	553.7	4.69

Table A8. Farmer reported variety names and their area share in 2009/10 and 2013/14.

2009/10				2013/14			
No.	Variety	Area (ha)	Area share (%)	No.	Variety	Area (ha)	Area share (%)
1	Kubsa	395.09	30.91	1	Digalu	324.45	28.04
2	Galema	119.70	9.36	2	Kubsa	212.84	18.39
3	Tusie	117.64	9.20	3	Danda'a (Danphe)	67.73	5.85
4	Dashen	87.99	6.88	4	Kakaba (Picaflor)	62.02	5.36
5	Mada-Walabu	64.44	5.04	5	Pavon-76	47.69	4.12
6	Pavon-76	42.94	3.36	6	Dashen	37.70	3.26
7	Filatama	42.19	3.30	7	Tusie	30.07	2.60
8	Digalu	31.30	2.45	8	ET-13	26.84	2.32
9	ET-13	23.94	1.87	9	Galema	19.71	1.70
10	Simba	21.13	1.65	10	Mada-Walabu	16.16	1.40
11	Key	20.56	1.61	11	Hawii	13.77	1.19
12	Enkoy	20.16	1.58	12	Wabe	8.78	0.76
13	Israel	18.13	1.42	13	Kenya	8.55	0.74
14	Dushre	15.14	1.18	14	Roma	6.20	0.54
15	Triticale	13.50	1.06	15	Bobitcho	4.50	0.39
16	Hawii	12.06	0.94	16	Simba	3.82	0.33
17	Wabe	11.25	0.88	17	Rusia	2.63	0.23
18	Bonde	9.72	0.76	18	Millennium	2.32	0.20
19	K6290-Bulk	9.63	0.75	19	Gurati	2.26	0.20
20	Mirt zer	8.31	0.65	20	Legamo	2.00	0.17
21	Jegole	6.38	0.50	21	Sof-Oumer	1.88	0.16
22	Abesha	6.28	0.49	22	Misoma	1.88	0.16
23	America	6.25	0.49	23	Filatama	1.75	0.15
24	Sof-Oumer	5.63	0.44	24	Israel	1.50	0.13
25	Kulilit/kulkulit	5.63	0.44	25	Holland	1.50	0.13
26	Tikur	5.60	0.44	26	Shamame	1.26	0.11
27	Gojame	5.31	0.42	27	Dure	1.25	0.11
28	Shemet	5.25	0.41	28	Techenker	1.12	0.10
29	Nech Sinde	5.25	0.41	29	Tay	1.00	0.09
30	Shina	4.75	0.37	30	Lakech	0.94	0.08
31	Millennium	4.63	0.36	31	Sirbo	0.75	0.06
32	Techenker	4.50	0.35	32	KGB-01	0.75	0.06
33	yigzaw	4.50	0.35	33	Mirt zer	0.75	0.06
34	Dure	3.88	0.30	34	Obsa	0.75	0.06
35	kurist	3.50	0.27	35	Qamadi	0.64	0.06
36	Fuabel	3.50	0.27	36	Wetera	0.50	0.04
37	Shamame	3.38	0.26	37	Doddota	0.50	0.04
38	Logaw shibo	3.25	0.25	38	Mamba	0.50	0.04
39	Loya	3.25	0.25	39	Dima	0.50	0.04
40	Bulga	3.00	0.23	40	Mabaza	0.50	0.04
41	K 6290-4A	2.75	0.22	41	Nech Sinde	0.44	0.04
42	Legamo	2.75	0.22	42	K6290-Bulk	0.38	0.03
43	Shaham	2.69	0.21	43	Biyadufe	0.38	0.03
44	kinkina	2.50	0.20	44	Menzie	0.32	0.03
45	Magala	2.38	0.19	45	Shina	0.25	0.02
46	Kenya	2.38	0.19	46	Boohai	0.25	0.02
47	Gudle/Gundele	2.38	0.19	47	Mulatu	0.25	0.02
48	Demeto	2.31	0.18	48	FAO	0.25	0.02
49	Salato	2.13	0.17	49	Demeto	0.13	0.01
50	tehire	1.94	0.15	50	Mirte	0.08	0.01
51	Denkeze	1.88	0.15	51	Others	234.15	20.24
52	Canada	1.81	0.14		Total wheat area	1157.14	100
53	Lakech	1.75	0.14				
54	Holland	1.75	0.14				

Table A8. (cont'd).

2009/10				2013/14			
No.	Variety	Area (ha)	Area share (%)	No.	Variety	Area (ha)	Area share (%)
55	Agere	1.75	0.14				
56	Lawa	1.75	0.14				
57	Miruts	1.75	0.14				
58	Gomadle	1.69	0.13				
59	Foka	1.63	0.13				
60	Batu	1.63	0.13				
61	Salelign	1.56	0.12				
62	Komate	1.56	0.12				
63	K6295-4A	1.50	0.12				
64	Bafini	1.50	0.12				
65	Gumedo	1.50	0.12				
66	Hodewa	1.50	0.12				
67	Oromo	1.50	0.12				
68	Anbete	1.38	0.11				
69	Biyadufe	1.25	0.10				
70	Eskirmo	1.25	0.10				
71	Goffa	1.16	0.09				
72	Roma	1.13	0.09				
73	Duragna	1.13	0.09				
74	Babani	1.13	0.09				
75	Hobel	1.13	0.09				
76	Yesher	1.08	0.08				
77	Wasma	1.03	0.08				
78	Arus	1.00	0.08				
79	Extension	1.00	0.08				
80	Kurshit	1.00	0.08				
81	Kindibe Key	0.88	0.07				
82	Tamo adane	0.88	0.07				
83	Fulane	0.88	0.07				
84	Indayi	0.88	0.07				
85	Leliso	0.75	0.06				
86	Gosh Ginbar	0.75	0.06				
87	Shere	0.75	0.06				
88	Rusia	0.75	0.06				
89	Mekole	0.75	0.06				
90	Wetera	0.63	0.05				
91	ferenj	0.63	0.05				
92	Tlian	0.56	0.04				
93	Senkegna	0.50	0.04				
94	Bollo	0.50	0.04				
95	Gurati	0.50	0.04				
96	Ude	0.50	0.04				
97	Asasa	0.50	0.04				
98	Behilu	0.50	0.04				
99	Korcha	0.50	0.04				
100	Borena	0.50	0.04				
101	Kishafa	0.50	0.04				
102	Zembolele	0.50	0.04				
103	Zinde	0.50	0.04				
104	Asase	0.50	0.04				
105	Meto asir	0.50	0.04				
106	Mirte	0.50	0.04				
107	Rasheni	0.50	0.04				
108	Mabaza	0.50	0.04				
109	Bamba	0.38	0.03				
110	Jiru	0.38	0.03				

Table A8. (cont'd).

2009/10				2013/14			
No.	Variety	Area (ha)	Area share (%)	No.	Variety	Area (ha)	Area share (%)
111	Enzosh	0.38	0.03				
112	Enat	0.38	0.03				
113	Atosali	0.38	0.03				
114	Shimagile	0.38	0.03				
115	Sese	0.38	0.03				
116	Arsi-Robe	0.31	0.02				
117	Shay	0.31	0.02				
118	Sirbo	0.25	0.02				
119	Gasay	0.25	0.02				
120	Doddota	0.25	0.02				
121	Yerer	0.25	0.02				
122	Chekole	0.25	0.02				
123	Geja	0.25	0.02				
124	Shage	0.25	0.02				
125	Buruntush	0.25	0.02				
126	Miraku	0.25	0.02				
127	Mulatu	0.25	0.02				
128	Balka	0.25	0.02				
129	Fafane	0.25	0.02				
130	Gallabma	0.25	0.02				
131	Mamba	0.25	0.02				
132	Shimti	0.25	0.02				
133	Furgno	0.25	0.02				
134	Kilinto	0.13	0.01				
135	Kirzaza	0.13	0.01				
136	Gofer	0.13	0.01				
137	Kebetu	0.13	0.01				
138	Gibrina	0.13	0.01				
139	Swed	0.13	0.01				
140	Kumete	0.13	0.01				
141	Misoma	0.13	0.01				
142	Sorge	0.13	0.01				
143	Makorone	0.13	0.01				
144	Geraredo	0.13	0.01				
145	Shetan	0.13	0.01				
146	Arestay	0.13	0.01				
147	Gundersa	0.13	0.01				
148	Abonegir	0.13	0.01				
149	Kuami/Quami	0.06	0.01				
150	Global	0.06	0.01				
151	Bira	0.06	0.00				
152	Menze	0.06	0.00				
153	Arseta	0.06	0.00				
154	Others	6.53	0.51				
Total wheat area		**1278.34**	**100**				

Figures

Spatial Distribution of Common Varieties in 2009/10 and 2013/14

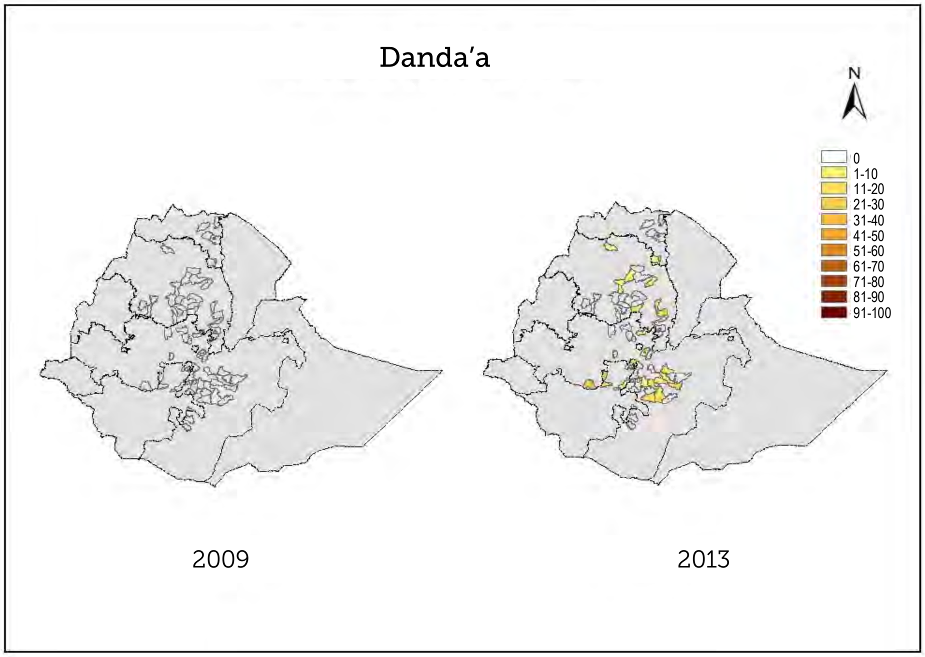

Figure A1. Change in the area sown to the variety *Danda'a* between 2009 and 2013 in the surveyed districts.

Note: Color intensity shows the relative intensity of the wheat variety in each of the specific districts surveyed.

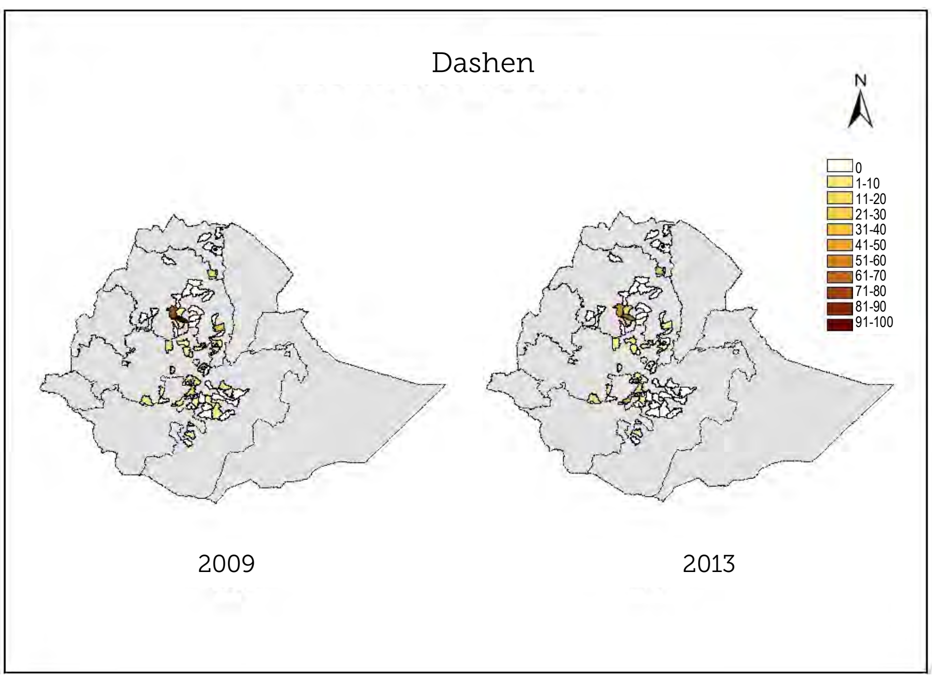

Figure A2. Change in the area sown to the variety *Dashen* between 2009 and 2013 in the surveyed districts.

Note: Color intensity shows the relative intensity of the wheat variety in each of the specific districts surveyed.

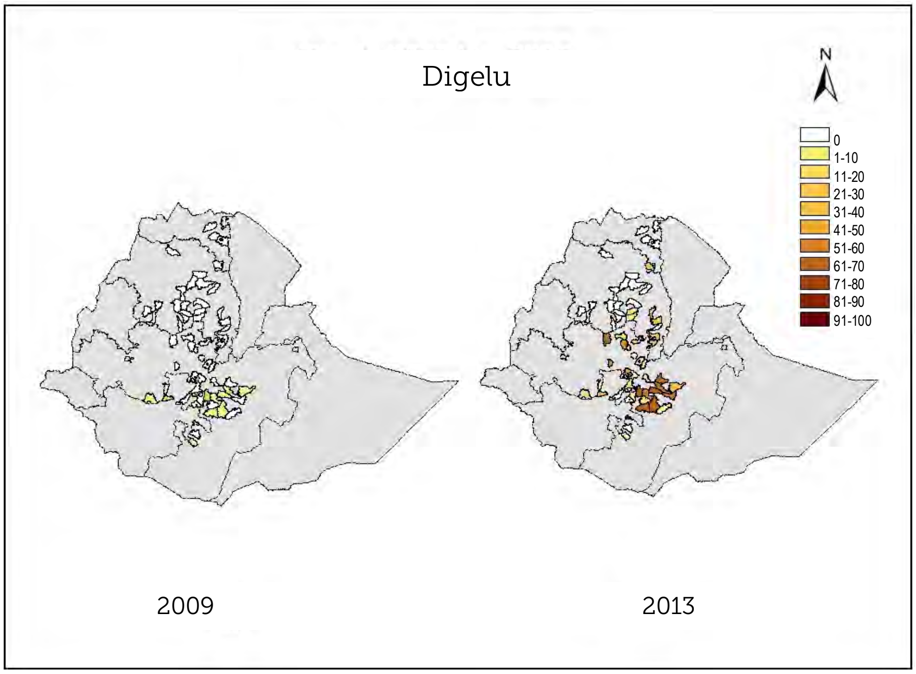

Figure A3. Change in the area sown to the variety *Digalu* between 2009 and 2013 in the surveyed districts.

Note: Color intensity shows the relative intensity of the wheat variety in each of the specific districts surveyed.

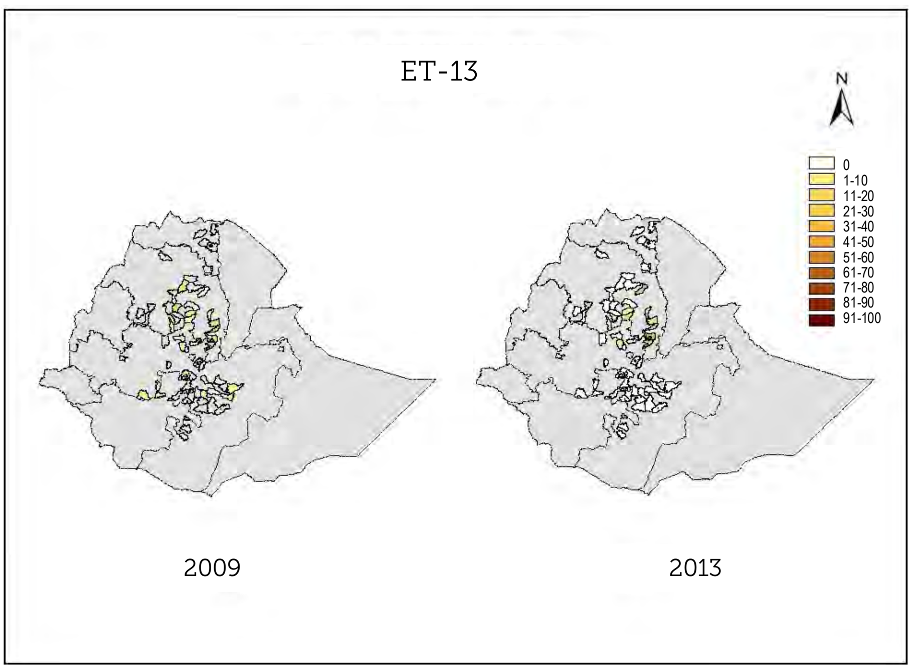

Figure A4. Change in the area sown to the variety ET-13 between 2009 and 2013 in the surveyed districts.

Note: Color intensity shows the relative intensity of the wheat variety in each of the specific districts surveyed.

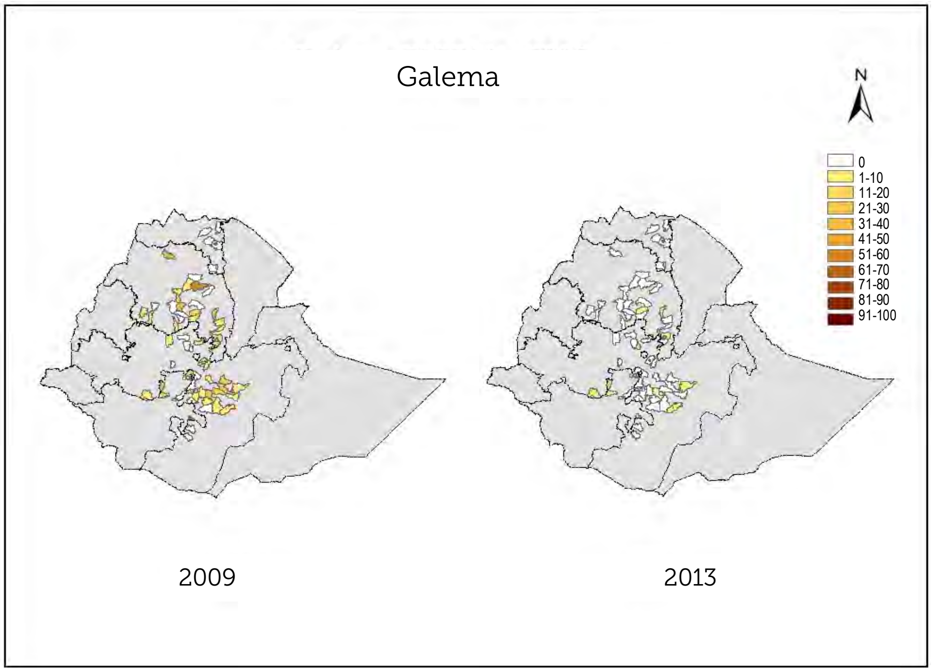

Figure A5. Change in the area sown to the variety *Galema* between 2009 and 2013 in the surveyed districts.

Note: Color intensity shows the relative intensity of the wheat variety in each of the specific districts surveyed.

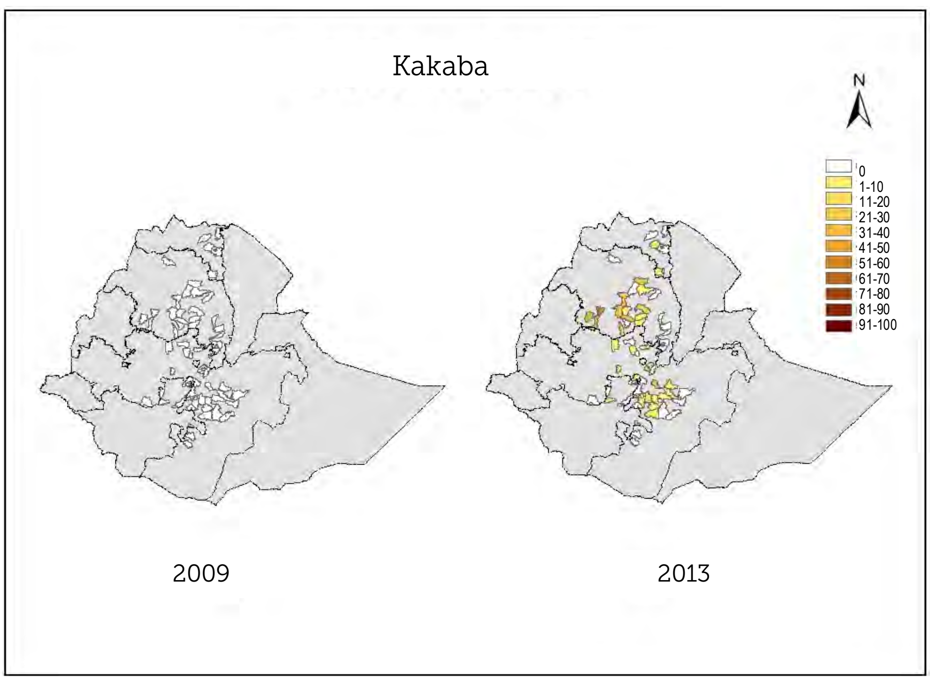

Figure A6. Change in the area sown to the variety *Kakaba* between 2009 and 2013 in the surveyed districts.

Note: Color intensity shows the relative intensity of the wheat variety in each of the specific districts surveyed.

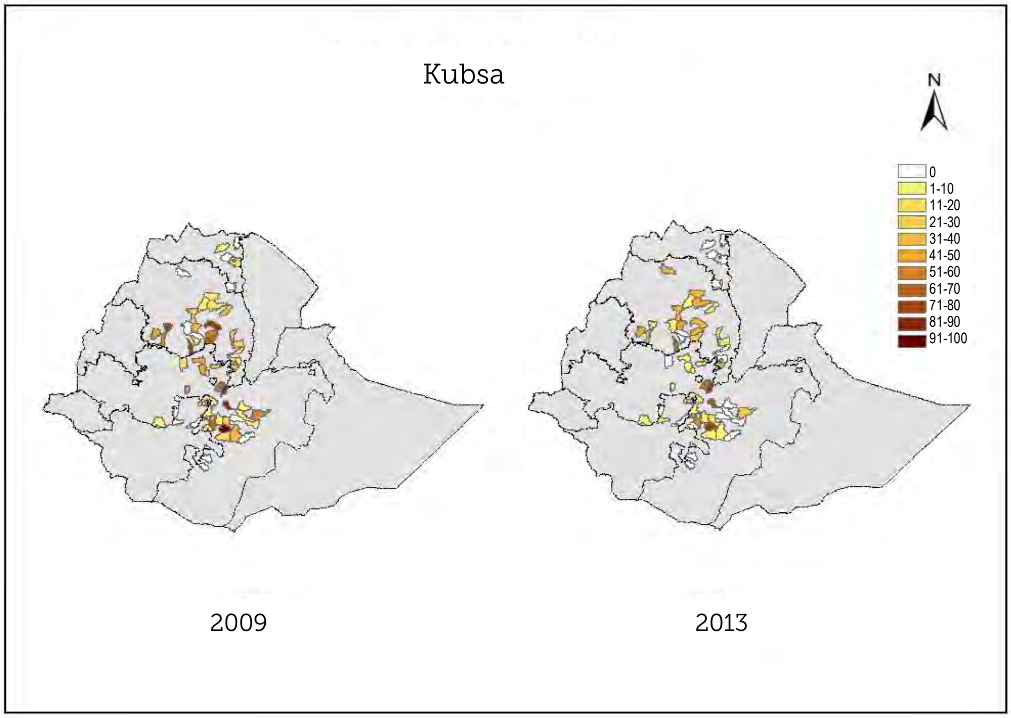

Figure A7. Change in the area sown to the variety *Kubsa* between 2009 and 2013 in the surveyed districts.

Note: Color intensity shows the relative intensity of the wheat variety in each of the specific districts surveyed.

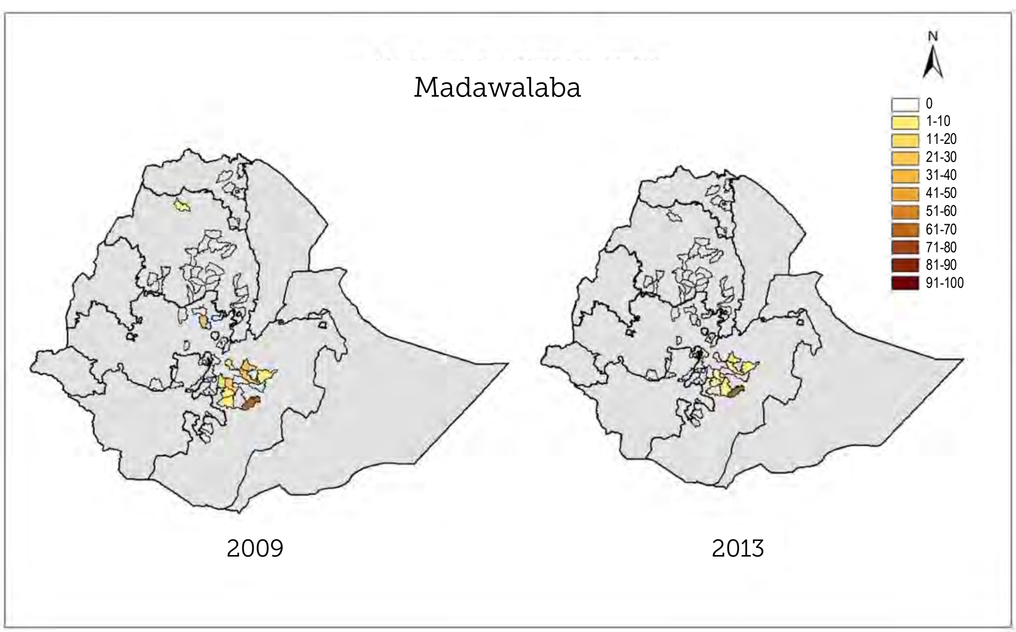

Figure A8. Change in the area sown to the variety *Mada-Walabu* between 2009 and 2013 in the surveyed districts.

Note: Color intensity shows the relative intensity of the wheat variety in each of the specific districts surveyed.

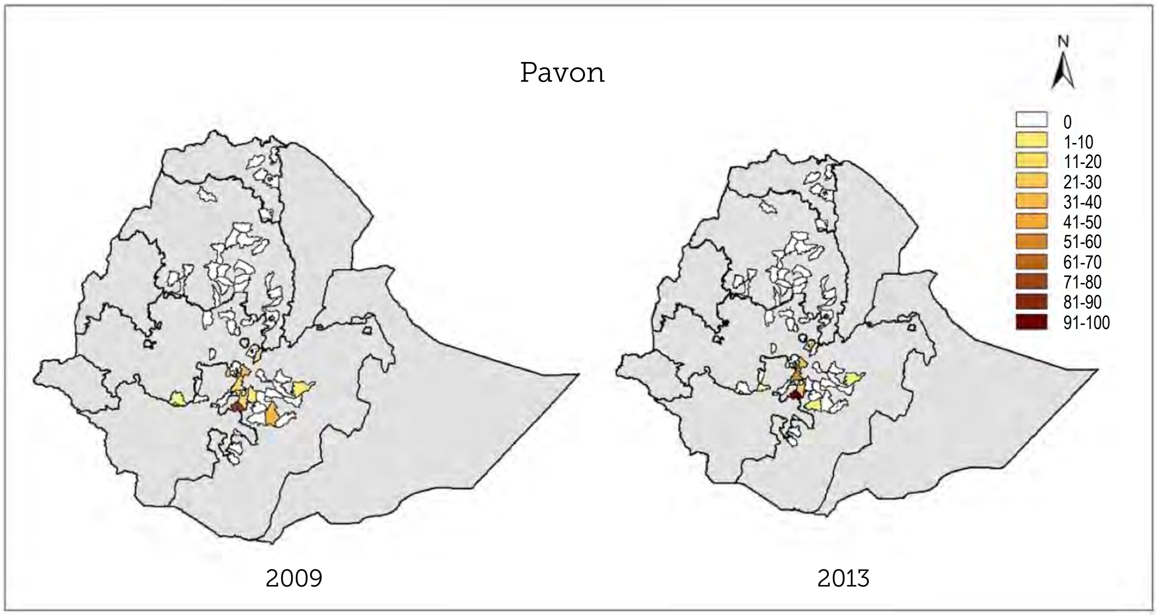

Figure A9.Change in the area sown to the variety *Pavon-76* between 2009 and 2013 in the surveyed districts.

Note: Color intensity shows the relative intensity of the wheat variety in each of the specific districts surveyed.

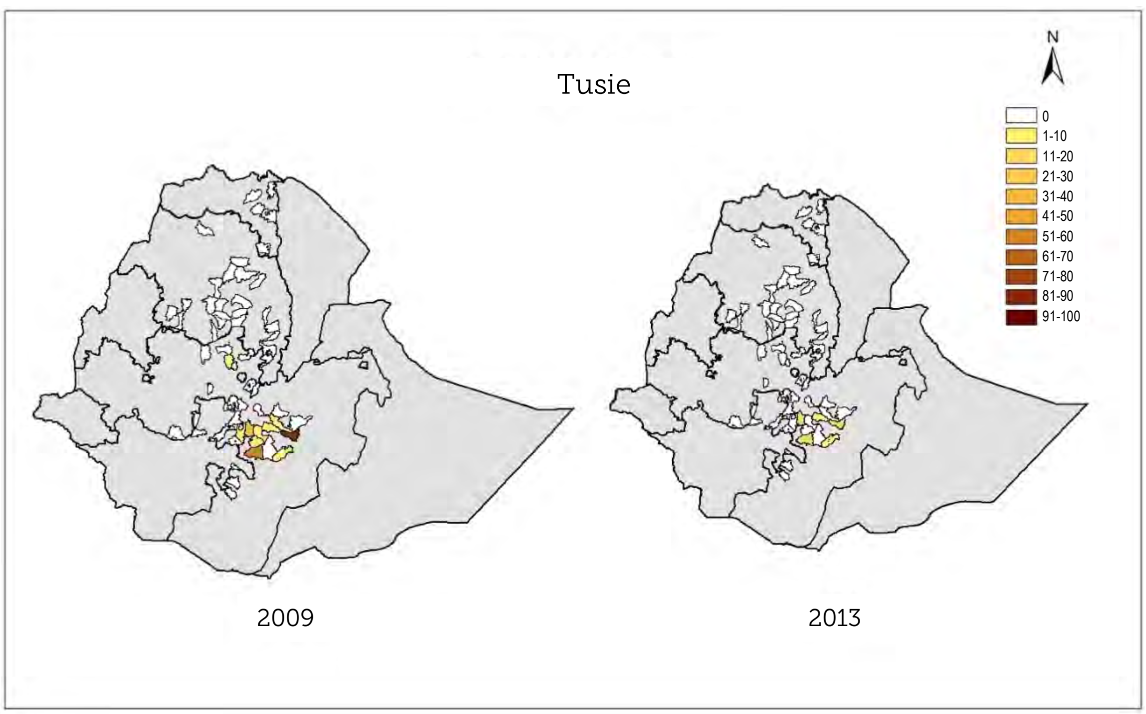

Figure A10. Change in the area sown to the variety *Tusie* between 2009/10 and 2013/14 in the surveyed districts.

Note: Color intensity shows the relative intensity of the wheat variety in each of the specific districts surveyed.

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