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Bridging the yield gaps of bread wheat at a scale through an innovative method of lime application in the acidic soils of Northwestern Ethiopia

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Abstract: Soil acidity is one of the major constraints for crop production in the highland areas. The finding of a 25% lime application method was recommended to amend the problems. This research was carried to increased productivity of wheat and creates wider demands through strengthening linkages among stakeholders and assesses farmer's perceptions. It was implemented in the 2018/19 rainy season at four selected districts of the Amhara region. Farmers' and clusters were selected in collaboration with agricultural extensions. Soil samples were collected and exchangeable acidity was determined. A total of 15.3 tons of wheat seed and 9.2 tons of lime were used which carried on 230 farmers and 102 hectares. Based on the exchangeable acidity one-fourth of lime was applied. The training was given for 288 trainees and field days were organized for 1715 participants for further dissemination. The mean grain yield and marginal rate of return were 4525 kg ha\(^{-1}\) and 252%, respectively; there was a yield advantage of 90.23% compared to the previous year. The overall results showed that the applications of 25% of lime on wheat production were efficient and the real way out for soil acidity problems due to reduced cost and logistics. This research work proved that the technology tremendously increased wheat productivity in the acidic soils and hence; it must be

ABOUT THE AUTHOR

Asmamaw Demil is an Agricultural extension and economics researcher at Adet Agricultural Research center, Amhara Agricultural Research Institute, Ethiopia. He holds a BA degree in Rural Development and Agricultural Extension from Haramaya University in 2013; His overall researches focused on the agricultural extension promotion and dissemination of innovative technologies and assess the adoption and impacts of the technologies on the livelihoods of the community. Asmamaw has practical experiences and solid talents, and believed synergy result in the planning, design, and implementation process with the participation of actors in agricultural extension systems. He is involved in participatory evaluation and selection, demonstration and pre to wider scale-up of agricultural technologies, agricultural marketing and value chains, and gender-based adoption of the technology through organized FREG, FFS groups, and seed multiplication and marketing cooperatives and unions.

PUBLIC INTEREST STATEMENT

In the highlands of Ethiopia soil acidity is the major problem for crop production; though wheat is the most important crop produced by smallholder farmers; due to it has high nutritional value and economic importance. Despite these, the productivity and area coverage of wheat is reduced year to then; because soil acidity causes inhibition of nitrogen fixation and availability of essential nutrients and increased toxicity of elements in the soil. The overall research findings proved that 25% of lime application methods significantly increased the productivity in the acidic soils where production was about impossible in some areas. Ultimately, the innovative application methods come up from the real cause and demands of users which improves crop yield and the physical property of acid soils. Therefore, implementing such best and suiting technologies must be scale wider with the involvement of stakeholders to satisfy the nutritional and food security of citizens.
effectively used in the acidic soils at a larger scales through incorporating in the extension packages to address more farmers to meet the food and nutritional security and improves citizens' livelihoods of the nation.

**Subjects:** Agriculture and environmental sciences; Soil science; Rural development; Gender and development; Plant and animal ecology; Food additives and ingredients; Social work and Sustainable development

**Keywords:** exchangeable acidity; farms clustering; innovation; lime; scale up; soil acidity

1. **Introduction**

Soil acidity is one of the most important and widespread factors which affect plant growth and ultimately limit crop production and profitability in many parts of the world (Fageria, 2009; VAN Straaten, 2007). Large areas of Ethiopia's highlands are affected by soil acidity and low availability of P due to a non-sustainable form of agricultural practices and leaching of the base-forming ions attributed to high precipitation (Melese & Gebrekidan, 2014). It is estimated that about 40.9% of the total arable land of Ethiopia is affected by soil acidity of which about 27.7% is moderately acidic (pH 4.5–5.5) and 13.2% is strongly acidic (pH < 4.5) (Taye, 2007). According to Elias (2016), 80% of Ethiopia's Nitisols are strongly acidic. The problem of acidity is common where precipitation is high enough to leach appreciable amounts of exchangeable bases from the soil surface (Achalu et al., 2012).

Wheat is one of the most important highland cereal crops and used for food and raw material for industries. Ethiopia is one of the largest wheat producer countries in the sub-Saharan Africa (Minot et al., 2019). Mean wheat yield in 10 years was increased from 1.67 t ha⁻¹ in 2006/7 to 2.53 t ha⁻¹ in the 2015/16 (Central Statistical Agency (CSA), 2007; Central Statistics Agency (CSA), 2016). Recent wheat production of Ethiopia was on average 2.3 t ha⁻¹ which showed that 29% below the Kenyan average, 13% below the African average, and 32% below the world average (FAO (Food and Agriculture Organization), 2014). The production yield was well below the experimental yield of over 5 t ha⁻¹ (Mann & Warner, 2015). Thus, Ethiopia's current wheat production is insufficient to meet the domestic demands, challenging the country to import 30–50% of its demand (Minot et al., 2019). In the 2015/16 cropping season, the Amhara region took 32.7% of area coverage and 28.96% production of wheat yield from the national production system. Its productivity (2.24 t ha⁻¹) was also below the national average. The major yield-limiting factors are low soil fertility, low levels of input including fertilizer and quality seed, and soil chemical degradation (soil acidity). Therefore, a serious and present threat has been needed in the highlands of Ethiopia for crop production (Haile et al., 2009).

Moreover, Acid soil is a challenge for crop production in the highlands which affects the growth of crops due to high concentration of acidic cations such as H, Al, Fe, Mn and NH₄⁺ toxicity to plant roots, shoots and inhibit microorganisms activity which influences nutrient uptake and crop growth, lack of response to fertilizers and causes the deficiency of P, Ca, Mg and Mo in the soil; and thus, the negatively charged ions are strongly tied up by the Al and Fe components of acid soils, thereby the leaching of cations and binding of anions becoming unavailable for plant uptake (Abebe, 2007; Caires et al., 2005; Harter, 2007). The low pH affects significantly the fixation and the availability of soil nutrients and the abundance of acidic cations on system colloid soil solution can be toxic to crop growth and leads to reduced crop yield (Asmare, 2014; Zheng, 2010). Besides these consequence, the yield losses of various crops induced by acidity or Al toxicity and associated factors ranged from 25 to 80% (Herrero-Estrella, 2003).

Although liming acidic soils have been suggested an effective measure to amend acidic soils for the growth of crops as it improves nitrogen fixation and availability of essential nutrients (Ca, P and Mo), decreasing the solubility of toxic elements Al and Mn in the soil and enhances root development, water, and nutrient uptakes (Crowford et al., 2008; Marschner, 2011). Research finding of Adet Agricultural Research Center indicated that one and half of exchangeable acidity-based lime
calculation and applying 25% of the value in rows at planting resulted in equivalent yields of the full rate application of lime in broadcasting that makes the finding innovative and cost-effective (Birhanu et al., 2016). Following the finding, plot-level demonstrations were made and greater interests were created for further expansion of the technology. Generally; the problems of low productivity in the highlands were plainness by the wider dissemination of the technology to the users.

Therefore, this research was carried to boost the productivity and production of wheat in the acidic areas by the application of 25% lime rate in rows at planting with fertilizer and other agronomic managements of the crop and also to assess the feat of developed lime application methods and rates on the productivity of wheat in acidic areas at a larger scale through intensive and active involvement of farmers, the research, and the extension system.

2. Materials and methods

2.1. Description of the study areas
The work was conducted at South Gondar (Farta district) and East Gojam zones (Machakel, Gozamen, and Debre Elias districts) highland areas of the Amhara region (Table 1 and Figure 1).

2.2. Planning and team organizing
An organized team of researchers was formed from disciplines of research- extension, soil fertility management, and wheat breeding commodity. The team planned the activities with key stakeholders from the top (regional) level to the lower administrative (kebele) levels. Major Key activities of input provision and distribution, field clustering, training giving, field days organizing, and made a memorandum of understanding for the shared responsibilities to the stakeholders were planned and implemented.

2.3. Research design and farmers’ selection
The work was conducted at 7 Kebeles that is, the smallest administrative unit of Ethiopia with 8 clusters. Purposive selection of each district and Kebeles were made based on crop production problems associated with soil acidity to increase the productivity of wheat, accessibility, and representativeness to promote the technology to other farmers and stakeholders. The criteria of clustering were made based on the willingness of the farmers to implement the technology properly with their recommendation packages.

2.4. Soil sampling and Lime rate (LR) determination
Transect walks were made to identify sites of soil sampling that represent the major landscapes of the clusters. Representative soil samples were taken from each cluster at the depth of 0–20 cm from the upper, middle, and lower parts of the cluster by an auger. Three soil samples per landscape were collected and then mixed to form one composite sample of about 1 kg per landscape per cluster. Simultaneously, undisturbed core samples were collected for bulk density determination by using core sampler. Finally, soil pH, exchangeable acidity, and bulk density were analyzed at the soil laboratory of Adet Agricultural Research Centre. After all, the amount of lime was calculated using the following equation (Birhanu et al., 2016; Demissie et al., 2017).

\[
LR(\text{CaCO}_3 \text{kg ha}^{-1}) = \frac{(\text{Ex.Acidity of the soil} + \text{Bulk Density} + \text{Depth(m)} \times 10^4 \text{m}^2)}{2} \times 1.5
\]

Where LR = Lime requirement of the soil based on exchangeable acidity of the samples (exchangeable aluminium and hydrogen); Ex. Acidity is the exchangeable acidity in cent mole kg\(^{-1}\) of the soil, bulk density g cm\(^{-3}\) and the depth is 0.20 m. Finally, only 25% of the lime found with the above equation was applied at planting in rows as shown below Table 2.
| Characters                          | Machakel (ha) | Farta (ha) | Gozamin (ha) | Debre Elias (ha) |
|-----------------------------------|---------------|------------|--------------|------------------|
| Area of the district              | 107,077       | 121,807    | 75,186       | 116,580          |
| Location                          |               |            |              |                  |
| Latitude                          | 10°19′-10°40′N| 11°02′-12°33′N| 10°20′-10°35′N| 10°14′-10°45′N   |
| Longitude                         | 37°16′-37°45′E| 37°25′-38°43′E| 37°43′-37°71′E| 37°29′-37°38′E   |
| Altitude range (masl)             | 1200–3200     | 1500–4135  | 1200–3510    | 1400–2220        |
| Distance from Bahir Dar (km)       | 102           | 251        | 224          | 247              |
| Annual rainfall range (mm)         | 1500–1900     | 1250–1599  | 1448–1888    | 1200–1600        |
| Temperature range                  | 8°C–24°C      | 9°C–25°C   | 11°C–25°C    | 17°C–27°C        |
| Soil type in %                    |               |            |              |                  |
| Nitisol                            | 65            | 72         | 50           | 85               |
| Vertisol                           | 21            | 18         | 20           | 0.5              |
| Brow mixed                         | 14            | 10         | 30           | 14.5             |
| Exchangeable acidity (centimol kg⁻¹)| 3.27          | 1.15       | 0.35–1.04    | 0.57–0.78        |
| Agro ecology in %                  |               |            |              |                  |
| Lowland                            | 25            | 9          |              | 51.9             |
| Mid highland                       | 4             | 30         | 75           | 48.1             |
| Highland                           | 96            | 45         |              | 16               |
| Farming system                     | Mixed (crop-livestock) | Mixed (crop—livestock) | Mixed (crop-livestock) | Mixed (crop-livestock) |
| Dominant crops produced in the districts | Maize, Triticale, tef, wheat, potato, oat, noug, lupine and barley | Barley, Triticale, tef, potato, maize, wheat, oat, faba bean, field pea and noug | wheat, tef, maize, potato, triticale, barley, oat and faba bean | Wheat, maize, tef, faba bean, noug, barley, potato and field pea |

Sources: Districts office of agriculture, 2019
2.5. Inputs supplied and distribution
Supplying of lime and seed from different sources were arranged. A total of 9.20 tons of lime was used and it was supplied from Dejen lime factory. Three improved wheat varieties: 5.7 tons TAY, 5.1 tons Kekaba and 4.5 tons of Ogolcho were used.

2.6. Training
The training was prepared based on the needs and gaps were assessed from farmers, DAs, and experts. It was given for a total of 288 (18.4% female) trainees focusing on soil acidity and its reclamation methods mainly on lime as well as wheat production systems (Figure 2) shown below. Side by side leaflets and posters were distributed for wider understandings of the community about soil acidity problems and reclamation mechanisms

2.7. Implementation phase (Field Management practices)
Farms were plowed as per the recommendation for wheat that is 4–6 times on average with oxen draft power. A seed rate of 150 kg ha⁻¹ was used in rows. TAY, Ogolcho, and Kakaba varieties were used at Farta and Machikel, Debre Elias, and Gozamen, respectively. A fertilizer rate of 121 kg ha⁻¹ NPS and 261 kg ha⁻¹ Urea (in nutrients N = 1 38 kg ha⁻¹, P₂O₅ = 46 kg ha⁻¹, and sulfur (S) = 7kg ha⁻¹) were used. The whole recommended amount of NPS fertilizer was applied at planting while Urea was applied to two splits, one-third at planting and the other two-third at about 4 weeks after planting. Lime was applied at planting in rows. Planting date for Farta was from June 13 to 15 for Machikel and Debre Elias from July 17 to 19 and for Gozamen from July 24 to 26/2018. Tilt chemical was used once spray against yellow rust. Harvesting at Debre Elias and Gozamen was by combine harvester while for the rest of the districts were manually harvested.
Table 2. Average pH, exchangeable acidity and lime rate applied at each cluster of the study site, 2018

| No | Parameters | Machakel | Farta | Gozamen | Debre Elias |
|----|------------|----------|-------|----------|-------------|
|    |            | D/kelmo  | Sahirna | Yenebirna | Chimbor | Kebi | Dejiba | Genet |
| 1  | No of soil samples taken | 26 | 18 | 16 | 20 | 17 | 16 | 16 |
| 2  | Soil pH of samples | 5.30 | 5.65 | 5.72 | 5.59 | 5.62 | 5.17 | 5.38 |
|    | Higher pH | 5.76 | 5.16 | 5.46 | 5.03 | 5.29 | 4.77 | 4.79 |
|    | Lower pH | 5.04 | 5.36 | 5.59 | 5.29 | 5.54 | 5.05 | 5.12 |
| 3  | Ex. acidity centimol (kg⁻¹ of the soil) | Minimum Ex. Acidity | 1.772 | 0.334 | 0.112 | 0.168 | 0.152 | 0.172 | 0.304 |
|    | Maximum Ex. Acidity | 4.888 | 2.226 | 0.821 | 1.856 | 1.086 | 1.256 | 0.898 |
|    | Ex. Al | 3.232 | 1.179 | 0 | 1.352 | 0.590 | 0.376 | 0 |
|    | Ex. H | 1.656 | 1.047 | 0.821 | 0.504 | 0.496 | 0.880 | 0.898 |
|    | Average Ex. Acidity | 3.268 | 1.153 | 0.345 | 1.036 | 0.471 | 0.776 | 0.566 |
| 4  | Bulk Density (g cm⁻³) | Minimum BD | 1.092 | 1.141 | 1.364 | 1.101 | 1.281 | 1.411 | 1.432 |
|    | Maximum BD | 1.528 | 1.448 | 1.966 | 1.346 | 1.595 | 1.496 | 1.496 |
|    | Average BD | 1.23 | 1.32 | 1.61 | 1.21 | 1.35 | 1.62 | 1.45 |
| 5  | Lime requirement rate (kg ha⁻¹) | 6357.89 | 2420.5 | 2418.18 | 3122 | 2598 | 2829 | 2220 |
| 6  | 25% of lime rate applied (kg ha⁻¹) | 1589 | 606 | 605 | 781 | 650 | 708 | 560 |

Note: BD- Bulk Density; Ex- exchangeable Aluminum, Hydrogen
2.8. Share of responsibilities among the stakeholders
Technology transfer and dissemination with the collaboration and networks of stakeholders play pivotal roles in spreading innovation by increasing the share of resources, knowledge, and experiences (Davis et al., 2015) and also agricultural innovation systems require strong linkage between research and extension organizations in particular, and among the various actors engaged in the agricultural sector in general (Deneke & Gulti, 2016). According, to these roles and responsibilities, it was properly designed for each stakeholder as stated below.

2.8.1. The research system
Adet Agricultural Research Center was responsible to coordinate the entire activities as the centre is the owner of the technology. Accordingly, the centre played key roles for input supply (lime and improved seed), organized training, field days, soil sampling, analysis, and determination of the lime rate, data collection, and analysis.

2.8.2. Farmers
Farmers were responsible to use the technology with its full packages of fertilizer, weeding, and other management with their expenses. They were also actively participated to draw the strengths and drawbacks of the technologies to improve the productivity of wheat and the roles of stakeholders’ participation for further expansion of the technology.

2.8.3. Bureau of agriculture
The Bureau of agriculture is one of the organized systems that have a structure and enough manpower up to the lowest administrative unit (Kebele) level. Therefore, its role was in mobilizing the farmers to increase the yield and improves crop management during the planning, clustering, training, planting, monitoring, and evaluation and field days as well as evoking for further disseminations of the technology to other farmers and districts.

2.9. Joint Monitoring and Evaluation (M and E)
Team of researchers and major key stakeholders were jointly monitored and evaluated the work at different stages of the crop. The effect of lime, farmers’ perception, and associated challenges were assessed. These achievements were done based on ICRA (2010) number of efforts were made to improve the technology transfer system and linkages between different partners like research, extension, farmers, and other stakeholders.

2.10. Extension approaches used for technologies disseminations
Participatory extension research approaches were followed and innovation platforms (IPs) were comprised of the actors who worked in collaboration to perform responsibilities between the research and extension (higher to lower levels). These approaches were effectively used to enhance stakeholders’ engagement for joint planning, implementation, and monitoring and
evaluations. Farmers to farmers’ experience sharing were used for strategies and a means of wider spreading of the new technology and incorporating their indigenous knowledge of farmers. Group discussion per each cluster was held twice a month to solve the technical and managerial problems of farmers on time. These were done according to (Adefris Tiwold, 2011; Spielman et al., 2011) target of all actors creates an efficient interface it needs to have purposive and strong institutional linkages between the research system and extension. During these activity implementations, different systems and approaches were done as follows.

2.10.1. Clustering approaches
were implemented for the improvement of farmers to farmers’ relationship, increases experts and farmers’ linkage as well as monitoring and evaluation activities. It makes positive competition among and between farmers for easy of technology transfer, easy for harvesting, and threshing by combiners due to the same variety used and uniformly matured. It helps for pure seed production as well as to take corrective action measures on time. These approaches were done due to cluster approach is preferred and it helps to create competition among farmers in field management, pest and disease management, and control. Moreover, it attracts the eyes of neighbor farmers and inspires them to ask, observe, and finally to accept the technologies (Mihiretu & Abebaw, 2020; Porter, 1998).

2.10.2. Mobilization of farmers for starting one-day planting
Farmers were mobilized for planting with the same date at a cluster-based for the standard of uniformity, improves farmers motivation, easy addressed technical support to farmers, encourages experience sharing between them and crop matured at the same periods which kept within a cluster as shown in below Figure 3.

2.10.3. Monthly discussion and sharing of experiences between farmers
For the improving of shared experiences from the best performance and fallers, makes positive competition in good practices, problem identification, and made corrective actions by themselves and increases farmers’ linkage between cluster groups. These implementation extension approaches achievement agreed to the finding of Glenna et al. (2011) farmer to farmer experience sharing might be important due to economically efficient for the knowledge transfer and assessment of technology effectiveness.

2.10.4. Exchange visit
Farmers have got experience from other areas on different crops cultivation systems and adopted technologies. The main roles of visiting other areas are to improve the knowledge and the attitude of farmers for the involvement of new technologies for the next scale up implementation.

2.11. Field days
Field day is an event usually organized and opened to key stakeholders so that fast and effective technology transfer could be achieved (Asmelash, 2014; EJAR/JJCA, 2015; Maina & Gowland-Mwangi,
2014). A total of 13 field days were prepared for the participation of 1715 (26.4% female) people at different stages of the crop including policymakers were involved for further dissemination and wider understandings of the technology as shown below (Table 3 and Figure 4)

2.12. Technology promotion on the pre-scaling up activities
Extension promotion materials like posters, leaflets, lime application manuals, power points, and banners about the technologies were used. Generally, 520 leaflets and posters were distributed for further technology adoption and dissemination. Acidic soil management practices during planting and field day events were made by both district communication offices and broadcasted by Amhara TV and radio programs for wider demand creation to the community within and outside the intervention areas. This was done according to the study of Aflakpui (2007) the use of different means to transfer information about agricultural technologies or best practices, such as written materials (brochure, leaflets, pamphlets, manuals, journals, and proceedings), workshops, training, demonstration, and field days.

2.13. Types and sources of data collection
Qualitative and quantitative social data, as well as crop yield, were collected. Farmers' and experts' perceptions were collected by semi-structured questionnaires to assess satisfaction levels. Secondary data including published and unpublished information about acidic soil management and bread wheat were collected. Primary data were generated from host farmers through interviews, focus group discussions, and field observations.

2.14. Data analysis
Descriptive statistics including mean, minimum, maximum, percentage, standard deviation were computed using SPSS software. Qualitative data were described and summarized. The perception of farmers' satisfaction was rated by Likert scale measurements.

3. Results and discussions

3.1. Training gap and need assessment analysis
The results of need assessment and gap analysis gathered from farmers, development agents, and district experts indicated that Kekaba, Ogoicho, and TAY were preferred bread wheat varieties at Gozamen, Debre Elias, and (Machakel, and Farta) districts, respectively. Farmers were experienced to mix fertilizer with seed and applying together (all respondents) in the East Gojjam zone that was expected to reduce the efficiency of fertilizer and improved seed. Moreover, the respondents response results are top dressing of nitrogen fertilizer used (Yes (18.7%) and No (81.3%), row planting of wheat (Yes (52.6%) and No (47.4%) this gap is higher at Machakel and Farta districts on the other hand at Debre Elias and Gozamen districts almost all respondent farmers used for row application of wheat, row application of lime, and lime applications at plantings (Yes (2.6%) and No (97.4%) this showed almost all are not used by the community. These were the priority knowledge, skill, and technological gaps identified to be addressed. Accordingly, training was given based on the priority gaps and that was the main reason for the great achievement we made. This argument in line with Kassa (2005) who stated that assessment of farmers' problems, identify appropriate information and feasible technologies for their localities and facilitate a co-learning process both for themselves and for farmers and also Sajeev and Singha (2016) and Jacob and George (2013) they said that training is an organized activity designed to enhance the knowledge, skill, and competencies of persons for improving performance and working efficiency for attaining the required technologies.

3.2. Household characteristics
The participant farmers (230 in number) composed of 96.5% male and 3.5% female-headed households. The reason is the numbers of female-headed farmers in the selected cluster were small; but the participation of female-headed and the wives of male-headed farmers were included during training, evaluation, focus group discussion, and field day events for the wider
Table 3. Summary of the field days participants, 2018

| Organization  | Farmers | Experts | Others | Sum |
|---------------|---------|---------|--------|-----|
|               | M       | F       | T      | M   | F   | T     | M   | F   | T     |
| Research      | 144     | 51      | 195    | 93  | 10  | 493   | 102 | 10  | 112   | 339 | 71  | 406   |
| District level| 433     | 160     | 593    | 124 | 36  | 160   | 48  | 7   | 55    | 605 | 203 | 746   |
| Kebele level  | 504     | 174     | 678    | 18  | 5   | 23    | -   | -   | -     | 522 | 179 | 701   |
| Total         | 1081    | 385     | 1466   | 235 | 51  | 286   | 150 | 17  | 167   | 1466| 453 | 1715  |

Note: M = Male, F = Female and T = Total; Number of field days prepared by research = 2, district office of agriculture = 3 and at Kebele level = 8(at lower level organized during planting, vegetative stage, crop maturity and final yield obtained.)
adoption of innovative technologies for both women and men farmers. 28.9% of the participants were illiterate, 46.1% can read and write, 5.3% of them were having an educational status of 1–4\(^{th}\) grade, 18.4% of them learned 5–8\(^{th}\) grade while the remaining 1.3% of them educated from 9\(^{th}\) grade and above. This indicates a strategy must be designed to deliver new research findings for their fast dissemination including face to face training services. Further results of the study showed that education and the size of landholding have a significant positive relationship with access to agricultural technologies/information (Rehman et al., 2013). However, the level of education does not necessarily reflect their knowledge of agriculture as agriculture is the only means of livelihood inherited through generations.

The participant farmers’ data showed that farmers have owned averagely 2.12 oxen and 1.29 ha cultivated land per household. There is also a land renting system from farmers who are the shortage of animals for draft power and labor and it was about 0.47 ha on average rented in for the 2018/19 cropping season; from this 95.3% participant farmers does not want to apply lime for rented farms due to their cost and more than a year benefit of lime to the farm owners than rented in farmers. Participant farmers used some equine animals (donkeys, horses, and mules) for means of lime transport as shown in Figure 5(b).

The average walking distances from FTC to home and from home to farms were found to be 28.55 and 32.24 min, respectively. These indicating that transportation of lime took more than an hour walking distance (Table 4 and Figure 5). The finding is in line with the study of Kassie et al. (2012) and Hailu et al. (2014) where input adoption and farm income decrease as plot/farm distance increases. The main objective of this study results was aligned to Rao et al. (1993) most of resource poor farmers in the acidic soils are constrained by unavailability, transport, and
Table 4. Household characteristics of the participant farmers

| Parameter                        | Min | Max | Mean | SD  |
|----------------------------------|-----|-----|------|-----|
| Age of participant farmers       | 25  | 68  | 43.69| 9.88|
| Household asset                  | Oxen| 1   | 4    | 2.12| 7.82|
|                                  | Equines| 0   | 2    | 0.32| 0.59|
| Access to information            | Radio/TV| 0   | 1    | 0.22| 0.42|
|                                  | Mobile| 0   | 2    | 0.55| 0.53|
| Total cultivated land per household (ha) | 0.5 | 3.13| 1.29 | 0.54|
| Rented land (ha)                 | 0   | 1.5 | 0.47 | 0.40|
| Walking time from home to the near town (minute) | 30  | 180 | 96.65| 31.36|
| Walking time from home to FTC (minutes) | 5   | 60  | 28.55 | 16.31|
| Walking time from farm to home (minutes) | 5   | 90  | 32.24| 15.35|

Note: Number of samples taken = 76; Min = minimum, Max = maximum, SD = standard deviation

The high cost of bulky dose of lime. Therefore, the innovative of 25% of full dose lime application in rows at planting integrated with other nutrient and agronomic management is vital to cost effective, easy to transport (reduced by 75%), increased number of participant farmers (including resource poor) and pertain in a sustainable reclamation of the acidic soils. In general, the reclamation of acidic soil improves in coverage of area and number of farmers and thus the production and productivity of wheat increased thereby meets the national food security.

This was one of the main reasons that lime was less adopted by the farmers when assumed full amounts lime to be applied to the broadcasted way of application. However, our new application method of lime uses only 25% of the total lime requirement rate that significantly reduced the associated transport costs of lime. The new finding attracts more farmers due to less costly than the former lime rate and also proceeds with a high tremendous increase in yield that could help for the expansion of the technology within a short time-span.

3.3. Major crops and their share of production areas

Soil samples showed in the areas have a high content of exchangeable acidity with pH value that ranges from 4.5 to 5.5. Accordingly due to soil acidity problems; farmers shifted the farming system towards growing crops that are less acidic sensitive including oat, triticale, and lupine at the expense of nutritionally and economically important highland crops as shown below in Table 5. These study aligned with the result of Abate et al. (2017) substantial areas of land covered by barley on the outfields have been replaced by oat and also triticale was another introduced crop which was rapidly replacing the production of various indigenous crop species, as a result of its tolerance of soil acidity. This author also said that the diminishing suitability of the soil for once-popular crops such as barley, faba bean, and field pea and the differential suitability of such soils for acid-tolerant crops such as triticale, oat, and white lupine were another indicators of soil acidity. Similarly, Mosissa (2018) said that recently acid tolerant cultivars such as Walala (sweet lupine), 79 Ab 382 (Tx) 80 SA 94 (food oat), and ETCL-161 (triticale) were identified to perform well on hot spot acidic areas. The other finding reported that in some barley, wheat, and faba bean growing areas of central and southern Ethiopian highlands; farmers have shifted to producing oats and triticale which is more tolerant to soil acidity than wheat and barley (Beyene, 1988; Haile et al., 2009).

As shown in Table 5 above, 94.7%, 76.3%, and 64.5% of the farmers did not produce important crops including barley, faba bean, and potato, respectively; for the fact that soil acidity limits
| No | Main crops produced | Machakel (25) | Farta (15) | Gozamen (24) |
|----|---------------------|--------------|------------|--------------|
|    |                     | Sum         | Mean | % | Sum | Mean | % | Sum | Mean | % |
| 1  | Barley              | 0.25        | 0.01 | 0.66 | 0.125 | 0.008 | 1.12 | 0.00 | 0.00 | 0.00 |
| 2  | Faba bean           | 1.00        | 0.04 | 2.66 | 0.00 | 0.00 | 0.00 | 0.875 | 0.036 | 2.78 |
| 3  | Potato              | 1.75        | 0.07 | 4.65 | 2.625 | 0.175 | 23.6 | 0.625 | 0.05 | 1.98 |
| 4  | Wheat               | 2.125       | 0.09 | 5.65 | 0.375 | 0.025 | 3.37 | 5.625 | 0.234 | 17.86 |
| 5  | Maize               | 2.00        | 0.08 | 5.32 | 0.25 | 0.02 | 2.25 | 3.625 | 0.151 | 11.51 |
| 6  | Oat                 | 5.25        | 0.21 | 13.95 | 0.00 | 0.00 | 0.00 | 9.375 | 0.391 | 29.76 |
| 7  | Lupine              | 6.125       | 0.25 | 16.29 | 0.50 | 0.03 | 4.49 | 0.50 | 0.021 | 1.59 |
| 8  | Triticale           | 8.125       | 0.33 | 21.59 | 5.25 | 0.35 | 47.19 | 0.00 | 0.00 | 0.00 |
| 9  | Teff                | 11.00       | 0.44 | 29.23 | 2.00 | 0.133 | 17.98 | 10.875 | 0.453 | 34.52 |
| Total cultivated | 37.625        | 1.505 | 100 | 11.125 | 0.742 | 100 | 31.5 | 1.313 | 100 |

Source: Own data, 2018/2019

Note: numbers in parenthesis are number of samples taken from host farmers; Sum: shows total area coverage of the specific crop produced in hectare bases; Mean: shows the average area coverage of the specific crop in hectare; percentages (%): showed the percentage of specific crops produced compared to other total crops. This indicated that how many farmers shifted from acidic sensitive to tolerant crops.
The productivity of these economically and nutritionally important crops and diversity of crops as well. Farmers indicated that the productivity and area coverage of important crops reduced from time to time. Instead of these farmers produced acid-tolerant crops like triticale, oat, and lupine which are 81.1%, 69.7%, and 65.9% at Machakel, Farta, and Gozamen, respectively. Generally; on average more than 73.52% of farmers’ cultivated farms found to be covered with crops that are less sensitive to soil acidity as shown below (Figure 6). The situation needs strongly threatens to meet the food and nutritional security of the community.

3.4. Feedbacks from stakeholders
Farmers said that the crop was good and attractive at the vegetative stage and it should be continued for further endorsement. Participant farmers were eager to use 25% rates and row application methods of lime at planting than the full rate. Experts and other stakeholders including the policymakers satisfied the new methods of lime application as it opened a new opportunity for the poor farmers as the cost reduced by 75% and must be reached to more farmers and areas within the short time-span. So that productivity of wheat shall be increased. The current result supports the finding of Adesoji and Tunde (2012) the contribution of farmers’ involvement during the development and dissemination of technologies might help in its acceptance.

3.5. The response of wheat grain yield to applied lime
The average grain yield of TAY at Farta and Machakel was 3584 and 4223 kg ha⁻¹ respectively, while for Kekeba at Gozamen and Ogolcho at Debre Elias was 4481 and 5529 kg ha⁻¹ respectively. On average 4525 kg ha⁻¹ was obtained/achieved shown below (Table 6).

Lime application integrated with improved varieties and management resulted in a yield advantage of 90.23, 86, and 73.4% compared to the average yield of 2380, 2509, 2067 kg ha⁻¹ in the Amhara region, East Gojjam and South Gonder zones, respectively (Central Statistics Agency (CSA), 2017). These yield result increment agreed on (Asrat et al., 2014; Birhanu et al., 2016; Kidanemariam et al., 2013) lime application significantly increased wheat grain yield, biomass yield, plant height, tillering capacity and dry weights of the plant. Because; the application of lime has provided additional organic matters and free calcium carbonates which have helped increases soil pH, improves the solubility and availability of important nutrients to plants, easily available reclamation for P fixation by blocking or chelating acidic cations and ease fertilizer response to plant roots and growth, improves the movement of soil microorganisms activity need to stay healthy, improves the water-holding capacity and uptake of nutrients, maintain an ionic charging balance within the tissues (Curtin & Syers, 2001; Marschner, 2011).

The findings are in agreement with Kuma et al. (2018) the grain yield of wheat (2922.35 kg ha-1) brought about 78.8% compared to the control treatment by the application of lime with NP fertilizers at Banja districts and also at Bekoji areas the highest grain yield of wheat (6580.9 kg
| Varieties | Districts | Kebeles   | Unit    | Samples | Min  | Max  | Mean | Std. Dev |
|-----------|-----------|-----------|---------|---------|------|------|------|----------|
| TAY       | Machakel  | Debre Kelemo | kg ha⁻¹ | 12      | 2872 | 5265 | 4223 | 6.81     |
|           | Foro      | Sahima    | kg ha⁻¹ | 10      | 2430 | 4853 | 3584 | 6.66     |
| Kekeba    | Gozamen   | Yenebirna | kg ha⁻¹ | 14      | 3254 | 5333 | 4504 | 6.46     |
|           |           | Chimbord  | kg ha⁻¹ | 14      | 2984 | 5645 | 3956 | 8.79     |
|           |           | Kebi      | kg ha⁻¹ | 7       | 3653 | 6215 | 4989 | 9.66     |
| Ogolcho   | Debre Elias | Dejba   | kg ha⁻¹ | 9       | 4378 | 6995 | 5617 | 7.94     |
|           |           | Genet     | kg ha⁻¹ | 9       | 4050 | 7235 | 5442 | 12.38    |
| Total     |           |           |         | 75      | 2430 | 7235 | 4525 | 10.51    |

*Source: own data, 2018/19*
ha$^{-1}$) was obtained. The yield increment as compared to the control (without lime) brought about 23% (1233 kg ha$^{-1}$) (Hailu et al., 2014). Similar to this finding application of 10 tons ha$^{-1}$ lime has been reported to have increased wheat grain yield by 34.4% than control (without lime) on soils for cultivated land at Loma areas (Bore & Bedadi, 2016). Other crops also Ayalew (2011) found that yield increment of maize by 16% with the application of lime than the control along with NP fertilizers around Areka area South Ethiopia and also Achalu et al. (2012) reported that 27.22% of yield advantage on barley production in the cultivated land with the application of full rate of 8 t ha$^{-1}$ with NP fertilizer at western Oromia region.

The worst case of soil acidity was observed at Machakel district as shown in Table 5 that resulted in nearly no production of wheat. However, it was achieved a maximum grain yield of 5265 kg ha$^{-1}$ and a mean of 4223 kg ha$^{-1}$ by applying the innovation method and rates of lime application. The implication of the finding on the nutritional as well as food security of the community in particular and the country, in general, is highly significant. The mean grain yield at Gozamen and Debre Elias districts are higher compared to the adjacent fields planted without lime with a yield advantage of 72.21% and 37.67% respectively (Table 6). For Machakel and Farta districts, there was no wheat planted around our cluster instead the land was covered less acidic sensitive either by triticale or oat. Regular applications of recommended 25% lime rates are required for wheat based on production year of soil pH and exchangeable acidity levels, because soil acidification is an ongoing process until it reached the normal levels (Belda, 2014; Birhanu et al., 2016).

Generally, the benefit of the technology was very high with a marginal rate of return of 252% i.e. 2.52 Eth. Birr per one Birr investment as shown in the above (Table 7). That accounts for a net benefit of

| Table 7. Cost benefit analysis of 25% lime application |
|-------------------------------------------------------|
| Parameters                                           | Unit     | Amount per unit | Unit price | Total cost/ income |
|-------------------------------------------------------|
| I. Variable costs                                    |          |                 |            |                   |
| Seed                                                 | Kg ha$^{-1}$ | 150             | 16.80      | 2,520.0           |
| Fertilizer                                           | Kg ha$^{-1}$ | 350             | 12.45      | 4,357.5           |
| Lime                                                 | Kg ha$^{-1}$ | 900             | 1.35       | 1,215             |
| Pesticides                                           | Lit ha$^{-1}$ | 1.5             | 1050       | 1,575             |
| Ploughing                                            | Man day$^{-1}$ | 16              | 150       | 2,400             |
| Seed application                                     | Man day$^{-1}$ | 4               | 150       | 600               |
| Fertilizer application                               | Man day$^{-1}$ | 4               | 60        | 240               |
| Lime application                                     | Man day$^{-1}$ | 4               | 60        | 240               |
| Lime transport                                       | Eth. Birr (100 kg)$^{-1}$ | 9             | 10        | 90                |
| Weeding                                              | Man day$^{-1}$ | 36              | 60        | 2,160             |
| Pesticide application                                | Man day$^{-1}$ | 4               | 60        | 240               |
| Harvesting                                           | Man day$^{-1}$ | 16              | 120       | 2,080             |
| Threshing                                            | Man day$^{-1}$ | 12              | 100       | 1,200             |
| Grain transport                                      | Eth. Birr (100 kg)$^{-1}$ | 45.25     | 3.80      | 172               |
| Total variable cost                                  | Eth. Birr |                 |            | 19,089.5          |
| II. Revenue                                          |          |                 |            |                   |
| Average yield                                        | Kg ha$^{-1}$ | 4,525           | -          | 4,525             |
| Gross income                                         | Eth. Birr | 4525           | 14.85      | 67,196.25         |
| Gross margin (II–I)                                  |           |                 |            | 48,106.75         |
| MRR                                                  | %         |                 |            | 252               |

Source: Own computation data, 2018/19
48,106.75 Eth Birr per hectare. Considering the contribution of the new technology for the nutritional and food security of the community, the value is beyond the calculated financial return.

3.6. Farmers’ perceptions on reduced and row application of lime
The general perception of farmers on the introduced new methods of the lime application was positive as shown below. They raised advantages and some probable drawbacks of the technology.

Advantages:
- Increased grain yield and biomass of crops
- Reduced cost of lime and transport to apply
- Increased food security and income of the community
- Improved tillering and uniformity in vegetative growth and maturity
- Reduced drying of normal maturity
- Direct contact with the soil and crop
- Conserves soil more moisture
- Increased involvement of farmers on lime application

Drawbacks/Disadvantages:
- Needs additional labor at planting time
- Cementing at planting especially provided there rainfall
- Needs extended time to plant with a high amount of rain/wet of the soil

3.7. Quantitative aspects of Farmers’ perception of lime
In this case, the five categories of Likert scale were used; due to it is the most common and appropriate methods so the utilizing of such categories has been found to provide users-friendly and acceptable levels of reliability (Dillman et al., 2014). The responses are scored from 1 to 5 for each item and assuming the intervals between responses are equal (Boone & Boone, 2012; Brown, 2011). Based on Likert scale measurement as shown below (Table 8) more than 95% of the respondent farmers agreed and strongly agreed about the reduced (25%) rate of lime application for the associated cost of purchasing and the cost of transport. The finding also showed that 68.4% of respondents do not agree about the recommended seed rates in the acidic area must be higher than less acidic as the tillering capacity could be lower for the former case.

As indicated in the above (Table 8) the average scores result of the respondents was 4.19 (83.8%) accepted by the farmers; these indicating that farmers accepted the technology with full confidence, perceived well with its packages and the research achieved its ultimate objectives and hence the technology should be promoted for wider areas through the regular agricultural extension system. This is in agreement with the finding of Afrikpui (2007) technologies being properly packaged to meet the needs of the targeted clients and achieves the desired productivity and also Sewnet et al. (2016) said that comprehensive transfer of research knowledge and technology is demanded to impact the livelihood of the end-users; farmers.

4. Conclusion and recommendation
An innovative way of the lime application was implemented at a scale in the acidic areas of Northwestern Ethiopia where the productivity of acid-sensitive crops including bread wheat has been reduced. It was carried with the collaboration of key stakeholders: the research system, agricultural extension system, and the farmers. Joint planning, implementation, monitoring, and evaluation were the major activities. Responsibilities among the stakeholders were shared and implemented accordingly. The research system was responsible for the new technology awareness creation through intensive and focused training, the supply of the input, and set technology transferring systems. The extension system was responsible to facilitate and mobilize the farmers and
Table 8. Likert scale measure of farmers’ perception on acidic soil management, 2018/19

| Variables/Questions                                                                 | Farmers response to the posed questions and scores | S. agree | Agree | Neutral | D.agree | S.disagree | Sum | Acceptance |
|------------------------------------------------------------------------------------|----------------------------------------------------|----------|-------|---------|---------|------------|------|------------|
| Lime application at 25% rate in row with recommended agronomic practices increased productivity of wheat | N                                                  | 58       | 18    |         |         |            | 362  | 95.2%      |
|                                                                                   | %                                                  | 76.3     | 23.7  |         |         |            |      |            |
| Lime application at 25% rate in row improved uniformity in maturity               | N                                                  | 21       | 55    |         |         |            | 325  | 85.4%      |
|                                                                                   | %                                                  | 27.6     | 72.4  |         |         |            |      |            |
| Lime application at 25% rate in row reduced transport cost                        | N                                                  | 67       | 9     |         |         |            | 371  | 97.6%      |
|                                                                                   | %                                                  | 88.2     | 11.8  |         |         |            |      |            |
| Lime application at 25% rate in row is economically acceptable                     | N                                                  | 55       | 18    | 2       | 1       |            | 355  | 93.4%      |
|                                                                                   | %                                                  | 75.0     | 21.1  | 2.6     | 1.3     |            |      |            |
| Lime application at 25% rate in row increased participant farmers                | N                                                  | 26       | 33    | 9       | 8       |            | 305  | 80.2%      |
|                                                                                   | %                                                  | 34.2     | 43.4  | 11.8    | 10.5    |            |      |            |
| The seed rate used was enough                                                    | N                                                  | 5        | 19    | 2       | 39      | 11         | 157  | 41.2%      |
|                                                                                   | %                                                  | 6.6      | 25.0  | 2.6     | 51.3    | 14.5       |      |            |

(Continued)
Table 8. (Continued)

| Variables/Questions | Farmers response to the posed questions and scores |  |
|---------------------|---------------------------------------------------|--|
|                     | S. agree | Agree | Neutral | D.agree | S.disagree | Sum | Acceptance |
| The varieties supplied are better than what you have before | N | 52 | 24 | | | 356 | 93.6% |
|                     | % | 68.4 | 31.6 | | | | |
| Average             | | | | | | 318 | 83.8% |

Source: Own survey data, 2018/19

Note: N = Number of samples taken, S. agree = strongly agree, D. agree = disagree and S. disagree = strongly disagree
development agents and experts so that the new technology shall be effectively implemented and disseminated. Farmers were responsible to carefully attend the training and implement the technology as well as management of the crop as per the training. Finally, all of the stakeholders were responsible for designing and delivering messages to policymakers and non-participated farmers for a wider expansion of the technology. The overall research findings proved again the application of lime at a 25% rate based on exchangeable acidity in rows at planting significantly increased the productivity of wheat in the acidic areas where productivity was about impossible in such acidic cases. Average grain yield of 4525 kg ha\(^{-1}\) was achieved and the marginal rate of return (MRR) was 252%; this finding was shown a yield advantage of 90.23% compared to the previous year of wheat production of Amhara region. The new lime application method reduced purchasing and transporting cost of lime by 75% that highly encouraged more than 90% of the farmers to accept the technology. The implication of the finding on the local, regional, and national levels to satisfy the nutritional and food security of the people is very significant upon properly transferring the technology in the acidic areas of the region as well as the country. Its contribution towards self-sufficiency in wheat for the country could be significant as well. The new reduced rates of lime application could help to cover areas four times higher than the previous application method used by the extension system; it is a great relief for the government to satisfy the demands of lime efficiently inequitable manner. Therefore, the technology should be incorporated into the regular agricultural extension system to address more farmers where areas suitable for bread wheat with soil acidity management. Joint planning with farmers and further skill, awareness creations, and give training are critically important. The rate of lime was based on exchangeable acidity and hence other methods of lime determination could not be supported by this rate. Moreover, the rate was developed for bread wheat and hence could be used for other crops as a blanket. Recommended fertilizer rates, improved variety, seed rates, and other crop management should be parts and parcels of the lime package. Access to lime and its value chains needs wider strengthening. Further research efforts on seed rates in acidic soil and acidic-sensitive crops including potato, barley, and faba beans are needed.

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