Using Digital Repeat Photography to Strengthen Seasonal Monitoring in Ethiopia's R4 Rural Resilience Initiative

Working Paper No. 342

CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS)

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Photos:
Figure 2 includes a picture of field agent and a farmer working on crop cutting exercises. They both consented to have their picture taken and used for publications. Credits: Zelalem Gebeyehu.

Abstract

This paper discusses the feasibility of applying a near-surface remote sensing approach in the index insurance component of the R4 Rural Resilience Initiative in Ethiopia. Specifically, we test a prototype for using smartphone images of insured fields (or ‘picture-based insurance’) to monitor crops and manage basis risk in R4 insurance policies. We find that the proposed prototype, in which R4 agents send in images of crops grown by farmers in their communities, is feasible. Further, we find that crop losses are not only caused by droughts, which are covered by R4 index insurance products, but also by other perils such as pests or disease, which are not easily captured by index insurance. Despite limited smartphone penetration and current challenges in internet coverage, the near-surface remote sensing approach appears valuable and feasible in the context of the R4 Rural Resilience Initiative in Ethiopia.

Keywords

Resilience; Agricultural risk management; Index insurance; Basis risk; Teff; Ethiopia.

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Contents

Acronyms

CCE	Crop cutting experiment
GPS	Global Positioning System
Ha	Hectares
IFPRI	International Food Policy Research Institute
IRB	Institutional Review Board
PBI	Picture based insurance
R4	R4 Rural Resilience Initiative
WFP	World Food Programme

Section 1. Introduction

Vulnerability to climate-related shocks—made more frequent and intense by climate change—is a constant threat to nutrition and food security. In the face of these challenges, the World Food Programme (WFP) and Oxfam America launched the R4 Rural Resilience Initiative (R4) in 2011 to enable vulnerable rural families to increase their food and income security by managing climate-related risks. R4, active in Ethiopia, Senegal, Malawi, and Zambia, with pilots in Kenya and Zimbabwe, aims to reach farmers through a combination of four risk management strategies: improved resource management through asset creation (risk reduction); insurance (risk transfer); livelihoods diversification and microcredit (prudent risk taking); and savings (risk reserves).

Insurance, as one of the core activities within the R4 initiative, compensates enrolled farmers when they suffer catastrophic losses due to, for instance, a drought. This prevents farmers from having to sell productive assets, take out emergency loans, or take other desperate measures to cope with these losses, protecting their investments in case of a bad season, and helping unlock investments in riskier but more remunerative enterprises, better seeds, fertilizers, and new technologies. Although traditional indemnity-based products are typically too expensive to offer in a smallholder farming setting, R4 insurance products are affordable because they are index-based, using rainfall estimated through satellite remote sensing as a proxy for losses. This makes claim settlement cheaper, faster, and more objective compared to more traditional indemnification methods that rely on claims adjusters visiting affected fields to estimate losses.

At the same time, the R4 program has been challenged by basis risk in the implementation of rainfall indices. Basis risk means that the index that triggers payouts (rainfall estimated through satellite remote sensing in the case of R4) does not always coincide with plot-level conditions. When the index does not correlate sufficiently with actual crop losses, farmers may end up paying the insurance premium and experiencing damage without receiving insurance payouts (‘downside’ basis risk), or they may receive insurance payouts during good years when they did not suffer any actual production losses (‘upside’ basis risk). For a risk averse farmer, this will reduce the willingness to pay for insurance and thus reduce the capacity of insurance to impact positively farmers’ livelihoods. Moreover, for a given level of basis risk, using an index to trigger payouts might be less tangible to farmers than when payouts are based on actual losses. This could further reduce demand.

For the R4 initiative to have positive impacts on farmer livelihoods, it is important that farmers trust its insurance component to make payouts when they suffer catastrophic losses. To address these challenges, R4 has introduced seasonal monitoring of crop conditions. R4 is seeking ways to make these seasonal monitoring activities more effective and reliable. WFP R4 therefore partnered with the International Food Policy Research Institute (IFPRI) to study the use of digital repeat photography through smartphone cameras (also called 'near-surface remote sensing') as a tool to strengthen seasonal monitoring of crop health and damage in Ethiopia. IFPRI has tested this concept in India, showing its potential to reduce basis risk in index-based insurance for smallholder farmers (Ceballos, Kramer and Robles, 2019).

Near-surface remote sensing to strengthen seasonal monitoring

Near-surface remote sensing entails taking repeat pictures of insured sites at regular intervals from sowing to harvest through low-cost smartphone cameras. The system is tamper-proof: Pictures are taken within a smartphone app, which automatically uploads the pictures to a server, along with geotags, date and time stamps. When taking a repeat picture, the app displays a background image showing the original picture taken at that site, allowing the user to align static features in the landscape and creating a stream of pictures with the same view angle throughout the crop growing season (almost like a time-lapse). The idea behind this approach is to provide high resolution and visually interpretable ground data on crop growth stage and crop health that complement satellite remote sensing, while also being collected at much lower cost than other expensive near-surface imaging techniques such as drones. This smartphone-based approach is easy to understand and implement, potentially increasing tangibility and trust among insurance providers and other stakeholders in the insurance supply chain.

This approach aims to combine key advantages of both index-based insurance—timely compensation without expensive loss assessments—and indemnity insurance—minimum basis risk and an easy to understand product. Quantitative vegetation indices and other features can also be extracted from pictures, providing information about crop growth stage and damage from droughts and other natural disasters to support rapid and reliable in-season and post-harvest loss verification (Hufkens *et al.*, 2019). Near-surface remote sensing takes advantage of the general trend of increasing smartphone ownership in developing countries, improved penetration of low-cost mobile internet services among smallholder farmers, and recent advances in image processing for near-surface remote sensing through digital repeat photography, which can help to automate loss assessment made based on data derived from smartphone camera images.

Research objectives and overview

This project evaluates the feasibility of near-surface remote sensing approaches to strengthen existing seasonal crop monitoring activities in the R4 program in Ethiopia. In this first season, the focus was on testing equipment and prototype, as well as the potential for using the images in future claims discussions. The main research question around this participatory crop monitoring solution addressed in this first season is to what extent the near-surface remote sensing approach corroborates and complements information captured through existing seasonal monitoring procedures and satellite indices.

This paper describes the main findings from a first implementation season. In the next section, we will describe an overview of the methods, including sampling, data collection methods and study procedures. Section 3 describes the study sample and statistics regarding losses and basis risk in the current season. The final section concludes.

Section 2. Methods

Sampling

The study was conducted in two regions of Ethiopia, Tigray and Amhara, starting in May 2019, in the Meher production season, which ended in December 2019. The study targeted six pre-selected villages in the two regions, in collaboration with the two R4 implementing partners for these regions:

- Amhara: Three villages of Libokemkem woreda in Southern Gonder zone. *Implementing partner:* Organization for the Rehabilitation and Development of Amhara (ORDA).

- Tigray: Two villages of Kilte-Awlaelo woreda in Eastern Tigray and one village of Raya Azapo woreda in Southern Tigray. *Implementing Partner*: Relief Society of Tigray (REST).

These six villages were selected by the R4 program because of the frequent mismatches between on the one hand the level of rainfall measured through seasonal monitoring and satellite imagery, and on the other hand farmer reports of droughts. In each village, the implementing partners selected 10 teff farmers to be included in the study, resulting in a total sample of 60 farmers. These farmers were selected based on the following criteria:

- The farmer should have signed up for R4 insurance for teff in the late sowing season
- The farmer is accessible / based in a central location to facilitate crop monitoring
- The farmer should be willing to participate in the full study

The implementing partners made sure that farmers were willing to participate, and that they had the right expectations to minimize attrition from the start to the end of the project. Farmers unwilling to participate in the study would need to be replaced at the start of the season, but we did not encounter such cases. In a few cases, replacements were however required because these farmers had initially signed up for teff insurance, but later decided to grow a different crop.

Data collection

An agent from the implementing partner would enroll farmers and select, together with the farmer, one plot to be monitored through weekly follow-up pictures of the plot, from sowing to harvest. Four sources of data on sampled farmers and their selected plots are being used in this paper:

- Enrollment: Farmer and plot characteristics, including initial picture of selected plot (see Appendix 1)
- Repeat visits: Regular crop pictures and characteristics from sowing to harvest, including crop growth stage, damage and input use (see Appendix 2)
- Loss assessment: Expert assessments of crop damage, including timing and cause of damage, and picture quality (see Appendix 3)
- Crop cutting exercises: Measured yields (see Appendix 4)

To collect data, the project leveraged software developed as part of [IFPRI's picture-based insurance initiative](), which works with insurance initiatives to use smartphone pictures of insured crops to monitor crop phenology and strengthen insurance coverage for climate-related risks.

Two data sources (enrollment and repeat visits) were collected using a smartphone application called ***AzmeraCam***, adjusted for the R4 program in Ethiopia from an app tested in IFPRI's ongoing research in India. Through AzmeraCam, agents registered the personal details of participating farmers and plots to be enrolled. At this time, they also submitted initial georeferenced pictures for these plots (see Appendix 1—Registration questionnaire).

For enrolled farmers, throughout the season, built-in reminders asked agents to take georeferenced repeat pictures of the registered sites. The app interface would show—as a 'ghost' image—the initial picture for that site in order to ensure repeat pictures were always taken from the same location with the same view frame (see Figure 1). To prevent tampering, agents could only take and upload pictures within the AzmeraCam app. Agents were instructed to take a repeat picture every week of this same plot, holding constant the view frame across all pictures of the same plot. A few follow-up questions on crop development, crop damage and input usage were asked after taking a repeat picture (see Appendix 2—Repeat picture questionnaire).

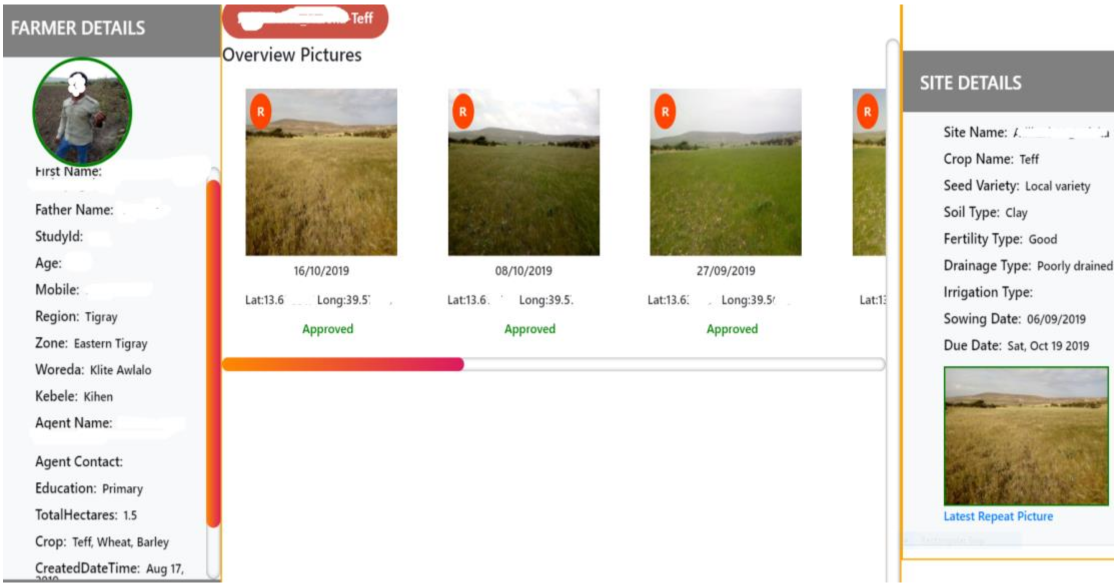

Figure 1: Farmer registration and initial picture from AzmeraCam database. Farmer details and GPS coordinates have been removed to protect the anonymity of the farmer.

In addition to the regular repeat pictures, close-up pictures were taken in case of problems such as a pest or disease, waterlogging or nutrient deficiency that could potentially affect the crop. These close-up pictures could display any part of the plant (leaf, stem or root) in order to capture the affected area clearly. They were primarily used to identify the cause of damage and could be taken only after a repeat overview picture in case damage was reported in *AzmeraCam*.

The third data source (loss assessment) was collected through a web-based portal that was attached to the *AzmeraCam* application and was showing the stream of pictures collected from sowing to harvest for a given plot. This portal was used to monitor the pictures for signs of visible crop damage by an agricultural specialist. Specifically, three agronomists inspected the stream of repeat pictures and indicated, for every plot, whether there was damage visible for a plot, and if so, when and how the damage had most likely occurred. They also indicated whether the quality of the pictures was sufficient to make an assessment (see Appendix 3 – Loss Assessment Form).

Finally, at the end of the Meher season, agents from implementing partners measured yields for each of the selected fields by conducting crop cutting exercises (see Appendix 4 – Crop Cutting Experiments (CCEs) Data Collection Sheet). Figure 2 illustrates the CCEs. CCE data were recorded first on paper and later entered using SurveyCTO. We will triangulate these data with the picture-based loss assessments and farmer self-reported data to validate the use of pictures as a method to monitor crop phenology in insurance applications.

Figure 2. Agents and Farmers Working on the Crop Cutting Exercise.

Procedures and ethical considerations

At the start of the project, an IFPRI researcher met with R4 field monitors in Ethiopia to go through the project objectives, project activities, the final smartphone application and associated web application. The field monitors were responsible to conduct the training of the 5 agents working in each of the selected villages. During the initial visit and training, the field monitors (and agents during the training) would download AzmeraCam from the Google Play Store, using smartphones provided by the project.

To implement the CCE, we had planned on a hands-on practical training in the Tigray and Amhara regions for the five agents from implementing partners (two in Amhara and three in Tigray) at a suitable time towards maturity of the crops. However, because of unexpected and untimely rainfall, farmers were forced to harvest the crops earlier than intended. Consequently, we decided to change strategy and provided a half-day training of trainers to two R4 coordinators at Debre Zeit Agricultural Research Center. Soon after the training, the necessary materials (digital spring balance, polythene bags, pocket meter tapes, and nylon strings) were procured and provided to the five agents who would implement the CCEs on the field along with the study farmers.

Agronomic data at the plot level were collected, including sowing date, heading date and harvesting date. These were used to compute the number of days from sowing to heading as well to maturity and harvesting, and grain filling period as the number of days from heading to maturity. The actual crop cutting samples were taken from five randomly taken approximately equidistant squares of one m^2 from the central parts of each field. These plots were delineated using 1 m^2 string quadrats supported by four pegs (see Appendix 4). For these squares, data were taken on plant height, panicle length, total biomass (grain + straw) yield, grain yield, straw yield and harvest index. The crops in each quadrant were harvested close to the ground and the total biomass was determined using a digital spring balance. The harvested crops were then threshed and cleaned, and the grain yields were determined using the spring balance.

Finally, throughout each stage of the research process, the following measures were taken to comply with ethical standards for research on human subjects:

- IRB approval was obtained through the IFPRI IRB board, which also provides explicit mechanisms for reporting and redressing ethical violations;
- Participation in the study was on a voluntary basis and farmers provided informed consent prior to enrolling in the AzmeraCam application;
- As part of the informed consent procedure, farmers received accurate information on what participation entails, including costs, benefits, and potential risks associated with their participation;
- Farmers received a small reward to compensate them for the time that they made themselves available for the study and in particular for their participation in the crop cutting exercises.
- Pictures and personally identifiable information, including losses, were encrypted and hosted on a secure server;
- Pictures will be anonymized and stripped of their precise GPS coordinates before making them publicly available;
- IFPRI researchers working on the project had all taken an ethics training and they included aspects around interview ethics in their training of the field team.

Section 3. Findings and lessons learnt

Description of the sample (farmer and plot registration)

Table 1 presents descriptive statistics for the sample of 60 farmers in the first column, and by village in the remaining columns. For about 13 percent of enrolled farmers, the primary adult farmer in the household was female. The average respondent was 44 years old. Most farmers (70 percent) had received no education or a few years of primary education without having completed their primary education. Around one fifth of the sample did not own agricultural land and were primarily cultivating under rented-in arrangements. The average farmer cultivated 1.6 hectares of land. In addition to teff, most farmers produce maize (57 percent) and barley (47 percent) in the long season.

Table 1. Descriptive statistics of the study sample by village.

	Total	Tigray			Amhara		
		1	2	3	1	2	3
Demographics:							
Average age of farmer (years)	44.4	50.5	36.3	43.5	44.5	40.1	51.4
% of female heads	13.3%	10%	30%	20%	0%	0%	20%
Average household size	5.8	6.2	4.8	6.6	5.3	5.4	6.4
Education of main farmer:							
No education	38.3%	40%	40%	50%	40%	30%	30%
Some Primary but not complete	31.7%	30%	40%	30%	10%	30%	50%
Primary school	13.3%	0%	10%	10%	40%	10%	10%
Middle school	1.7%	0%	0%	0%	10%	0%	0%
High school	15.0%	30%	10%	10%	0%	30%	10%
Agriculture:							
Average operational land size (ha)	1.6	0.7	1.7	0.7	2.2	2.2	1.9
Percentage of farmers growing:							
- Barley	46.7%	70%	100%	0%	40%	50%	20%
- Maize	56.7%	40%	0%	20%	90%	100%	90%
- Sorghum	23.3%	100%	0%	0%	30%	0%	10%
- Wheat	33.3%	100%	100%	0%	0%	0%	0%
- Beans	25.0%	0%	0%	0%	20%	90%	40%
- Potato	1.7%	0%	0%	0%	0%	10%	0%
- Millet	16.7%	0%	0%	0%	0%	50%	50%
Percentage farming on own land	79.3%	88.9%	100.0%	100.0%	55.6%	50.0%	80.0%
Percentage farming on leased land	20.7%	11.1%	0%	0%	44.4%	50.0%	20.0%
Teff specific:							
Uses improved teff seeds	41.7%	0%	0%	0%	90%	80%	80%
Planted non-teff precursor crop	31.0%	100%	90%	0%	0%	0%	0%

Repeat pictures

Figure 3 plots the number of repeat pictures received per site over time (by month). A first set of pictures started coming in during August, which is when the fieldwork started. During September, we received the highest number of images for a site, which reduced in October as the training for CCEs took place in that month and the first few farmers had started harvesting around that time. In November, the crops in the majority of sites reached maturity, and the agents conducted CCEs instead of sending in images through AzmeraCam.

FIGURE 3: NUMBER OF PICTURES UPLOADED ON AZMERACAM

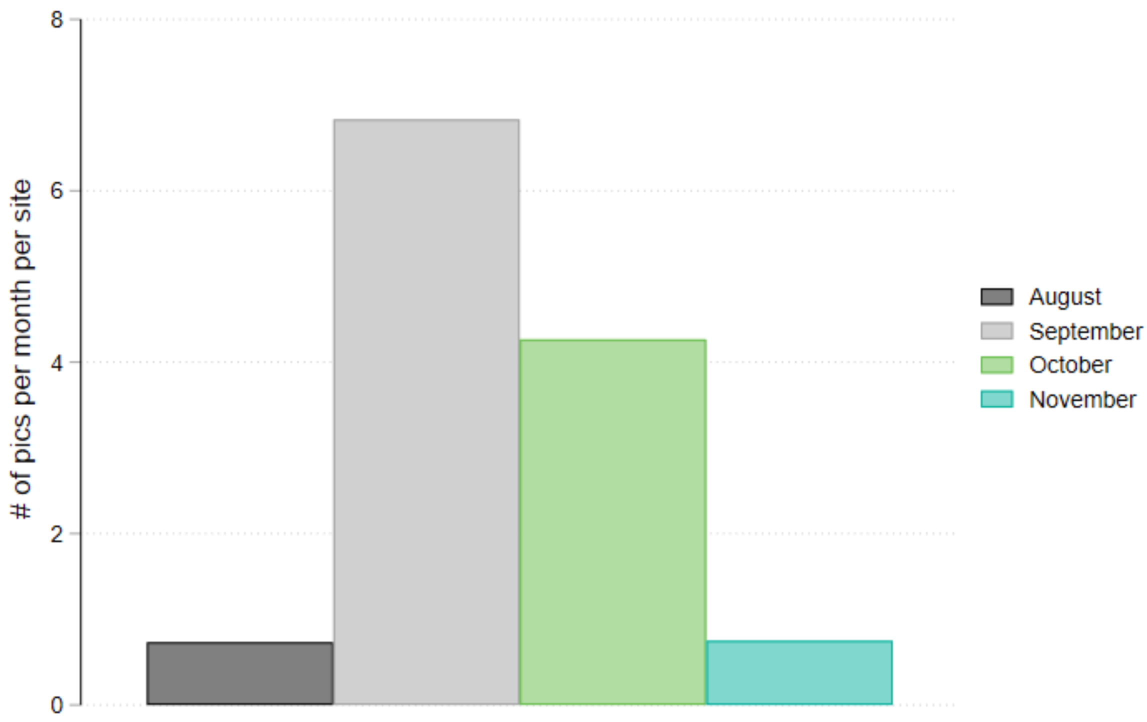

Table 2 presents the average number of pictures uploaded in total, throughout the season, per site. The average number of pictures uploaded was 12.6 pictures per site, with a minimum of 5 pictures and a maximum of 22 plots. There was substantial variation in the number of pictures submitted per site, with lower numbers in the Tigray villages and higher levels in the other three villages in Amhara. Lower numbers of pictures in Tigray were caused by lower smartphone familiarity in this region, with agents having more difficulties in accessing and using the smartphone application compared to the more educated and experienced agents in Amhara.

Table 2. Total number of pictures uploaded on AzmeraCam

	Total	Tigray			Amhara		
		1	2	3	1	2	3
Average # of pictures per site	12.6	8.6	9.6	6.7	15.0	16.1	19.5
Minimum # of pictures per site	5	6	6	5	12	14	16
Maximum # of pictures per site	22	12	12	8	18	18	22

Notes: Number of pictures available on AzmeraCam website including initial pictures (1 picture per site), close-up pictures of damage (about 1 picture for every 2 sites), and repeat pictures with same view frame as the initial picture.

Table 3 presents the percentage of damage reported by farmers after a repeat picture had been taken, using repeat pictures as the unit of observation. Although the majority of farmers did not report damage, we do find a number of moderate to more severe damage cases, especially in September (with 26.7 percent of farmers reporting damage), and a few cases in October (3.4 percent of farmers reporting severe damage of more than 30 percent).

Table 3. Percentage of teff damage reported by farmers after taking a repeat picture

	August	September	October	November
No damage	91.2%	73.3%	96.6%	100%
1 – 10 % damage	2.9%	0%	0%	0%
11 – 20% damage	5.9%	20.0%	0%	0%
21 –30% damage	0%	5.0%	0%	0%
More than 30% damage	0%	1.7%	3.4%	0%

Notes: Farmer-reported data entered in AzmeraCam for every repeat picture (see questionnaire in Appendix 2).

Table 4 summarizes farmer-reported levels and causes of damage by village. Most damage cases were due to drought (42.6 percent), pests (31.1 percent), a combination of the two (9.8 percent), and hail (9.8 percent). Table 4 also shows that the incidence of damage varies across villages. In one village (Amhara 2), farmers did not report any damage, whereas in another village (Tigray 2), a substantial 60 percent of farmers reported damage. Further, drought was the main cause of damage only in two villages (Tigray 1 and Tigray 2). In other villages, damage was caused by other perils. Given that the insurance product covers only drought, the high incidence of pests and hail damage in those villages is crucial to consider in product design, as it introduces a source of basis risk. Absence of payouts in villages where pests, hailstorms, wild animals and excess rains instead of drought damaged the crops could harm farmers' trust.

Table 4. Farmer-reported teff damage by village and cause of damage

	Total	Tigray			Amhara		
		1	2	3	1	2	3
No damage	68.3%	50%	40%	70%	60%	100%	90%
1-20% damage	21.7%	30%	40%	20%	30%	0%	10%
21-30% damage	5%	0%	20%	0%	10%	0%	0%
Above 30% damage	5%	20%	0%	10%	0%	0%	0%
Cause of damage							
Rain	1.6%	0%	0%	25%	0%		0%
Hail	9.8%	0%	27.3%	0%	0%		0%
Drought	42.6%	45.5%	72.7%	0%	0%		0%
Wild animal	1.6%	0%	0%	25%	0%		0%
Pest	31.1%	18.2%	0%	50%	100%		100%
Heat & drought	3.3%	9.1%	0%	0%	0%		0%
Drought & pest	9.8%	27.3%	0%	0%	0%		0%

Notes: Farmer-reported data in AzmeraCam for every repeat picture (see questionnaire in Appendix 2).

In Table 5, we go a step further and analyze whether farmers reporting damage also reported lower yields. This table reports the percentage of farmers with no damage, moderate damage and severe damage, respectively, by farmer-reported yield terciles defined by region. Among the 41 farmers reporting no damage and the 13 farmers reporting moderate damage, self-reported yields are distributed across all terciles, with farmers who report moderate damage also being more likely to report yields that fall into the lowest tercile. Self-reported yields among farmers reporting severe damage are substantially lower; we find that among this group, 83.3% of self-reported yields falls in the lowest tercile, and among this subsample, no farmer reports yields falling in the highest tercile.

Table 5. Farmer-reported damage versus self-reported yields

	Yield tercile 1	Yield tercile 2	Yield tercile 3
Farmer reported no damage (N = 41)	39.0%	36.6%	24.4%
Farmer reported moderate damage (1-20% damage; N = 13)	46.15%	23.08%	30.8%
Farmer reported severe damage (21% damage or higher; N = 6)	83.3%	16.7%	0%

Notes: Based on farmer-reported data entered by agents in AzmeraCam after taking a repeat picture. Farmers are the level of observation, with data from multiple repeat pictures for the same site aggregated by taking the maximum level of damage and the minimum level of yields reported by a farmer throughout the season. Yield terciles are calculated separately for each region and are 3-5, 6 and 7-8 quintals per hectare in the Tigray region, versus 3-5, 6-8 and 9-14 quintals per hectare in Amhara.

Loss assessments

This section describes the expert assessments of losses experienced by farmers. Three agronomists inspected the pictures and assessed whether there was damage for every site. For sites with damage, they indicated which portion of the field was affected, and within the affected portion of the field, by what percentage the crop had been damaged. In previous research in India, high levels of inter-rater reliability were obtained for these measures, in that experts' loss assessments correlated well with one another.

Table 6. Pairwise correlation in ratings by experts

		Expert1	Expert2	Expert3
Percentage of field affected according to expert	Expert1	1.0000	0.2744	-0.0002
	Expert2		1.0000	0.2556
	Expert3			1.0000
Percentage of loss in affected portion of field according to expert	Expert1	1.0000	-0.1841	-0.0620
	Expert2		1.0000	0.0389
	Expert3			1.0000
Whether the expert attributes damage to causes other than mismanagement	Expert1	1.0000	-0.1892	-0.0292
	Expert2		1.0000	0.1158
	Expert3			1.0000
Percentage of field affected by damage not due to mismanagement according to expert	Expert1	1.0000	-0.2045	-0.0155
	Expert2		1.0000	0.1545
	Expert3			1.0000
Percentage of loss not due to mismanagement in affected portion of field according to expert	Expert1	1.0000	-0.1841	-0.0620
	Expert2		1.0000	0.0389
	Expert3			1.0000

Notes: Expert-reported damage during loss assessment in AzmeraCam web portal, with this table using different expert observations for the same site or field as the unit of observation.

Table 6 verifies whether this is the case also for this sample in Ethiopia, by presenting the pairwise correlation between the three experts' loss assessments. Although loss assessments will never overlap perfectly, and correlation coefficients will never reach unity, good inter-rater reliability would be characterized by correlation coefficients across experts' loss assessments of at least 0.6-0.8. However, in contrast to the India experience, we find that experts did not agree with one another in terms of the levels of damage, with low—often even negative—correlation coefficients across expert loss assessments.

Because of low agreement across experts, the remainder of the paper will focus on data reported by the most senior expert: Expert 1. Table 7 presents this expert's loss assessments by village. The senior expert concluded that there was damage in every site (and for all but one case, the damage was assessed to be between 1 and 20 percent of potential crop yields). However, most damage was assessed to have been caused by mismanagement (70 percent of all cases). Among sites with damage not due to mismanagement, the expert attributed damage in Tigray 2, Amhara 1 and Amhara 3 often to droughts, whereas farmers reported drought only in Tigray 1 and Tigray 2; and damage due to lodging and heavy winds was detected by the expert whereas farmers never reported this type of peril. By contrast, this expert found no evidence of pests, which were frequently reported by farmers.

Table 7. Damages reported by loss assessment experts

	Total	Tigray			Amhara		
		1	2	3	1	2	3
No damage	0%	0%	0%	0%	0%	0%	0%
1-20% damage	98.3%	100%	90%	100%	100%	100%	100%
21-30% damage	1.7%	0%	10%	0%	0%	0%	0%
Above 30% damage	0%	0%	0%	0%	0%	0%	0%
Causes of damage							
- Only due to mismanagement	70%	90%	50%	60%	50%	90%	80%
- Too much rain, flooding	5%	10%	10%	0%	0%	10%	0%
- Lodging, heavy winds	13.3%	0%	0%	40%	30%	0%	10%
- Drought	11.7%	0%	40%	0%	20%	0%	10%
Main sources of mismanagement							
- Poor sowing practice	76.7%	90%	90%	90%	70%	70%	50%
- Poor soil conservation	13.3%	10%	10%	10%	10%	0%	40%
- Lack of weeding	1.7%	0%	0%	0%	0%	0%	10%
- Too little fertilizer	8.3%	0%	0%	0%	20%	30%	0%

Notes: Expert-reported damage during loss assessment in AzmeraCam web portal, with this table using Expert 1 observations for a given site as the unit of observation.

Table 8 explores the overlap between expert loss assessments and farmer assessments more formally, focusing on different types of damage that farmers reported. The senior expert was more likely to find damage not due to mismanagement for farmers who reported damage (ranging between 37.5 and 66.7 percent depending on the cause of damage) than for farmers who did not report damage (with experts finding damage in only 17.5 percent of all sites). The next three columns show that as a result, the expert also indicates on average a higher percentage of damage for farmers who self-reported damage than for those who did not. The difference is however not too pronounced, and experts agree with farmers on the main cause of the damage only for 7 of the 11 sites (63.6%) with drought; for the sites where farmers reported damage due to hail, pests and other perils, experts attributed damage, if any, to other perils.

Table 8. Comparison of damage causes mentioned by farmers and loss assessment expert

Farmer report	Number of farmers	Expert finds damage	(A) Expert assessment of portion of field damaged	(B) Expert assessment of loss in affected portion of field	(A * B) Expert assessment of percentage damaged	Expert finds same type of damage as farmer-reported cause
Damage due to						
- Drought	11	45.5%	33%	9.6%	6.0%	63.6%
- Hail	3	66.7%	32%	28.3%	4.3%	0%
- Pest	8	37.5%	21%	3.3%	2.0%	0%
- Other perils	3	66.7%	58%	9.0%	7.9%	0%
No damage	40	17.5%	15%	1.6%	1.4%	82.5%*

Notes: Expert assessments conducted by Expert 1. The symbol * means that expert finds no damage due to mismanagement. Focus on damage not due to mismanagement.

More research is required to analyze why the different expert reports and farmer reports do not correlate with one another as well as was the case in the India study. It could be for instance that either the farmer or expert reports were not always entered accurately. Experience with smartphone- and internet-based data collection was profoundly lower among the field team in Ethiopia than it was in India, and this is a challenge that could be addressed with an improved interface. It could also be that experts need higher-quality images, which can be explored through software development, or that an expert would need more background when interpreting a stream of images, for instance whether the farmer self-reported damage and what the farmer reports as the cause of damage. These are areas for future research.

Crop cutting yields

The CCEs provide another source of data to triangulate with the farmer- and expert-reported data. Table 9 summarizes yield traits of sampled fields by region (Tigray versus Amhara) and teff variety (local versus improved). The means for grain and biomass as well as straw yields were generally higher in Tigray than Amhara, due to a few outliers in the Tigray yield data. Because local varieties are grown relatively more often in Tigray, the pooled means for yield and yield-related traits were also greater for local varieties than for the improved varieties.

Table 9. Region and variety type means of phonologic and yield related traits of the sample teff fields

	Means ± standard deviations				
	Region		Teff variety		Overall mean
Traits	Tigray	Amhara	Local	Improved	
Plant height (cm)	58.34 ±7.69	66.20 ±19.42	59.16 ±9.54	73.03 ±24.04	62.27 ±15.28
Panicle length (cm)	58.34 ±3.76	66.20 ±9.23	25.38 ±7.84	39.13 ±10.80	28.46 ±10.33
Biomass yield (kg/ha)	5632.62 ±1831.60	4373.52 ±1879.56	5155.02±1790.26	4477.08 ±2383.64	5003.07 ±1959.62
Grain yield (kg/ha)	5632.62 ±970.80	796.90 ±313.58	1187.60 ±847.71	771.69 ±307.98	1094.38 ±780.31
Straw yield (kg/ha)	5632.62 ±1463.40	3576.62 ±1688.50	3967.42 ±1398.71	3705.38 ±2191.76	3908.69 ±1614.48
Harvest index (%)	24.31 ±11.16	19.17 ±5.05	22.53 ±7.84	19.01 ±5.43	21.74 ±9.03

Notes: Statistics based on analyses for data obtained through CCEs (see Appendix 4).

Table 10 compares the different types of yield data—those based on farmer reports, expert loss assessments and crop cutting exercises—across villages. On average, farmers report expecting to earn 6.3 quintals per hectare, which is well below the yield based on crop cutting exercise (10.9 quintals per hectare) and yields based on expert loss assessments (12.6 quintals per acre). It appears that across villages, farmers expect lower yields than what we measured using CCEs, except for Amhara 2; and experts generally expect higher yields than what we measure using the CCEs, except for Tigray 1, where CCE yields appear unrealistically high, and are subsequently dropped from the analyses.

Table 10. Comparison of yield from different sources

	Total	Tigray			Amhara		
		1	2	3	1	2	3
Yield expected by farmer (self-reported)	6.3	5.5	5.3	5.3	6.9	8.6	6.1
Yield based on expert loss assessment	12.6	16.5	9.2	15.8	11.3	11.3	11.3
Yield based on crop cutting exercises	10.9	25.5	9.5	7.9	7.1	5.5	10.9

Notes: All yields reported in quintals per hectare. Expected yield reported by farmer is the minimum yield reported by that farmer throughout the season. Yield based on loss assessment is the typical yield reported by a farmer * (100 - the percentage of yield loss according to loss assessment) / 100.

Table 11 uses the CCE data to compare grain yields for farmers who reported no damage, farmers who reported moderate damage, and farmers who reported severe damages. Among farmers not reporting damage, about one-third of CCE yields fall into each of the terciles. Among farmers with moderate damage, the proportion of farmers with yields in the lowest tercile is only 20 percent, whilst the more farmers fall into the second yield tercile. Measured yields are lowest among the 4 farmers who reported severe damage; amongst these farmers, yields fell into the lowest tercile for two farmers, and the middle tercile for another two farmers, without any farmer falling into the highest yield tercile.

Table 11. Percentage of sites by yield terciles and farmer-reported damage

	Tercile 1	Tercile 2	Tercile 3
Farmer reported no damage (*N* = 35)	37.1%	28.6%	34.3%
Farmer reported moderate damage (1-20% damage; *N* = 10)	20.0%	50.0%	30.0%
Farmer reported severe damage (21% damage or higher; *N* = 4)	50.0%	50.0%	0%

Notes: Data are shown for farmers with no damage, moderate damage and severe damage by yield tercile, calculated separately for each region: in Tigray, the three terciles are 4.2-7.5, 8.1 – 9.1 and 9.6-15.6 quintals per hectare; in Amhara, the three terciles are 3-3-5.7, 6-9.5, and 9.5-13.4 quintals per hectare. Data exclude Tigray 1 with anomalously high yields.

We do not test for the statistical significance of these differences, because of low sample sizes. Moreover, yields are determined not only by whether a farmer experiences damage but also by among others management practices, varieties used and soil quality. In future research, with greater sample sizes, we will model yields as a function of these variables and explore in more detail to what extent the farmer self-reports and expert loss assessments are related to measured yields; and which source of data is more indicative of the actual situation on the ground.

Section 4. Conclusion and recommendations

This paper provides an initial description of results from a pilot of near-surface remote sensing, or picture-based crop monitoring. Bearing in mind that these findings based on a small sample size, and that more research with larger samples across multiple seasons will be needed, the following key findings stand out:

1. With the handholding from R4 field monitors, agents were able to follow image-taking protocols and send in a sufficient number of images to track crop phenology in targeted sites.
2. The level of damage reported on average by farmers remained limited, with many farmers not reporting any damage, and if reporting damage, damage remaining often at moderate levels.
3. Farmers who reported damage however attributed this damage to drought in only half of the cases; the remainder of cases was due to pests and other perils.
4. Farmer-reported damage is not always reflected by lower yields measured objectively using CCEs. We found that this was partly due to outliers in one village in Tigray, but

another limitation is the small sample size, limiting our ability to control for management practices, varieties used and soil quality.

5. In a context with uncertainty about these factors, images can provide an important objective source of data to track phenology and crop health in a transparent, tangible way.
6. However, expert loss assessments based on the images often disagree with one another, with CCE yields and with farmer reports; efforts in future seasons will need to focus on addressing these gaps.

Summarizing, there is a clear need to monitor crops and have a system in place to address basis risk, and pictures can play an important role in this regard. Additional data and analyses are however required to obtain better insights in the discrepancies between different data, and how to make optimal use of the images as an objective source of data that can help resolving the gaps between farmer reports, insurance indices and yield data. We will, in doing so, partner more closely with R4 stakeholders, including the index design team that has been established by the scheme. Moreover, we will pay attention to the question how an approach like this could be applied at a larger scale within the R4 scheme in Ethiopia. One could for instance think of using the images mainly in cases where farmers claim experiencing damage, while the index did not trigger a payment. Future analyses will provide insights on the ability of experts to interpret the images for that specific objective; for instance, by allowing experts to access farmer reports along with other background information, like an insurance loss adjuster would be able to do.

We also note lessons learnt and implications for future project design. On the technology side, a major lesson learnt was low familiarity with smartphones among agents. It is encouraging to find large numbers of images submitted, and good adherence to the protocols, despite this constraint. In future efforts, using a picture-based crop monitoring approach will again require agent training and continued handholding. We also recommend additional investments in improved user interface and robustness of the smartphone app in order to make it easier for agents to use the app. Moreover, low internet speed and interruptions in coverage were a challenge in uploading images. Software development should focus on improving the robustness of image uploading, especially of higher-resolution and close-up images of damage. These require more data but could improve the ability of experts to detect losses.

Second, it will be important to increase sample sizes in future research activities to have more cases of damage included in the sample. In our original proposal, we were planning to do the study in 8 villages, which was on the lower end but was reasonable given that the current study aimed to test the prototype within the context of the R4 program. We had to reduce the sample size to six villages due to a lack of villages in which farmers were enrolling teff under late sowing coverage. This resulted in a small number of damage cases, along with low statistical power. For this reason, we did not report standard deviations and perform significance testing in the paper. In future seasons, when the focus shifts from prototype testing to model development, it will be important to work in a larger number of villages with greater numbers of farmers. This would help generate more data to have the statistical power for developing and testing the approach. In doing so, it is important though to keep in mind that a larger number of agents, spread across a wider geographical region, will require extra training and monitoring.

Third, the discrepancy in expert loss assessments highlights the importance of findings ways to triangulate different sources of information. Reliable ground truth data from various sources, including the crop images, can play an important role in this regard. Over time, as more data is coming in, images could be used along with other data to predict damage, cause of damage and yields. One could for instance use vegetation indices derived from the crop pictures, mechanical damage from hail storms or lodging visible from the images, along with weather data, crop models and machine learning algorithms to automate loss assessment, so that loss assessment based on experts' visual inspection would not be needed.

In conclusion, despite limited smartphone penetration and current challenges in internet coverage, the near-surface remote sensing approach appears valuable and feasible in the context of the R4 Rural Resilience Initiative in Ethiopia. Different sources of data—farmer reports, expert loss assessments and objective yield measures—are all portraying a different situation, and farmers are experiencing crop damage not only from drought but also other perils. Having a ground picture will provide the context to interpret the information from different sources of data, and agents were able to provide these images with relatively limited training and handholding. They sent in large numbers of images and the field team was able to establish an effective working process in which challenges were addressed adequately. Based on the lessons learnt and findings from this first season, we recommend further refining and adapting the picture-based crop monitoring approach and testing the approach in an increased number of villages as a potential strategy to manage basis risk in index insurance.

References

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Hufkens, K., Melaas, E.K., Mann, M.L., Foster, T., Ceballos, F., Robles, M. and Kramer, B., 2019. Monitoring crop phenology using a smartphone based near-surface remote sensing approach. *Agricultural and Forest Meteorology*, 265, pp.327-337.

Appendix 1. Registration Questionnaire

Part 1 – Farmer details for owners of selected fields

		Question (text to display)	Response Options (text to display)	Description
creen 1	1	Farmer First Name:	[text]	
	2	Farmer Last Name (Father's name):	[text]	
	3	Gender:	Male Female	[single choice], dropdown
	4	Age	Integer constrained between 10 and 100	
	5	Press the camera button to click a profile picture for yourself:		Direct to camera view frame. Store file name/path in db.
Screen 2	6	Region	Select from dropdown	[single choice]
	7	Zone	Select from dropdown	[single choice], dynamic filtering based on previous response
	8	Woreda	Select from dropdown	[single choice] dynamic filtering based on previous response
	10	Village (Kebele)	Select from dropdown	[single choice] dynamic filtering based on previous response
	11	Highest Level of Education (or equivalent):	No education Primary (upto 5th std) Middle or High school (5th - 10thstd) Higher secondary (11th or 12th std) Diploma Undergraduate Graduate and above	[single choice], dropdown
Scr een 4	12	Total no. of hectares farmed	[decimal] hectares	

	13	Which crops do you plan to cultivate this upcoming meher season (2011-12 EC or 2019 GC)?	Teff Beans (bakela) Maize (bekolo) Wheat (sende) Barley (gebis) Sorghum (mashela) Nothing cultivated 30. Other (Specify)	[multiple choice]
Screen 5	14	Please enter your R4 identifier		

Part 2 – Details of the randomly selected field

		Question (text to display)	Response Options (text to display)	Description
Screen 1		For which crops would you like to enroll sites?	Teff Beans (bakela) Maize (bekolo) Wheat (sende) Barley (gebis) Sorghum (mashela)	
Screen 2 (loop for each crop)	1	Variety sown/to be sown:	Local variety Improved variety Others	
	2	Typical yield in your area (village)	[decimal] constrain between 0 and 50 for teff Quintals per hectares	
	3	Expected yield from your field:	[decimal] constrain between 0 and 50 for teff Quintals per hectares	

Appendix 2. Repeat Picture Questionnaire

After taking a repeat picture of the enrolled plot, the following questions were answered:

		Question (text to display)	Response Options (text to display)
Screen 1 (alongside picture taken)	1	Growth stage	Select from menu (Not planted yet/crown root/Tillering/Booting/Heading/Flowering/milking/Dough Stage)
	2	Crop health	Did you suffer any damage since the last picture? Yes No If yes, cause of damage Rain/Hail/Heat/Cold/Drought/Heavy Wind/Wild Animal/Fire/ Pest How much yield do you expect from this site now? ___ quintals/hectare
	3	Input used	Select which of the following you have done since the last picture No input used/Seed/Fertilizer/Chemical/Machinery/Labor Total amount Spent in Birr

Appendix 3. Questionnaire for loss assessment

1. Do you see any crop damage on this site?

Yes / No

ONLY IF YES, ASK THE FOLLOWING QUESTIONS. IF NO, PROCEED TO QUESTIONS 2 AND 3:

1.a.1 What are the probable causes of damage?

[multiple choice checklist of options]

NOT DUE to mismanagement

- *Too much rain, flooding*
- *Hail*
- *Heat stress, temperatures too high*
- *Frost, temperatures too low*
- *Pest or disease*
- *Lodging, heavy winds*
- *Wild animals*
- *Fire*
- *Drought*
- *Other (Specify)*

DUE to mismanagement

- *Poor quality seed*
- *Poor sowing practice*
- *Poor soil conservation*
- *Lack of weeding*
- *Too little fertilizer*
- *Waited too long to harvest*
- Other (Specify)

1.a.2 What is the main cause of damage? *(ONLY IF 2 OR MORE CHOICES IN 1.a.1)*

[single-choice button list displaying only the subset of choices that have been selected in 1.a.1]

(Heading) NOT DUE TO mismanagement (Heading) DUE TO mismanagement

1.b What percentage of the area is affected by this damage? (%)

1.c On the affected portion of the field, what percentage of the yield is lost due to the damage? (%)

1.d Please indicate the potential dates of damage: (select multiple dates if damage occurs at more than one date)

1.e How certain are you about your loss assessment based on the pictures sent by this farmer?

(a) Very certain (b) Reasonably certain (c) No opinion (d) Uncertain (e) Very uncertain

ALWAYS ASK THE FOLLOWING QUESTIONS:

2. What portion of the view frame is representative of the site (that is, not covered by a ridge, canal or large area without crop?

Some / Most / All

3. What is the overall quality of the pictures of this site?

Poor / Fair / Good

Comments

Appendix 4. CCE data collection sheets

Materials needed

No.	Material	Unit	Quantity required
1	Quadrat (1 m X 1 m) (1/agent)	No.	5
2	Sickles (4/agent)	No.	20
3	Nylon string (50 m roll)- 1/agent	No.	5
4	Cattle skin (4/agent)	No.	20
5	Wooden sticks (4/agent)	No.	As many
6	Local plates (4/agent)	No.	20
7	Sieves (4/agent)	No.	20
8	Spring/field balance- battery (1/agent)	No.	5
9	Grain bags (4/agent)	No.	20
10	Pocket meter tape (1/agent)	No.	5

Procedure

1. **Training**:-Hands-on practical-based training will be given on crop cutting experiments to the two R4 Field Monitors and/or five agents. The training will be given at Debre Zeit Agricultural Research Center and its sub-stations for two days at suitable time when the crops are ready for harvest (Early November 2019)

2. **Sampling**:- From each plot five samples sites will be taken in a crisscross manner using the quadrat (1 m X 1 m) as follows.

   - One of the plots will be right in the middle of the plot
   - From two adjacent angles of the plot, take one plot each approximately half-way from the middle plot
   - Again, from the two opposite angles, take one plot each approximately half way from the middle plot
   - In this way, the four plots will be approximately equidistant from the middle plot (See Figure 1).

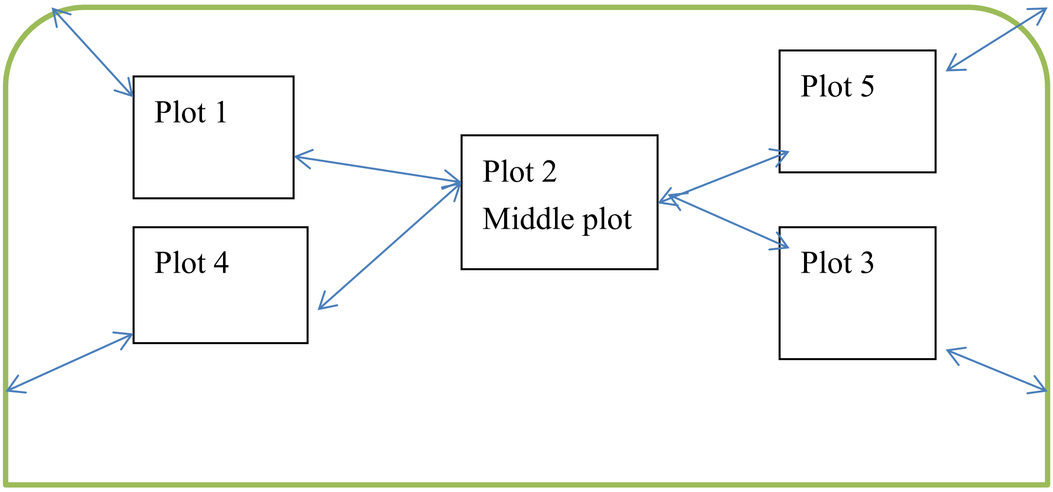

Fig. 1. Schematic representation of sample plots for CCE on each farm. Please, note that arrows indicate approximately the same distances

Height and panicle length measurement: Before, harvesting take data on total plant height and panicle length on five random samples of plants from each of the five plots using meter stick or meter tape

4. Harvesting: Harvest all the crops in each quadrat of the five plots separately using sickles. Do not harvest weeds with the crops if there are some.

5. Sun-drying: Sun-dry the harvested samples for 2-3 days in order to make the moisture content more or less homogenous or similar.

6. Total above-ground biomass/phytomass yield::After sun-drying, tie the harvested crop in each plot with the string and take the entire weight using field balance. This gives the total above-ground crop biomass or phytomass (straw+ grain) yield

7. Threshing and cleaning: Thresh the crops harvested from by hitting using suitable sticks on the cattle skin. After ensuring that all the grains are properly threshed out, separates the coarse straw using your hand for raising the crops slightly up. Then separate the fine chaff from the grain using sieves and by blowing using wind and plates. Put the clean harvested plots into bags and take the weight. This gives the grain yield per plot. Then by subtracting the grain yield from the total above-ground biomass yield, you will get the straw yield.

8. Data Collection Sheet

Data to be taken on whole farm basis

No.	Parameters	Value
1	Region	
2	Zone	
3	Woreda	
4	Kebele	
5	Locality name	
6	Farmers' description	
	Name	
	Gender	
	Family size	
7	Farm land ownership	
	Own	
	Rent-in	
	Other (please specify)	
8	Site position from nearest town, or identifier such as river, mountain, hill, or road	
9	Geographical coordinates and altitude	
	Latitude (N)	
	Longitude (E)	
	Altitude (m.a.s.l.)	
10	Site topography	
	Flat	
	Gentle slope	
	Steep slope	
	Other (Please, specify)	
11	Soil type	
12	Precursor crop	
13	Total plot area (m^2)	
14	Number of times the field was plowed	
15	Sowing date	
16	Tef variety used	
17	Seed amount used (in kg)	
18	Sowing method (row or broadcast)	
19	Fertilizer type and rate used	
	Type	
	Amount (kg)	
	Time of application (at sowing or split)	
No.	Parameters	Value

20	Weed control	
	Method (hand or herbicide with type and amount of herbicide)	
	Frequency/time of weed cont.	
21	Date of heading	
22	Date of maturity	
23	Harvesting date	

Data to be taken on the Sample plot basis

	Parameters	Value					
		Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Mean
24	Yield of biomass (in grams)						
25	Grain yield (grams)						
26	Plant height (cm)*						
27	Panicle length (cm)*						

N.B.:- Data on plant height and panicle length are to be taken as the average of a random sample of plants from each of the five sample plots per farm using pocket meter tape/meter stick

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