



# Challenges and resilience of an indigenous farming system during wartime (Tigray, North Ethiopia)

Tesfaalem Ghebreyohannes<sup>1</sup> · Jan Nyssen<sup>1,2</sup> · Emnet Negash<sup>2,3</sup> · Hailemariam Meaza<sup>1</sup> · Zbelo Tesfamariam<sup>1</sup> · Amaury Frankl<sup>2,4</sup> · Biadgilgn Demissie<sup>1,2</sup> · Bert Van Schaeybroeck<sup>2,5</sup> · Alem Redda<sup>6</sup> · Sofie Annys<sup>2</sup> · Fetien Abay<sup>7</sup>

Accepted: 25 July 2022  
© The Author(s) 2022

## Abstract

Due to war conditions, the local farmers had to largely rely on their own crop production, mainly by subsistence farming, in Tigray, North Ethiopia. We assessed the crop stands in 2021 and evaluated the level of resilience of the indigenous farming system. Quantitative data were collected from 161 farm parcels in various ecoregions of this tropical mountain region, in order to detect the share of sown land, crop types, and their status. This participatory monitoring was accompanied by semi-structured interviews. Farmers cultivated their farms late, left it uncultivated or marginally sowed oil crops as improved fallow (28%), due to lack of farming tools, oxen, fertilizer, seeds, or manpower. As compared to peace years, only few lands were sown with sorghum as there was active warfare in the sorghum planting period. The relatively good stands of wheat and barley (47%) are in line with the farmers' priority given to cereals. Teff got a large land share because it could be sown up to the middle of the main rainy season and because farmers had consumed the seeds of their major cereal crops (wheat and barley) when hiding for warfare. Seeds left from consumption were only sown by late June, when troops had retreated, and the communities could revive. With almost no external support, the local farming system has proven to be remarkably resilient, relying on indigenous knowledge and local practices, block rotation, manure, improved fallow, changes in relative importance of crops, seed exchange, and support for one another. This is the first analysis of the socio-agronomic roots of the 2021–2022 Tigray hunger crisis, with a cereal harvest that could not at all sustain the local population as the planting season had been largely missed. The ability of the indigenous farming system to partially rebound in times of autarky is another novel finding.

**Keywords** Cereal cultivation · Fallow land · Famine · Indigenous knowledge · Subsistence farming · Tigray War

## 1 Introduction

The North Ethiopian region of Tigray experienced harsh conditions since late 2020, with a war and the consequent famine (or equivalent conditions of food emergency) (IPC 2022; USAID 2022; WFP 2022). In the first half of 2021, armed forces of the Ethiopian government and from Eritrea as well

as from the neighboring Amhara region were engaged in warfare against the forces of Tigray's regional government; in the second half of the year, warfare was essentially outside of Tigray, more to the south, while Tigray itself was submitted to a blockade with all telecommunication and lifelines to the outside world cut (Pellet 2021; Gayim 2021; Ramos 2021), a blockade that continued into 2022. The near-absence of

✉ Jan Nyssen  
jan.nyssen@ugent.be

<sup>1</sup> Department of Geography and Environmental Studies, Mekelle University, Mekelle, Ethiopia

<sup>2</sup> Department of Geography, Ghent University, Ghent, Belgium

<sup>3</sup> Institute of Climate and Society, Mekelle University, Mekelle, Ethiopia

<sup>4</sup> INRAE, AMAP, IRD, CIRAD, CNRS, University of Montpellier, Montpellier, France

<sup>5</sup> Royal Meteorological Institute, Brussels, Belgium

<sup>6</sup> May Tsebri Agricultural Research Centre, Shire, Tigray, Ethiopia

<sup>7</sup> Department of Crop and Horticultural Sciences, Mekelle University, Mekelle, Ethiopia

economic activities, combined with limited food stocks and restricted humanitarian access, resulted in 70% of the population experiencing starvation (*sensu* Stratton et al. 2003), i.e., high levels of acute food insecurity and excess mortality (Plaut 2021; Istratii 2021; Weldemichel 2021; Oxford Analytica 2021; Devi 2021; Müller and Read 2021). The famine was worst from September to December 2021, as it took up to December before the years' poor harvest (Fig. 1) could be consumed; the lean period (also called “lean season,” “hunger season”) has been very severe. The lean season is the time in between finishing the last food that people had at hand and starting to consume the new harvest (Hirvonen et al. 2016).

Farming system resilience may be defined as the ability to maintain livelihoods, recover, and develop in the face of both foreseen and unexpected shocks, such as wars (Folke 2016; Diserens et al. 2018). Resilience studies are based on the notion of systems, in which natural and human systems are linked in time and place to form a single complex system and focus on the durability, adaptability, and transformability of social-ecological systems (Walker et al. 2004). Commonly cited assets for resilience are the ability to adapt to variable agroecological zones, food sovereignty (*sensu* Wittman 2011), and internal or external social security systems (Lallau 2016). Particularly, subsistence farming, the dominant farming system in Tigray, is associated with a number of resilience factors: diverse livelihood strategies allowing the spreading of risks (Ellis 2000), efficient use of family



**Fig. 1** Unprocessed wheat grain harvested on a farmers' field in Yeresere, December 2021 (Fitsum Berhane, Pers. Comm, 26 December 2021). There are very few fully matured well-rounded white grains; most grains are unfilled or partially filled with watery or reddish color. Quite some *Avena fatua* weed seeds (elongated, with spike) are present — the weed is tolerated by the farmers as it increases the straw mass.

labor (Lipton 2004), attachment to land and place (Ford et al. 2020; Quinlan et al. 2015), and indigenous environmental knowledge (Richards 1985; Hunn 1999; Jellason et al. 2021). These factors (Cabell and Oelofse 2012) allow exploiting a variety of environmental niches and hence coping with crises (Schroeder 1985). Examples of resilient subsistence farming systems in the worst of crises, i.e., wartime, are in northern Nigeria (Jellason et al. 2021), Myanmar (Ringer et al. 2021), Somalia (Ncube 2019), and Kenya (Haokip 2020).

In Tigray, however, the greatest fears raised, when it was observed, in early May 2021, that many farm parcels had not been tilled. By the end of June, an interpretation of Sentinel-based True Color Composite images indicated that there had been good plowing progress in most of the region (except for Western Tigray) with often more land plowed than in 2020 (Nyssen et al. 2022). However, in most areas, it was reported that war conditions made crop cultivation very difficult: oxen had been looted or killed, and farm inputs and tools had been destroyed (World Peace Foundation 2021; Tghat 2021b; WeForest 2021). Furthermore, farmers who wanted to till their land felt vulnerable; in many places, Eritrean soldiers prevented the farmers from plowing (AFP 2021; Addis Standard 2021). While trying to produce in February–June 2021, farmers evaluated whether plowing was risky or not and organized watch posts to verify the absence of soldiers (Nyssen et al. 2022).

By the end of June, based on remote sensing data and interviews (yet without formal ground truthing), it was anticipated that the land would have been partly sown (Nyssen et al. 2022), without using fertilizer, although that is necessary on reactive fields (Nyssen et al. 2017; Tittonell and Giller 2013). Late sowing was assumed to have led the farmers to plant crop varieties with a short growing cycle, similar to drought years, particularly fast-maturing wheat landraces as well as the local barley cultivar called *sa'isa'a* (all terms in local Tigrinya language are in italics), obviously with a lower yield (Frankl et al. 2013). Our evidence in August 2021 shows a different situation with only part of the farm parcels being cropped, and another part fallowed (Fig. S1, electronic supplementary information).

Here, we present spatially explicit field data on crop type and crop status collected through participatory monitoring by the end of August 2021; the data were analyzed in order to determine the share of Tigray's land that has been sown timely, which crops had been sown, and how they were growing. We investigate whether the dire conditions have led to shifts in crop types and fallowing patterns, whether lean crops have been privileged, the extent to which the harvest failed, and the potential resilience of the indigenous farming system. In this way, we uncover how the Tigray war led to a largely failed harvest and to the hunger crisis in 2021–2022.



## 2 Study area

### 2.1 A patchwork of terroirs

The study was carried out in Eastern and Southeastern Tigray, in an area covering around 5000 km<sup>2</sup>, situated between 13°10'–14°05'N and 39°05'–39°45'E, at elevations ranging from 1700 to 2800 m a.s.l. From south to north, it includes the Samre district, Hintalo district (with Addi Gudom town), Inderta (with Mekelle town), Dogu'a Tembien (with Hagere Selam town), Kilté Awula'ilo (with Wukro town), as well as the Tsa'ida Imba district, all in a radius of 70 km around Mekelle, the capital of the Tigray Region (Fig. 2). The study area, where farming has been done in the midst of conflict and battles, was considered to be representative for a wide range of regional environmental characteristics. Lithologies exposed are the Precambrian basement, Paleozoic (fluvio-)glacial rocks, Mesozoic sedimentary rocks, Tertiary volcanics, and Quaternary deposits (Gebreyohannes et al. 2010); dominant soils are Leptosols, Luvisols, (often Calcaric) Regosols,

(Vertic) Cambisols, and Vertisols (Nyssen et al. 2019); agroclimatic zonation in this semi-arid region is particularly dependent on elevation, hence temperature (from “cool” to “hot”) (Alemie et al. 2010). The Tigrinya term *addi* (“ecoregion,” or “land character,” the French *terroir* sensu Bérard (2016) or Unwin (2012)) points to an area characterized by the symbiosis between the combined environmental characteristics and the local traditional farming system and expertise. The land cover is dominated by cropland and shrubland (Zenebe 2009; Guyassa et al. 2018).

There were relatively few military battles (yet numerous troop movements and also air bombardments) in Mekelle, Addi Gudom, and most of Inderta in 2020–2021, whereas the other study districts have been strongly affected by warfare (ACLED 2022; Annys et al. 2021).

### 2.2 Rainfall and crop growing season

Annual rainfall in Tigray varies between 400 and 1800 mm (Annys et al. 2021) and follows a south-north gradient, with

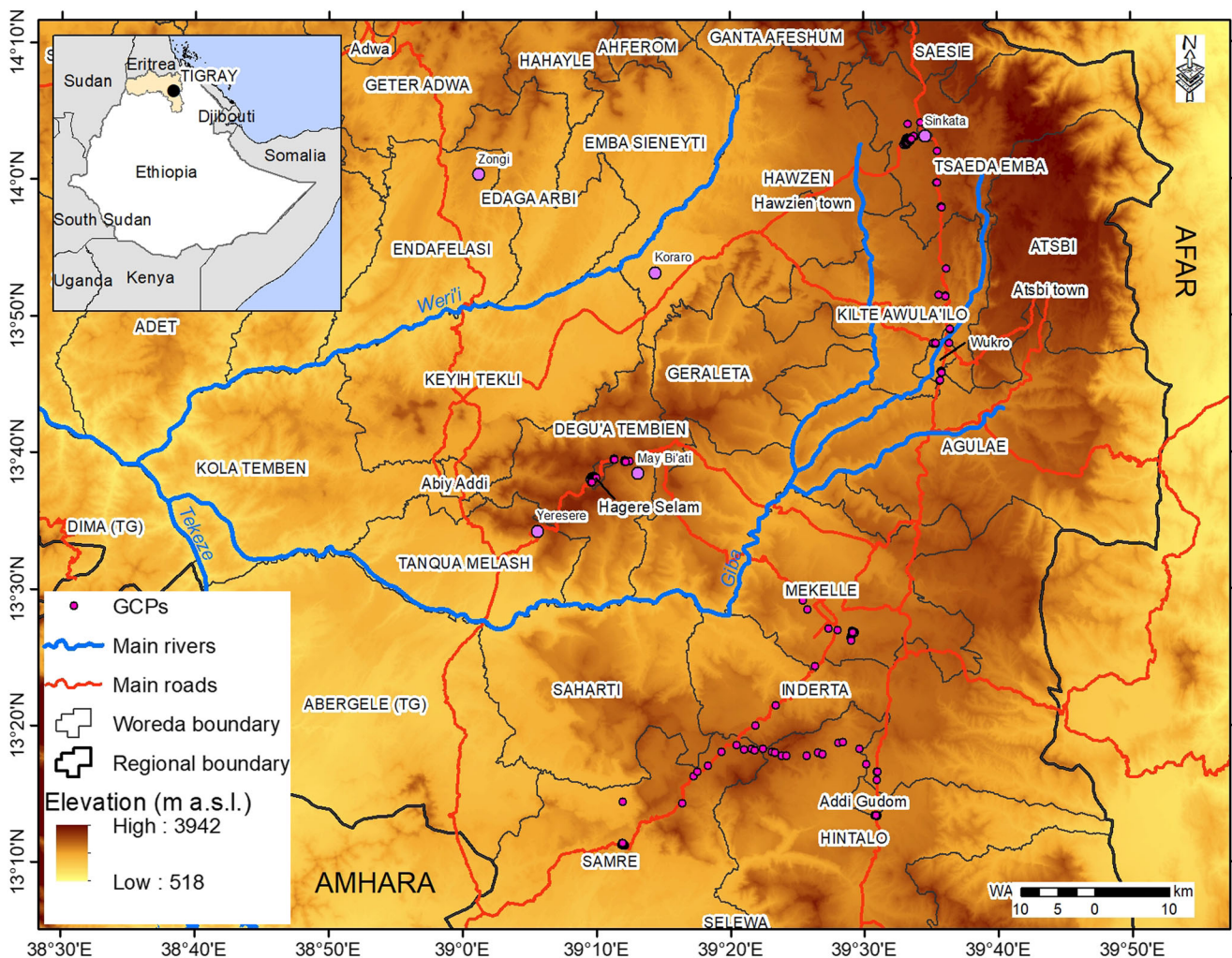


Fig. 2 Study area centered around Tigray's regional capital Mekelle and location of studied farmlands. GCPs, ground control points.

annual rainfall decreasing as one moves away from the equator (Jacob et al. 2013). Rainfall is very seasonal, with a main rainy season in the summer (*kremti*), and a less reliable spring rainy season (*belgi*). Overall, in most places, the crop growing period starts in the month of June and lasts 90 to 120 days (De Pauw and Ramasamy 2017). In the two to three months before this growing period, fine seedbeds are prepared by plowing the land several times with a non-reverting oxen-drawn ard (Gebreegziabher et al. 2009). Once the seedbed is ready and when the soil is sufficiently moist, the seeds are hand broadcast over the land.

When the spring rains are sufficient and soil moisture lasts up to the main summer rainy season, a productive long growing season is possible (*azmera*). At lower and warmer locations, crops with longer growing period requirements will particularly be sown, such as sorghum, maize and finger millet (Frankl et al. 2013). Reversely, the overall short growing period may lead to crop failures with small variations in moisture availability. This is one of the reasons why Tigray is often at risk of crop failure (Gebreegziabher et al. 2009).

### 2.3 Farming system

In the study area, small-scale family farms operate in a cereal-based permanent farming system, where oxen are used for traction (Westphal 1975). Crop agriculture is practiced in Tigray since at least three thousand years (D'Andrea 2008; Blond et al. 2018), which allowed fine-tuning the farming system over time, including great farmers' knowledge of land suitability and seed selection processes (Abay et al. 2008). The indigenous knowledge (*sensu* Bruchac 2018) also comprises a rich language on soil types (Nyssen et al. 2019) and the ability to interpret the rainy season when choosing the crop to be sown (Frankl et al. 2013). Since the 1980s, the egalitarian land tenure regime has been strengthened, what has led to a broad equality in landholding size (Hendrie 1999). A typical household in the study area uses two or three parcels of cropland, together comprising less than a hectare. Grasslands, rangelands, and forests are communally owned and managed (Nyssen et al. 2008).

The basic goal of the indigenous farming system is to increase the food security of the household, as it is predominantly a subsistence farming system. Cropping focusses on cereals, particularly barley (*Hordeum vulgare*), wheat (*Triticum aestivum*), and teff (*Eragrostis tef*), an endemic fine-grained cereal. All study districts are known for wheat and barley production, with Inderta among the top 25 wheat producing districts in Ethiopia, and Inderta and Hintalo among the top 25 for barley (Warner et al. 2019). If the spring rains allow risking a long growing period, maize (*Zea mays*), sorghum (*Sorghum bicolor*), and finger millet (*Eleusine coracana*) are grown (Fig. 3). Nitrogen-fixing legume crops are grown in rotation with cereals such as field pea (*Pisum sativum*), horse bean (*Vicia*

*faba*), grass pea (*Lathyrus sativus*), lentil (*Lens culinaris*), chickpea (*Cicer arietinum*), or fenugreek (*Trigonella foenum-graecum*) (Tsegay et al. 2019). Sowing crop mixtures like field pea-horse bean or wheat-barley (*hanfets*) is common as it allows avoiding total crop failure in case of pest occurrence or drought (Frankl et al. 2013).

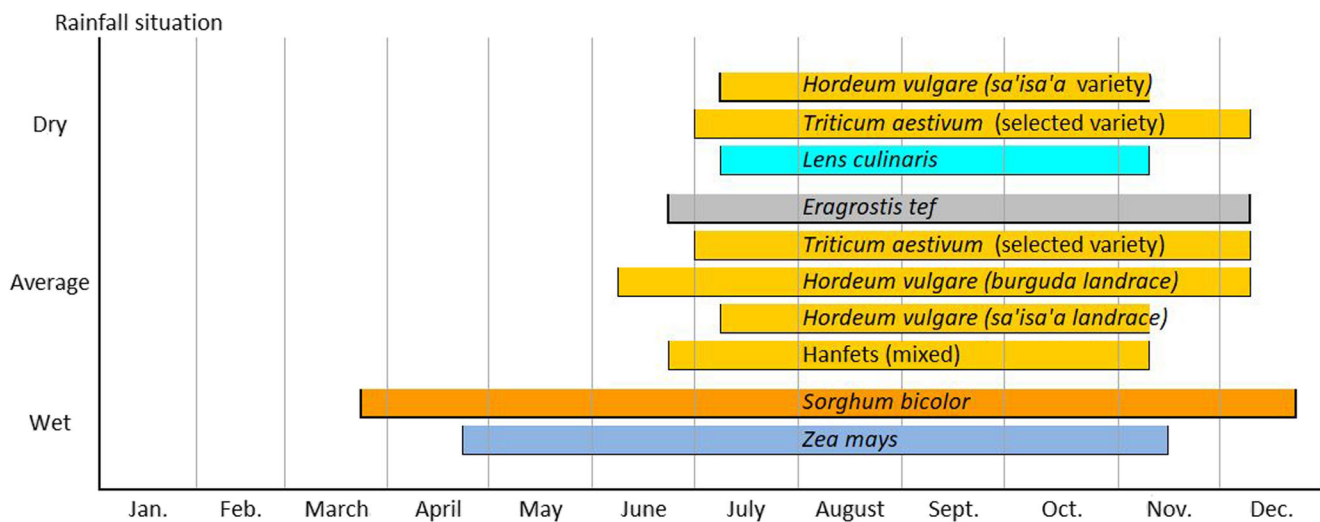
In the crop production systems of the study area, generally, 2 years of cereals are alternated with 1 year of legumes. Block rotation is a common feature; farmers with adjacent lands agree and rotate their crops in the same way over the years. Typically, such rotation blocks include 10–20 farm plots with a combined area of 4 to 7 ha. The creation of larger areas in which the same crop is grown, facilitates protection, and eases stubble grazing after harvest. On fertile soils, cereals may be monocropped for many years without any rotation. Generally, the crop rotation schemes are not very rigid; besides soil nutrient depletion, they also depend on the availability and price of seeds, meteorological conditions, the progress of land preparation, and whether people are available for weeding, especially in case teff is grown. Moreover, high-valued cereals are preferred above legume crops (Nyssen et al. 2008).

Though the inclusion of community fallowing in the block rotation is well-known and positively valued, there are normally few farm plots left fallow (*tsig'e*) because of the high pressure on the land (Nyssen et al. 2008; Redda 2021). Also, the cultivation of legume crops has become spaced within crop rotation schemes (Corbeels et al. 2000). Sometimes, farmers are reluctant to grow no crops at all, but prefer to plant lentils, niger seed (*Guizotia abyssinica*), or linseed (*Linum usitatissimum*) instead when they want to restore the soil fertility (Nyssen et al. 2008). Chickpea is also planted with a single plow operation at the end of the rainy season around end of August and beginning of September.

In the peace years 1990–2020, the Tigray Region heralded a strategy combining conservation-based agricultural development and food security, including pro-poor development programs (Pender and Gebremedhin 2006; Gebremeskel et al. 2018; Förch 2012). The food balance sheet of Tigray indicated that the regional food self-sufficiency had substantially improved over the years (van der Veen and Gebrehiwot 2011).

### 2.4 Characterization of the 2021 rainy season

The 2021 rainfall conditions were analyzed by the time of the year at which normally all crop types had been planted and emerged well. The CHIRPS 2.0 dataset (Funk et al. 2015) covering January 1981–August 2021 was used for this. In the spring months February–April of 2021, rainfall conditions were mostly normal, though extremely dry in southern Tigray (Nyssen et al. 2022). In this period, March 2021, however, was overall abnormally dry with a probability of only 23% for a March being even drier, based on the CHIRPS dataset. Throughout this paper, we follow the AMS (American



**Fig. 3** Crop calendars (from sowing to harvest) in the May Bi'ati valley (2200 m a.s.l., in Dogu'a Tembien), deemed to stand representative for the study area. Tillage takes place in the months before sowing. After Frankl et al. (2013).

Meteorological Society) conventional terminology related to drought (Svoboda et al. 2002). The summer rainfall conditions (up to August) were wetter than normal in large parts of Northern Ethiopia. Particularly, the study area — located in a radius of 70 km around the regional capital Mekelle — experienced moderately to extremely wet rainfall conditions (Fig. S2).

### 3 Methodology

Conducting research in a conflict-stricken environment is highly challenging; hence, data collection was adaptive (Cohen and Arieli 2011; Kara and Khoo 2021; Moss et al. 2019). Due to war conditions, the study area could only be visited by the co-authors residing in Mekelle. The field team visited 161 farm plots in an area representative for the wide-ranging bio-physical conditions of the wider region, particularly with regard to elevation (plots were located at 1767–2598 m a.s.l.), lithology, soil type, rainfall conditions, and hence cropping systems. Land use types other than rainfed farming — such as irrigated land, grassland, barren land, bushland, or forest — have been excluded from the analysis. During transect walks, crop status was recorded, and interviews were conducted with farmers.

Data were transmitted using a rare internet connection (September 1, 2021). The statistical analysis comprised descriptive statistics,  $\chi^2$  tests, as well as a few regression analyses for which purpose the ordinal scale used during observations on the farmlands was promoted to a quantitative interval scale.

#### 3.1 Transect walks

Between August 20 and 30, 2021, we visited 28 ecoregions with different biophysical and agro-ecological characteristics,

along main roads, in six districts: Samre, Hintalo (including croplands at the fringes of Addi Gudom), Inderta (including Mekelle), Dogu'a Tembien (including Hagere Selam), Kilte Awula'ilo (including Wukro), and Tsa'ida Imba. When a new cropland area was reached, the researchers moved several hundreds of meters away from the road to make transect walks (Anderson 2004; Von Maltzahn and Van der Riet 2006) parallel to the road, to talk to the farmers who were present on the land, and to observe and assess the farmlands together with the farmers.

#### 3.2 Semi-quantitative and qualitative data collection

Data collection for each cropland was done through participatory monitoring: recording the crop type, a group assessment of the status of the crop according to local standards (failed, poor, medium, good; taking into account growth features such as plant height, greenness and density, ear length, homogeneity in crop stand), observations of whether or not cropping was done in block by neighboring farmers, as well as a semi-structured interview with the farmer or a group discussion with local people present near the land (Van De Fliert et al. 2000; Nyumba et al. 2018; Young and Hinton 1996). Besides the typical crop status assessment, attention was given to block-wise cropping with neighboring farmers because, similar to three-field systems, this practice is an indicator of (a) an internally well-organized community, and (b) the prevention of disturbances, and hence an outlook on better yields (Nyssen et al. 2008; Hopcroft 1994; Ruthenberg 1980). In these interviews, predetermined questions included the comparison of crop stands to previous years, the state of crops on nearby farmlands, and the presence or absence of block-wise cropping. The remaining questions were follow-ups to the answers provided. Part of the answers was coded manually



(with the help of Excel) and added to the database of the 161 observed farm plots, which has been published (Ghebreyohannes et al. 2022). We organized and analyzed the unstructured data further by categorizing, sorting, and arranging it to find themes and patterns. As the data set was relatively small, we used a step-by-step approach to first familiarize ourselves with the interview results by coding the quantitative portion of it: crop growth condition on the monitored farm parcel; if the land was fallow, had it been plowed or not; and condition of the surrounding farmlands. We then looked for themes to review and related them to our quantitative findings (Nowell et al. 2017).

### 3.3 Statistical analysis

The larger part of the analysis is through descriptive statistics, linked up with qualitative data obtained from the farming communities. The  $\chi^2$  test was used to analyze whether there were significant differences in crop stand distribution between the study districts, and among crop types. For the sake of temporal comparison, detailed information on crop cover for the pre-war situation (2019) was obtained from the Kilte Awula'ilo district's Agricultural Office. Rain conditions in this district were "normal" in 2021 and "moderately dry" in 2019 (Fig. S2). Also here, the  $\chi^2$  test allowed understanding the significance of differences in choice of crop or fallowing between 2019 and 2021.

The categorical data on assessed crop status have also an ordinal character. In assigning them numeric values (0 for failed crop or fallow, 1 for "poor", 2 for "medium" and 3 for "good" crop stand), and assuming equal-appearing intervals (Thurstone 1928), the ordinal scale was promoted to a quantitative interval scale, allowing us to involve the data regarding crop stands in regression analyses, after averaging observational data per district. Potential explanatory variables that were recorded are as follows: longitude, latitude, and altitude; we used also the reported numbers of massacres and civilian victims per district in the period preceding the field observations (Vanden Bempt et al. 2021), as these were assumed to be a proxy for intensity of warfare and for war crimes that could have impacted the farm works.

## 4 Results

### 4.1 Qualitative observations during the crop growth stage

Upon return from field data collection, the local team summarized their qualitative observations (Fig. 4) and farmers' feedback. Farm parcels had not been adequately plowed in all ecoregions visited, as would have happened in the previous years. On most observed farmlands, the crops were also "late,"

i.e., in a growth stage that was too small for the end of August. In many places, the farm activities only really started by the end of June, when governmental and Eritrean soldiers had left the wider surroundings. At the time, everyone who could began working on the land with the surviving oxen, as well as cows and donkeys. While plowing is generally a man's job, this time, it was also done by women and children. Owing to the shortage of human resources and herbicides, weeds were common in almost all farm plots with crops, which was expected to reduce yields. Reversely, due to a lack of off-farm work prospects as a result of the war, a few farmers were able to plow their fields earlier than usual, at least for those who could cope with the aforementioned obstacles. Most farmers did not use chemical fertilizers, as fertilizer supply was either late or very low. Those who applied fertilizer used leftovers from the previous year or had (borrowed) cash to purchase it informally on the black market, a practice that has become common in Tigray, in parallel to the formal fertilizer market (Nyssen et al. 2017).

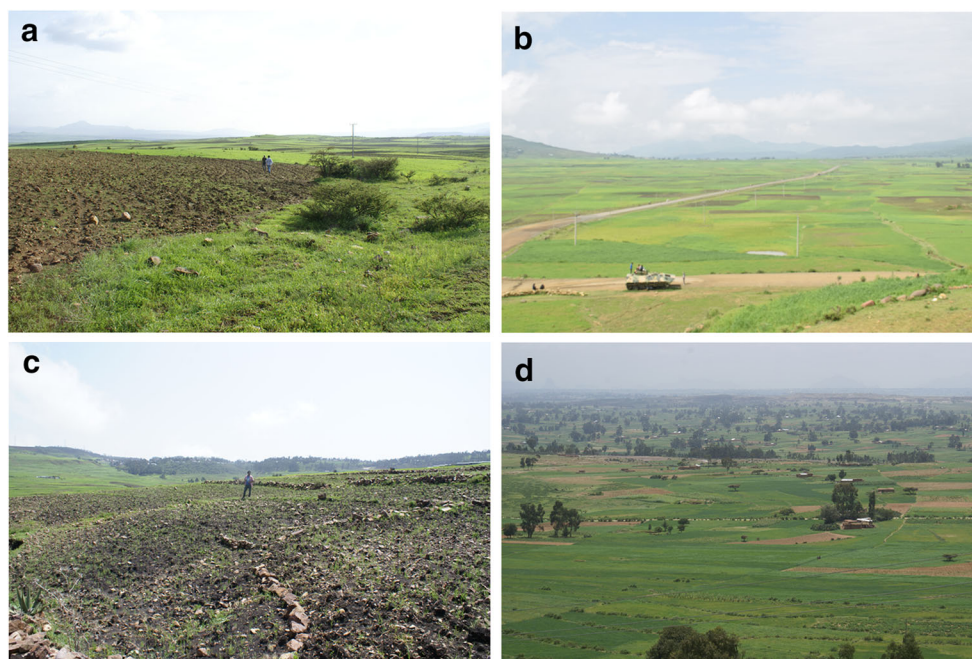
Like in most other sectors, at *woreda* (district) level, the agricultural and rural development offices were generally not operational. Few agricultural development agents (extensionists) were present to advise and assist farmers. "Helpless" farmers were supported in their agricultural activities by the community (labor, borrowing of oxen or seed) and locally by some staff present in the agricultural office.

Crop diversity was highest in *woreda* Tsa'ida Imba, with crops such as potato, sorghum, maize, wheat, barley, lentil, and flax commonly grown on the lands of almost each visited village. Also, the two monitored plots with rainfed potato were in this district (Table S1), which is very well known for potato growing. Consumers of the wider area pay more for these potatoes due to their quality; local traders announce it as the "Sinkata potato."

### 4.2 Quantitative parcel data

The quantitative dataset shows that by the end of August, 21% of the farm parcels had been left fallow without any crops (34 plots out of 161). However, out of these fallow plots, almost half was without weeds indicating that the land had been plowed but not sown. A further 7% of the plots was under oil crops (flax or niger seed), sown because these crops require minimal land preparation or because that was the only seed at hands. Among the cropped lands, half were under wheat, barley, or a mixture of both (*hanfets*), followed by teff. Only 4% of all lands were cropped with maize and a meagre 3% with sorghum (Fig. 5). All seeds were at the farmers' hands from the previous year or had been obtained from other farmers, mostly through bartering and occasionally by borrowing or purchasing.

Among all observed plots with crops, 40% had been sown in block, in concertation with the owners of neighboring lands.



**Fig. 4** Photographic documentation of the qualitative field observations at the end of August 2021: upper left (a) — tef plots in Hintalo district; the plot at the foreground has been sown very lately; upper right (b) — at Dengolat in Samre district, most of the lands have been sown but the crops were too late. The fallow lands at the mid-plan were scattered and not in block, which may indicate that something happened to these families and they could not make it; lower left (c) — emerging grass

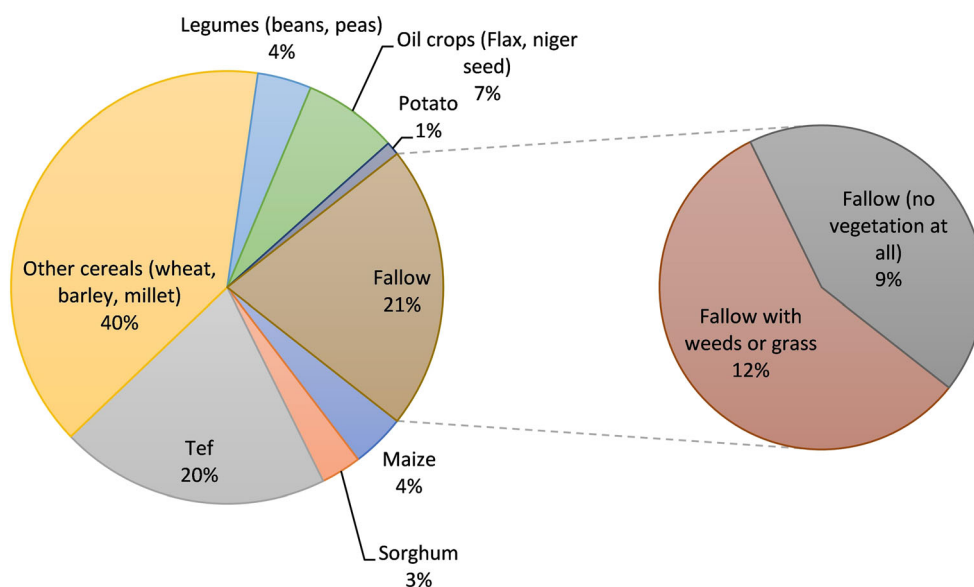
pea with many weeds near Hagere Selam, surrounding crops are too small for the end of August. Some fallowed lands at far; lower right (d) — in Tahtay Sinkata (Tsa'ida Imba district), some plots are covered with maize, scattered over the landscape, those farmers have sown early; other crops are too small for the season. Some plowed lands that remained fallow are also visible.

Especially about half of the wheat and barley parcels were sown in block. For three of the seven lands with maize, it was grown in block, but the five observed lands with sorghum were all stand-alone, with the neighbors growing other crops that had been sown later (Table S1). Small cereals were dominant in all districts, with wheat and barley widely grown in the Inderta and Tsa'ida Imba districts and teff in Samre. The farm plots with

maize were in the districts of Tsa'ida Imba, Hintalo and Samre (Table S1). Oil crops were especially observed in Dogu'a Tembien (flax), Inderta (flax), and Kilte Awula'ilo (flax and niger seed), and the two assessed plots with rainfed potato were in the Tsa'ida Imba district (Table S1).

For the Kilte Awula'ilo district, the percentages of cover by different crop groups could be contrasted between 2019

**Fig. 5** Crop status of 161 investigated rainfed croplands in a radius of 70 km around Mekelle between August 20 and 30, 2021.



(“relatively dry” peace year) and 2021 (war year with “normal” rainfall). The data collection method was totally different in 2019 when there was an exhaustive survey of all agricultural land by the district Agricultural Office. In 2021, on the other hand, we have the 22 sampled fields, selected as being representative of the situation of the district. For the sake of comparison, both datasets were normalized into percentage share of croplands. The share of crop types and fallow lands was significantly different between the two years ( $p < 0.001$ ): In 2021, there has been a very strong decrease in wheat and barley (in yellow on Fig. 6), essentially due to the increases of fallowed land and areas under teff and oil crops.

Nearly half of the wheat and barley lands were in good condition, as well as two of the five sorghum lands. Differences in performance among crop types are however not significant, due to the small number of lands sampled for several crops: Out of the seven lands with maize, four were in poor shape and one totally failed. Other fields in poor condition include 67% of the teff lands and 75% of the oil crops (mainly flax) (Fig. 7; Table S1). Similarly to the qualitative field observations (Sect. 3.1), the quantitative data (Fig. S3) also show that the Tsa'ida Imba district holds the greatest crop diversity: wheat, barley, sorghum, maize, rainfed potato, lentil, and flax.

There was a significant difference in crop performance among districts ( $\chi^2 = 43.6$ ;  $n = 127$ ;  $p < 0.001$ ); particularly in the Hintalo and Samre districts, there were few croplands with “good” performance (Fig. 8). The regression analyses of the data regarding crop stands, treated as quantitative data assuming

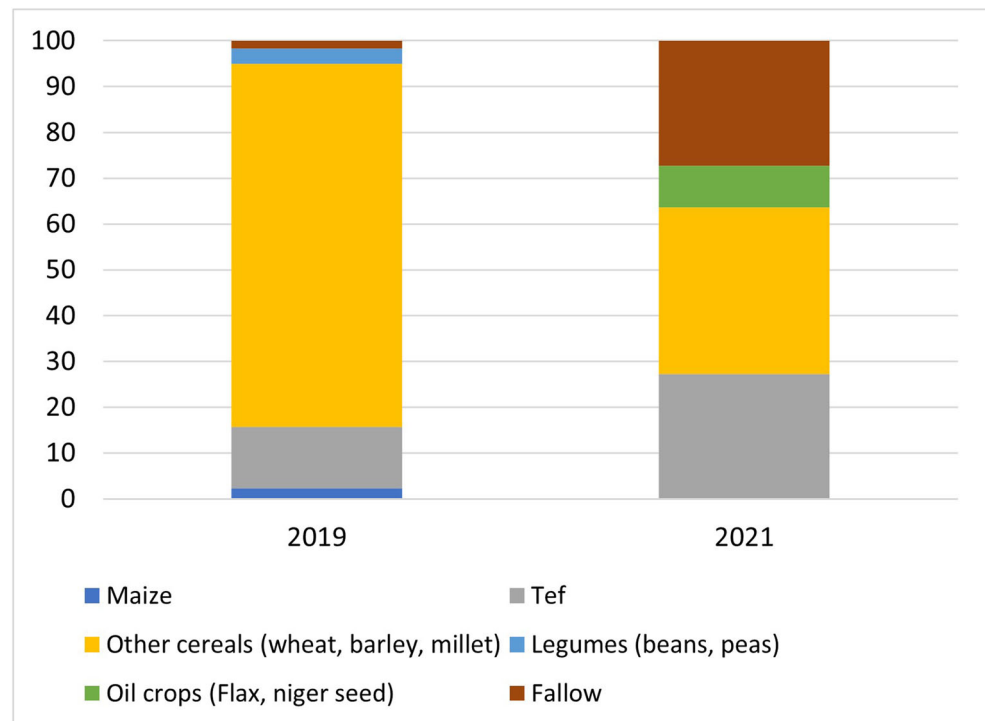
equal-appearing intervals between ordinal categories of crop stands (Thurstone 1928), did not show correlations with parameters related to civilian casualties at district level, most probably because the casualty recording of the Tigray war is not completed (Vanden Bempt et al. 2021). However, if we consider the regional capital Mekelle and surrounds as an outlier that was a bit safer from excesses by governmental troops (Nyssen et al. 2022), we find relatively good correlations between longitude (i.e., distance from the main south-north running road) and average crop status at district level ( $R^2 = 0.56$ ;  $n = 5$ ; n.s.), as well as better crop status in districts at higher (wetter) elevations ( $R^2 = 0.35$ ;  $n = 5$ ; n.s.).

## 5 Discussion

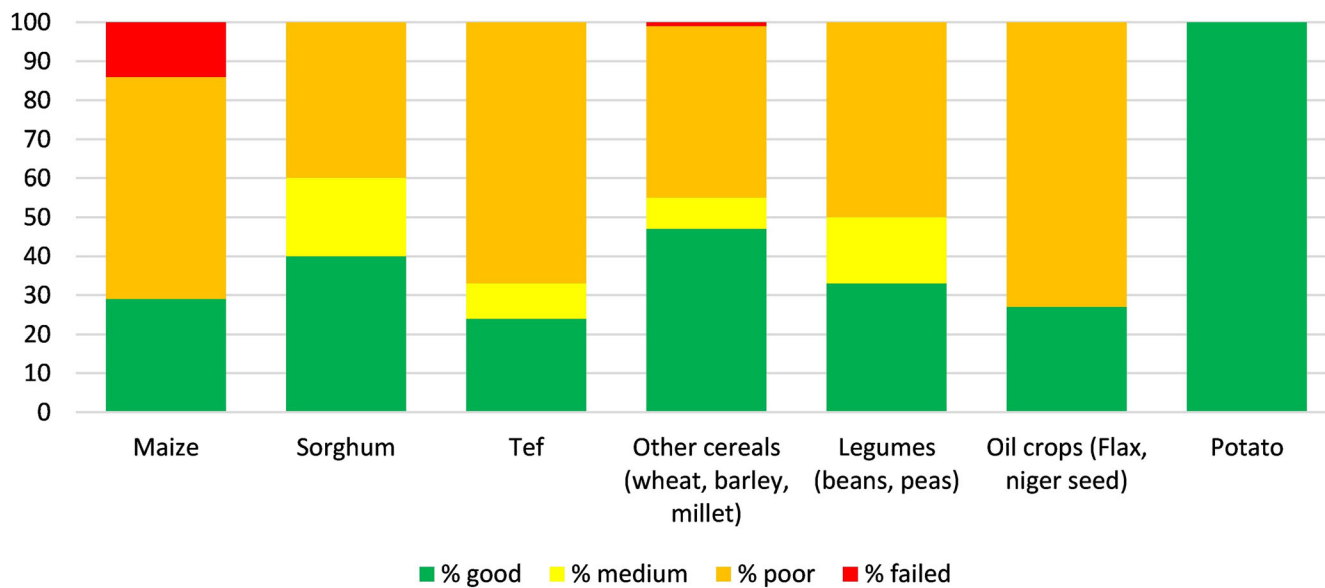
### 5.1 Weediness and fallowing

Here we show for the first time the agronomic roots of the Tigray hunger crisis in 2021–2022, with largely failed planting due to war conditions. The 21% of the land left fallow (Fig. 5; Fig. S4) confirms earlier observations (Nyssen et al. 2022) that a large share of the farmers were either absent (refugees or fighters), forbidden to plow, or were unable to manage their land due to a lack of resources, injuries, sickness, etc. Qualitative observations also showed that when lands had been plowed, it had often been done hastily. Oil crops were especially observed in the *woredas* Dogu'a Tembien, Inderta, and Kilte Awula'ilo (Fig. 6; Table S1). The outlook of oil crops such as flax shows 73% in poor condition (Fig. 7) —

**Fig. 6** Share of crop types and fallow in the Kilte Awula'ilo district in peace year 2019 and war year 2021.





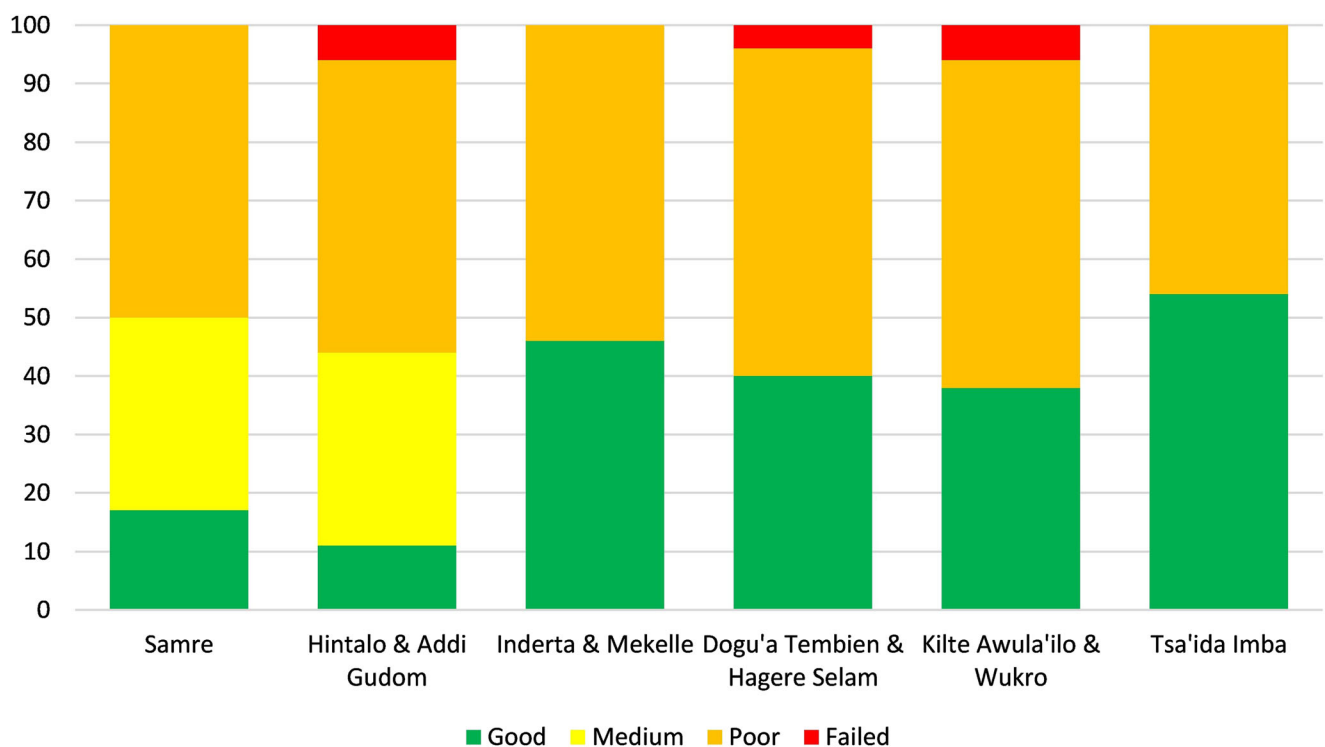


**Fig. 7** Assessment of the crop status per crop type by the end of August 2021. There were only two potato farmlands formally recorded, but casual observations indicated that rainfed potatoes were doing extremely well in the Tsa'ida Imba district, the only location where they were observed.

it is indeed mainly used as an “improved fallow” crop (see Sect. 2.1.3). It also requires little land preparation and is easy to harvest; a farmer lacking helping hands or grain seeds may at least have tried to sow flax to improve his land for the next year. The failed maize has also turned the lands where it was sown into *de facto* fallow. Even the weedy nature of farmlands (Sect. 3.1) makes the lands to bear characteristics of fallow

land. Though these wide “fallow conditions” may be good for aiding the regeneration of future soil fertility, it strongly reduced the yields of the 2021 season.

Since the farmers were late to cultivate their land and there was a lack of farming tools, fertilizer, and manpower, it is evident that farmers were forced to leave some or all of their lands uncultivated. The crops are late because many farmers



**Fig. 8** Assessment of the crop status per district by the end of August 2021, with over 50% of the croplands in poor shape. Overall, there is a strong dichotomy in the dataset, with little room for “medium” crop stands.

could only start cultivation in late June, after governmental and Eritrean troops had left these areas. In the same period, and independently from our research, an NGO worker observed in Koraro (*woreda* Hawzen, slightly west of our study area) that more than a third of the croplands were not sown due to a lack of seeds or oxen, as well as the late onset of rainfall (Tghat 2021a). The lands under teff were for 67% in poor condition (Fig. 7). Teff is a crop with high requirements of workforce (for plowing and for weeding) (Tsegay et al. 2019), while relatives are often not in the village and no money is available to pay temporary laborers. Overall, the observed weediness of the crops is also in line with this lack of time and manpower.

## 5.2 Reliance on cereals

The large share of cropped lands under wheat, barley, or a mixture of both (*hanfets*) (49%) and next under teff (26%) (Fig. 5) is in line with the farmers' desire, more than other years maybe (see Sect. 2.1.3), to grow staple cereals (84% of all sown land), at the expense of legumes. To have one quarter of the land sown with teff (Fig. 6) may surprise; teff is a marketable high-value crop, but with lower yields (Mihretie et al. 2021). Most probably, the large share of land under teff is related to the fact that it could still be sown up to the middle of the rainy season as the crop easily grows on residual moisture after the rains have stopped (Tesfay et al. 2017). Its multiple deployability under adverse conditions is probably one of the reasons why teff emerged as a top crop in semi-arid North Ethiopia (see also D'Andrea 2008). Although teff is not high-yielding compared to wheat, barley, or sorghum, its ability to survive and ensure at least some level of productivity under depauperate conditions makes it a useful part of risk-management strategies. In some cases, risk minimization may be a higher priority for farmers (ancient and modern) than maximizing yields, and this may have been a factor in its domestication (A. Catherine D'Andrea, Department of Archaeology, Simon Fraser University, pers. comm., January 13, 2022).

Barley seeds are commonly kept from year to year by the farming community. For wheat, besides own saved seeds or purchased seeds from local sources (Alemu and Bishaw 2015), farmers increasingly counted on improved seeds provided by governmental institutions over the last years, due to the higher quality and because it is free from weeds — such improved seeds were not available in 2021. Also, farmers commonly have roasted or boiled their wheat and barley seeds and eaten them while hiding in the mountains for the war (Paravicini and Houreld 2021) and then teff became the only “cereal” option left.

The good stands of wheat and barley (47%) as well as sorghum (Fig. 7) are in line with the priority given to cereals for home consumption. Most probably, the little amount of

available fertilizer (Sect. 3.1) and the weeding activities have been concentrated on these lands. Wheat and barley were mostly sown in block (53%) consistent with crops on neighboring lands (Table S1), further indicating the high priority given to these crops. Legume crops such as beans or peas are nearly absent in our sample (5% of the lands that had been effectively cropped; Table S1), even in the traditional legume-growing areas such as the uplands around Hagere Selam (Fig. S3), confirming again the high priority given to cereals.

## 5.3 Lean crops

Similarly to potatoes, and though it is small, the 4% maize cover, in an area that is overall not very suitable for maize except for the Samre District (Table S2), indicates a willingness of the farmers to grow a lean crop. This reflects their resilient behavior towards a crisis, as they have experienced war, droughts and famine multiple times during their or their elders' lifetime (De Waal 1990; Hendrie 1994; Macrae and Zwi 1992). Hence, knowledgeable farmers always save part of their land for “a ready-made crop to be used easily and rapidly as a meal,” called *bsul ekhli*. These are crops that do not need much processing, no milling, no baking, and not being served with sauce. Maize is the most common *bsul ekhli*, and farmers typically try to grow it at least on one small plot (in a lower, i.e., warmer place, or near the homestead). The advantage of maize is that it can be consumed right away: just pick it when it is ripe, and boil or roast it. In extreme cases, the cobs may be picked at kernel milk stage and consumed raw (Ofori and Kyei-Baffour 2009), possibly with some salt. Potato is both a cash crop and a lean crop.

Formally recommended stress-resistant hybrid maize varieties such as the open-pollinated Melkassa 1 have been developed in Ethiopia to give yields in 3 months (CIMMYT 2013; Alemie et al. 2021). For more recent hybrids (Tadesse et al. 2014), the farmers may not have had seeds at hand given the largely dysfunctional agricultural extension services during the war. Yet, as a subsistence farming community, local farmers are very good at keeping their seeds (Teshome Hunduma, Norwegian University of Life Sciences, pers. comm.). Farmers saved seeds of open-pollinated varieties (Melkassa 1) or “local” varieties, such as *kayih 'ilbo* and *tsa'ida 'ilbo*, and have resown them in this planting season. Indeed, local farmers developed such own maize varieties over the years from seeds originally obtained from research centers (Redda 2021).

## 5.4 Failed sorghum and maize planting

In normal conditions, maize and sorghum are planted early in the year, provided rains are good. The 4% cropped with maize and 3% with sorghum (Fig. 5) indicate that farmers could

however hardly use the spring rains for sowing these crops with a long growing period — though the 2021 spring rains were sufficient for planting (Nyssen et al. 2022). The stand-alone growing of sorghum, with the neighbors growing other crops (Table S1), is remarkable. It is common to see sorghum in Tigray occupying wide areas homogeneously (Fig. S5), and a wide array of landraces exist, adapted to agro-ecological variability (Semere et al. 2019). The small areas cropped and the absence of block cropping with sorghum in 2021 indicate that among the farmers who were present, only few dared coming out with their oxen and planting this high-yielding crop in spring, when soldiers were still present in Tigray's countryside (Fig. S6). An additional reason for the small sorghum coverage is that its' harvest comes a month later than other cereals (Fig. 3).

Three out of the seven lands with maize were grown in block (Table S1), which is common practice in order to easily protect the crops from predators (particularly porcupine or *Hystrix cristata*) and theft. Yet, most of the maize lands were in poor shape or the crop even failed. Sorghum was doing a bit better, maybe also because it is more drought-resistant (Amelework et al. 2016) (Fig. 7). The poor status of all crops is most probably due to war-related stress (e.g., destructions, late planting, late or lack of inputs) on the farming communities leading to poor management. In order to succeed maize or sorghum growth, *gemma* plowing, an indigenous supplementary plowing technique about a month after crop emergence, is necessary; it enhances growth by root pruning and crop thinning (Nyssen et al. 2011). Farmers may not have had sufficient manpower, time, or oxen to carry out this supplementary plowing. Many maize and even more sorghum farm parcels are not part of a block in the rotation system (Fig. S7), what makes them sensitive to storm, predator, and human interference, potentially leading to poor stand or failure (Nyssen et al. 2008; Ruthenberg 1980).

The lower share of maize (Fig. 5) is also explained by the fact that none of the studied districts is a top maize-producing area. Yet, our sample shows decrease in two districts where a comparison with a peace year is possible. In Kilde Awula'ilo, no rainfed maize had been planted in 2021, in contrast to 2.3% in 2019 (Fig. 6); and in the Samre district, 12% of the croplands was occupied by maize in 2019, against 7% of its observed croplands in 2021 (Table S2). Though the only observation method possible in 2021, i.e., expert-based selection of representative farm parcels in each ecoregion, contrasts to the exhaustive inventory in 2019, changes observed are consistent.

## 5.5 Insufficient harvest

Our field observations (Sect. 3.1) show that all crops were late, even though some farmers without family help or other resources told that they had been supported in their agricultural

activities by the community, occasionally by the local agricultural development office. Such late plowing particularly affected maize and sorghum. In Tsa'ida Imba, wheat and barley are conventionally sown in early-mid June, while in June 2021 Eritrean soldiers were still in the area. On September 2, 2021, OCHA stated that “only 25% to 50% of the normal cereal production will be available this year as the agricultural planting season has been missed in many parts of Tigray.” The main rainy season's harvest (including grain crops, tubers, fruit and vegetables) in the region fell from  $2.1 \times 10^6$  Mg before the war in 2019 (CSA 2020) to  $0.88 \times 10^6$  Mg in 2021 (Sew 2022).

During this crisis, the farmers' self-organization and struggle for survival still led to 20–50% of the farm plots being “promising” (Fig. 8; Fig. S8); these are lands that were not fallowed, and with medium to good crop stands — land that would allow to yield a reasonable harvest. Nevertheless, the crops were anticipated to be late and rely on sufficient rain until the end of September to sustain crop growth. The earlier-mentioned NGO worker also observed in Koraro that summer season crops grew well and that farmers were trying to weed their crops (Tghat 2021a). However, September rainfall was less than 40 mm (Fig. S9), which, jointly with late sowing, led to a large share of poorly filled grains at harvest time (Fitsum Berhane, pers. comm, professional translator for international media, 26 December 2021; Fig. 1). For instance, in the Yeresere ecoregion (southern edge of Dogu'a Tembien), most wheat grains were partially filled only at harvest. In 2021, given that there was warfare from March up to the end of June in the wider Tembien area, farmers did not have the opportunity to plant sorghum. Planting wheat, barley, *hanfets* mixture, or beans was the only option left. After harvest, the low quality of unprocessed wheat grain in Yeresere (Fig. 1) further suggests that even this crop was sown lately (Fitsum Berhane, pers. comm., 26 December 2021).

However, all-in-all, with distance from the main road, crop status was a bit better; despite guerrilla warfare and reprisal by government troops on civilians (Sky News 2021), farmers in the remoter districts had a greater opportunity to work their farmlands, in contrast to farmers in districts along the main north-south road. In other zones of Tigray, well away from the study area, the situation may be different: often worse such as in Western Tigray, where many more lands have been left fallow, due to ethnic cleansing of the population (Human Rights Watch and Amnesty International 2022), and Northwestern Tigray due to shortage of rainfall, possibly better in Southern Tigray due to better rains and less warfare during the planting season.

## 5.6 Farming system resilience

This study shows, for the first time, how the traditional farming systems in Tigray, in times of war and autarky (2020–



2022) have partially rebounded, mainly relying on indigenous knowledge. Indeed, our field observations (Sect. 3.1) show that the agricultural and rural development offices were working at a low ebb. Hence, farmers did not count on advice from development agents. The Tigray farming communities were largely on their own in 2021, yet their ability of self-organization during this crisis was remarkable. Despite the multiple challenges that farmers encountered (poor access to land, looting of assets), the farmers used their indigenous knowledge of the farming system to a full extent.

The large cropping in block (40% of the sown lands, hardly less than what would be observed in peaceful years), in concertation with the owners of neighboring lands (Table S1), shows that community relations have largely been kept intact. Indeed, smallholder agriculture builds upon intra- and inter-household social relations, which strongly affect the negotiation of production decisions (such as block rotation), acquiring inputs, management of knowledge, and output marketing (Fairhead and Leach 2005). This is in line with earlier observations on the resilience of indigenous farming systems, where informal social structures exist — “away from the towns, the people are creating new administrative structures of their own” (Mulugeta Gebrehiwot, February 2021, pers. comm., senior fellow at the World Peace Foundation, Tufts University, residing in rural Tigray); block-wise crop rotation works perfectly also in absence of government support. Similarly, the farmers substituted the absence of formal seed distribution by a revival of the indigenous village seed exchange system (*sensu* Alemu and Bishaw 2015).

The fact that 9% of the lands had been fallowed, after being plowed was sometimes due to lack of seeds; in other cases, it testifies of good land husbandry by local farmers. Indeed, the best fallowing technique in the study area is not only to interrupt cropping for a year, but also to plow it once at the beginning of the rainy season in order to enhance infiltration (Redda 2021). The early 2021 conditions made plowing of the arable land very difficult, and many farmers additionally may have lost their ox or their homestead. Farmers have also become internally displaced persons (IDPs), forcefully absent from their land. For those remaining, the indigenous social security system, called *idir* (Maxwell et al. 2010) led to farmers sharing what they have including the use of their ox and to help the families of war victims. However, the plight is beyond that. Oxen have been looted, and those that remain may be insufficient to plow all the lands of whole villages. In some villages, there might be no oxen remaining at all (Mulugeta Gebrehiwot, February 2021, pers. comm.).

As a smallholder livelihood system, the local and indigenous dryland farming system is complex (Bauer 1987; Kraaijvanger et al. 2016): It involves a number of crop species, oxen, and other livestock. There are interactions between

the components of the farming system, intercropping, and potential substitutions (Morton 2007). Like other smallholder farming systems, the system includes the use of wild resources (Scoones and Wolmer 2003; Addis et al. 2005), roots, tubers, bulbs, shoots or young stems (Aregay et al. 2017), *Opuntia ficus-indica* cactus fruits (June–August), and cooked pads (Gebru et al. 2019). During the Tigray war, non-agricultural strategies were not available, neither the use of remittances (Ellis 2000) due to blocking of the bank sector, nor off-farm labor (Bolton 2020; FAO 2017) due to the overall collapse of the local economy (Oxford Analytica 2022; Ibreck and de Waal 2021). Among the wide array of possible coping strategies in times of crises (Morton 2007; Davies 2016; Swearingen and Bencherifa 2000; Ziervogel 2004), the local farmers only remained with (i) the indigenous seed supply system (hence restocking critical plant genetic resources) (Sperling and McGuire 2010), (ii) a perfect understanding of farmland management under adverse conditions, (iii) the use of fallowing (possibly accompanied by the strategic use of a single plow operation), (iv) changes in the relative importance of crops (Swearingen and Bencherifa 2000; Kuol 2014; Macrae and Zwi 1994; Adelaja and George 2019), and (v) an indigenous social security system, called “idir” (Maxwell et al. 2010).

Despite crop yields that are significantly below pre-war levels and insufficient to support the farmers’ households, the Tigray farming system has, to some extent, maintained livelihoods in the face of unforeseen stress, demonstrating its resilience. In time and place, the agricultural, ecological, and human systems are interwoven to form one holistic system, and this social-ecological system has demonstrated adaptation and persistence, and it has not been altered. This is in contrast to the findings of Zúñiga-Upegui et al. (2019), who investigated social-ecological systems in the post-conflict environment of Columbia and found a trend toward enhanced cash crop production at the expense of local socio-ecological systems. The concept of resilience has however practical constraints where people’s assets have been completely depleted by successive crises (Ncube 2019). Hence, another year of war and siege would be disastrous for Tigray’s agricultural sector.

## 6 Conclusions

This is the first analysis of the socio-agronomic roots of the Tigray hunger crisis in 2021–2022. Despite the difficult war-time conditions, collecting field data allowed us evaluating the status of cropping in part of the Tigray Region of Ethiopia, by the end of August 2021. We observed that local farming communities are remarkably resilient, also in times of conflict and instability.

When considering earlier mentioned assets for resilience (Choptiany et al. 2015; Lallau 2016; Diserens et al. 2018), local farmers could strongly rely on the opportunities offered by the smallholder farming system and local agroecology, yet external factors of resilience such as off-farm income or support by formal actors, locally, nationally, or internationally, were largely absent. Relying on, partly reviving indigenous knowledge and local practices, farmers have shifted to the production of crops that need minimal effort and resources or teff that could be sown up to the middle of the rainy season.

However, very few lean crops (maize, potato) were planted, and we estimated that only 20–50% of the farmland would produce a reasonable yield. The fallowing and poor crop stands were not related to meteorological conditions, which were slightly wetter than normal. What was growing was well below what is required to sustain the local population in a subsistence farming economy.

Even for the cropped lands, there was a real risk of bad harvest due to failing September rains, low manpower availability needed for processing the harvest, poor conditions of the fields (weeds), and above all, late sowing. These factual findings are valid for the study area and probably the adjacent districts, whereas further away, different rainfall or conflict patterns may have induced other adaptation strategies.

Remarkably, however, using the case of Tigray, the study shows how traditional farming systems in times of autarky may partially rebound, mainly relying on indigenous knowledge.

**Supplementary Information** The online version contains supplementary material available at <https://doi.org/10.1007/s13593-022-00812-5>.

**Acknowledgements** This study could be carried out thanks to support from the local farming communities. Mekelle University, College of Social Sciences and Languages provided a vehicle to carry out the field-work and access to the study area, and fuel was granted by the command post of Mekelle City. We also thank driver Melaku Desta, and Birhanu Belachew, Gebretsadkan Gebremichael, Yafet Tadesse, Desalegn Kiro, and Tadesse Hailemariam for their participation in field data collection, as well as “Every Casualty Counts.” We thank colleagues Kindeya Gebrehiwot, Mitiku Haile, Tesfay Gebremicael, Lutgart Lenaerts, Teshome Hunduma, Stefaan Dondeyne, and Seppe Deckers for useful exchanges of thoughts. Two anonymous reviewers as well as the section editor and editor in chief greatly supported this article with their numerous critical comments and encouragements.

**Authors' contributions** Tesfaalem Ghebreyohannes: conceptualization, funding acquisition, supervision, investigation, data curation, formal analysis, writing — original draft, review and editing; Jan Nyssen: conceptualization, project administration, supervision, writing — original draft, review and editing, formal analysis, validation, methodology, corresponding author; Emnet Negash: visualization, writing — review and editing, formal analysis, software; Hailemariam Meaza: writing — review and editing, investigation; Zbelo Tesfamariam: writing — review and editing, investigation; Amaury Frankl: visualization, writing — review and editing; Biadgilgn Demissie: writing — review and editing; Bert Van Schaeybroeck: writing — review and editing, data curation, software; Alem Redda: writing — review and editing, investigation; Sofie Annys: conceptualization, visualization, writing — review and editing, data

curation; Fetien Abay: conceptualization, writing — review and editing, investigation, formal analysis, validation

**Availability of data and materials** The datasets generated and analyzed in this study are available from the corresponding author on reasonable request.

**Code availability** Not applicable.

## Declarations

**Conflict of interest** The authors declare no competing interests.

**Ethics approval** Not applicable.

**Consent to participate** The interviewed farmers were informed about the conditions and purpose of the research. Verbal informed consent was obtained prior to these interviews.

**Consent for publication** All the authors whose names appeared on the submission approved the version to be published and agreed to be accountable for all aspects of the work in ensuring that the questions related to the accuracy of integrity of any part of the work were appropriately investigated and resolved.

**Open Access** This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit <http://creativecommons.org/licenses/by/4.0/>.

## References

- Abay F, Waters-Bayer A, Bjørnstad Å (2008) Farmers' seed management and innovation in varietal selection: implications for barley breeding in Tigray, Northern Ethiopia. *Ambio*:312–320. [https://doi.org/10.1579/0044-7447\(2008\)37\[312:FSMAII\]2.0.CO;2](https://doi.org/10.1579/0044-7447(2008)37[312:FSMAII]2.0.CO;2)
- ACLED (2022) The Armed Conflict Location & Event Data Project <https://acledata.com/dashboard/#/dashboard> (Consulted on 1/5/2022)
- Addis Standard (2021) Tigray Interim admin. deputy speaks of 'deliberate' attempts to prevent farming; says every part of the region affected by war (12/5/2021). <https://addisstandard.com/news-analysis-tigray-interim-admin-deputy-speaks-of-deliberate-attempts-to-prevent-farming-says-every-part-of-the-region-affected-by-war> (Retrieved on 18 June 2021)
- Addis G, Urga K, Dikasso D (2005) Ethnobotanical study of edible wild plants in some selected districts of Ethiopia. *Hum Ecol* 33(1):83–118. <https://doi.org/10.1007/s10745-005-1656-0>

- Adelaja A, George J (2019) Effects of conflict on agriculture: evidence from the Boko Haram insurgency. *World Dev* 117:184–195. <https://doi.org/10.1016/j.worlddev.2019.01.010>
- AFP (2021) Anti-farming ‘campaign’ under way in Tigray: state official. <https://news.yahoo.com/anti-farming-campaign-underway-tigray-113539985.html> (Retrieved on 18 June 2021). Agence France Presse
- Alemie A, Keesstra S, Stroosnijder L (2010) A new agro-climatic classification for crop suitability zoning in northern semi-arid Ethiopia. *Agric For Meteorol* 150(7–8):1057–1064. <https://doi.org/10.1016/j.agrformet.2010.04.003>
- Alemie A, Prasad P, Gowda P, Zambreski Z, Ciampitti I (2021) Management options for mid-century maize (*Zea mays* L.) in Ethiopia. *Sci Total Environ* 758:143635. <https://doi.org/10.1016/j.scitotenv.2020.143635>
- Alemu D, Bishaw Z (2015) Commercial behaviours of smallholder farmers in wheat seed use and its implication for demand assessment in Ethiopia. *Dev Pract* 25(6):798–814. <https://doi.org/10.1080/09614524.2015.1062469>
- Amelework BA, Shimelis HA, Laing MD, Ayele DG, Tongoono P, Mengistu F (2016) Sorghum production systems and constraints, and coping strategies under drought-prone agro-ecologies of Ethiopia. *S Afr J Plant Soil* 33(3):207–217. <https://doi.org/10.1080/02571862.2016.1143043>
- Anderson J (2004) Talking whilst walking: a geographical archaeology of knowledge. *Area* 36(3):254–261
- Annys S, Vanden Bempt T, Emnet Negash, De Sloover L, Ghekiere R, Haegeman K, Temmerman D, Nyssen J (2021) Tigray: atlas of the humanitarian situation. <https://zenodo.org/record/5805687> (Retrieved on 27 December 2021). <https://doi.org/10.5281/zenodo.5804284>
- Aregay N, Hruy G, Semere T (2017) Potentials and constraints of under-utilized tree fruits and vegetables in Tigray, northern Ethiopia. *J Drylands* 7(2):664–674
- Bauer D (1987) The dynamics of communal and hereditary land tenure among the Tigray of Ethiopia. In: BJ MC, Acheson JM (eds) *The question of the commons*, pp 217–230
- Bérard L (2016) Terroir and the sense of place. In: Gangjee DS (ed) *Research handbook on intellectual property and geographical indications*. Edward Elgar Publishing, pp 72–92. <https://doi.org/10.4337/9781784719470.00013>
- Blond N, Jacob-Rousseau N, Callot Y (2018) Terrasses alluviales et terrasses agricoles. Première approche des comblements sédimentaires et de leurs aménagements agricoles depuis 5000 av. n. è. à Wakarida (Éthiopie). *Géomorphologie: Relief, Processus, Environnement* 24(3):277–300. <https://doi.org/10.4000/geomorphologie.12258>
- Bolton L (2020) The economic situation for individuals and communities in Syria, vol 728. K4D Helpdesk Report Institute of Development Studies, Brighton, U.K
- Bruchac M (2018) Indigenous knowledge and traditional knowledge. In: Smith C (ed) *Encyclopedia of global archaeology*. Springer, New York, USA, pp 3814–3824. [https://doi.org/10.1007/978-1-4419-0465-2\\_10](https://doi.org/10.1007/978-1-4419-0465-2_10)
- Cabell JF, Oelofse M (2012) An indicator framework for assessing agroecosystem resilience. *Ecol Soc* 17(1):18
- Choptiany J, Graub B, Dixon J, Phillips S (2015) Self-evaluation and holistic assessment of climate resilience of farmers and pastoralists (SHARP). FAO, Rome 155. <https://www.fao.org/documents/card/en/c/a78ba721-9e03-4cfc-b04bc89d1a332e54/>
- CIMMYT (2013) Four new maize varieties released in Ethiopia <https://www.cimmyt.org/news/four-new-maize-varieties-released-in-ethiopia/> (consulted on 5 September 2021)
- Cohen N, Arieli T (2011) Field research in conflict environments: methodological challenges and snowball sampling. *J Peace Res* 48(4):423–435. <https://doi.org/10.1177/0022343311405698>
- Corbeels M, Shiferaw A, Haile M (2000) Farmers’ knowledge of soil fertility and local management strategies in Tigray, Ethiopia. IIED-Drylands Programme. Managing Africa’s Soils. No. 10
- CSA (2020) Agricultural sample survey 2019/20; report on area and production of major crops, vol 587. Statistical Bulletin. Central Statistical Agency, Addis Ababa
- D’Andrea AC (2008) T’ef (*Eragrostis tef*) in ancient agricultural systems of highland Ethiopia. *Econ Bot* 62(4):547–566. <https://doi.org/10.1007/s12231-008-9053-4>
- Davies S (2016) *Adaptable livelihoods: coping with food insecurity in the Malian Sahel*. Springer. <https://doi.org/10.1007/978-1-349-24409-6>
- De Pauw E, Ramasamy S (2017) Country case studies of changes in the land resource base for agriculture under climate change: Burkina Faso, Burundi, Ethiopia, Nigeria, Rwanda, Tanzania, Zimbabwe. Technical Report for FAO project “Development of Medium-Term Warning System for Africa”
- De Waal A (1990) *Tigray grain markets and internal purchase*. Oxfam, Oxford, U.K.
- Devi S (2021) Aid blocked as Tigray faces catastrophic hunger. *Lancet* 397(10293):2451. [https://doi.org/10.1016/S0140-6736\(21\)01433-1](https://doi.org/10.1016/S0140-6736(21)01433-1)
- Diserens F, Choptiany JMH, Barjolle D, Graeb B, Durand C, Six J (2018) Resilience assessment of swiss farming systems: piloting the SHARP-tool in Vaud. *Sustainability* 10(12):4435. <https://doi.org/10.3390/su10124435>
- Ellis F (2000) *Rural livelihoods and diversity in developing countries*. Oxford University Press
- Fairhead J, Leach M (2005) The centrality of the social in African farming. *IDS Bull* 36(2):86–90
- FAO (2017) Counting the cost: agriculture in Syria after six years of crisis. Food and Agriculture Organization of the United Nations, Roma, It
- Folke C (2016) Resilience. In: *Oxford research encyclopedia of environmental science*. Oxford University Press. <https://doi.org/10.1093/acrefore/9780199389414.013.8>
- Förch W (2012) Community resilience in drylands and implications for local development in Tigray, Ethiopia. The University of Arizona
- Ford JD, King N, Galappaththi EK, Pearce T, McDowell G, Harper SL (2020) The resilience of indigenous peoples to environmental change. *One Earth* 2(6):532–543. <https://doi.org/10.1016/j.oneear.2020.05.014>
- Frankl A, Jacob M, Haile M, Poesen J, Deckers J, Nyssen J (2013) The effect of rainfall on the spatio-temporal variability of cropping systems and duration of the crop cover in the Northern Ethiopian Highlands. *Soil Use Manag* 29(3):374–383. <https://doi.org/10.1111/sum.12041>
- Funk C, Peterson P, Landsfeld M, Pedreros D, Verdin J, Shukla S, Husak G, Rowland J, Harrison L, Hoell A (2015) The climate hazards infrared precipitation with stations—a new environmental record for monitoring extremes. *Sci Data* 2(1):1–21. <https://doi.org/10.1111/sum.12041>
- Gayim E (2021) The war in Tigray and the challenges faced by the United Nations. *Nordicum-Mediterraneum* 16 (03/01). <https://doi.org/10.33112/nm.16.1.21>
- Gebreegziabher T, Nyssen J, Govaerts B, Getnet F, Behailu M, Haile M, Deckers J (2009) Contour furrows for in situ soil and water conservation, Tigray, Northern Ethiopia. *Soil Tillage Res* 103(2):257–264. <https://doi.org/10.1016/j.still.2008.05.021>
- Gebremeskel G, Gebremicael T, Girmay A (2018) Economic and environmental rehabilitation through soil and water conservation, the case of Tigray in northern Ethiopia. *J Arid Environ* 151:113–124
- Ghebreyohannes T, De Smedt F, Hagos M, Gebresilassie S, Amare K, Kabeto K, Hussein A, Nyssen J, Bauer H, Moeyersons J (2010) Large-scale geological mapping of the Geba basin, northern Ethiopia, vol 9. Tigray Livelihood Papers. VLIR-Mekelle University IUC Programme, Mekelle, Ethiopia



- Gebru M, Oduor F, Lochetti G, Kennedy G, Baye K (2019) Ethiopia's food treasures: revitalizing Ethiopia's underutilized fruits and vegetables for inclusion in the Food-Based Dietary Guidelines for improved diet diversity, nutrition and health of the population. Bioversity International, Rome, Italy and Addis Ababa, Ethiopia
- Ghebreyohannes T, Nyssen J, Negash E, Meaza H, Tesfamariam Z (2022) Spatially explicit dataset on crop status of 161 farm plots in Tigray (20-30 August 2021). PANGAEA. <https://doi.org/10.1594/PANGAEA.943374>
- Guyassa E, Frankl A, Lanckriet S, Demissie B, Zenebe G, Zenebe A, Poesen J, Nyssen J (2018) Changes in land use/cover mapped over 80 years in the Highlands of Northern Ethiopia. *J Geogr Sci* 28(10): 1538–1563. <https://doi.org/10.1007/s11442-018-1560-3>
- Haokip T (2020) Escape agriculture, foraging culture: the subsistence economy of the Kukis during the Anglo-Kuki War. In: Haokip DL (ed) Kipgen N. Against the empire, Routledge India, pp 118–136. <https://doi.org/10.4324/9781003000655>
- Hendrie B (1994) Relief aid behind the lines: the cross-border operation in Tigray. In: Macrae J, Zwi A (eds) War and hunger: rethinking international responses to complex emergencies. Zed Books, London, U.K., pp 125–138
- Hendrie B (1999) Now the people are like a lord - local effects of revolutionary reform in a Tigray village, Northern Ethiopia. PhD dissertation. University College London, London
- Hirvonen K, Seyoum A, Worku I (2016) Seasonality and household diets in Ethiopia. *Public Health Nutr* 19(10):1723–1730. <https://doi.org/10.1017/S1368980015003237>
- Hopcroft RL (1994) The origins of regular open field systems in pre-industrial Europe. *J Eur Econ Hist* 23(3):563
- Human Rights Watch, Amnesty International (2022) "We will erase you from this land" - crimes against humanity and ethnic cleansing in Ethiopia's Western Tigray zone human rights Watch. York, New
- Hunn ES (1999) The value of subsistence for the future of the world. In: Nazarea V (ed) Ethnoecology: situated knowledge/located lives. University of Arizona Press, Tucson, AZ, USA, pp 23–36
- Ibreck R, de Waal A (2021) Introduction: situating Ethiopia in genocide debates. *J Genocide Res* 24:1–14. <https://doi.org/10.1080/14623528.2021.1992920>
- IPC (2022) Country analysis: Ethiopia. <https://www.ipcinfo.org/ipc-country-analysis/en/?country=ETH>
- Istratii R (2021) On the conflict in Tigray. (<https://publicorthodoxy.org/2021/06/29/conflict-in-tigray/>, accessed on 1/1/2022). Public Orthodoxy. Orthodox Christian Studies Center of Fordham University
- Jacob M, Frankl A, Haile M, Zwervaeagher A, Nyssen J (2013) Assessing spatio-temporal rainfall variability in a tropical mountain area (Ethiopia) using NOAA's Rainfall Estimates. *Int J Remote Sens* 34(23):8305–8321. <https://doi.org/10.1080/01431161.2013.837230>
- Jellason NP, Conway JS, Baines RN, Ogbaga CC (2021) A review of farming challenges and resilience management in the Sudano-Sahelian drylands of Nigeria in an era of climate change. *J Arid Environ* 186:104398. <https://doi.org/10.1016/j.jaridenv.2020.104398>
- Kara H, Khoo S-m (2021) Qualitative and digital research in times of crisis: methods, reflexivity, and ethics. Bristol University Press, Policy Press. <https://doi.org/10.2307/j.ctv2321kdr>
- Kraaijvanger R, Veldkamp T, Almekinders C (2016) Considering change: evaluating four years of participatory experimentation with farmers in Tigray (Ethiopia) highlighting both functional and human-social aspects. *Agric Syst* 147:38–50. <https://doi.org/10.1016/j.agsy.2016.05.001>
- Kuol LBD (2014) Confronting Civil War: the level of resilience in Abyei Area during Sudan's Civil War in the 1990s. *Civil Wars* 16(4):468–487. <https://doi.org/10.1080/13698249.2014.981943>
- Lallau B (2016) À la recherche du paysan résilient. *Les Cahiers d'Outre-Mer* 273:139–170. <https://doi.org/10.4000/com.7726>
- Lipton M (2004) Crop science, poverty, and the family farm in a globalising world. In: Proceedings of the 4th International Crop Science Congress, New Directions for a Diverse Planet Crop Science Society of Australia, Brisbane, Australia
- Macrae J, Zwi A (1992) Food as an instrument of war in contemporary African famines: a review of the evidence. *Disasters* 16(4):299–321. <https://doi.org/10.1111/j.1467-7717.1992.tb00412.x>
- Macrae J, Zwi A (1994) Famine, complex emergencies and international policy in Africa: an overview. In: Macrae J, Zwi A (eds) War and hunger: rethinking international responses to complex emergencies. Zed Books, London, U.K., pp 6–36
- Maxwell D, Coates J, Tadesse G, Abdissa F, Hailu S, Shishigu E, Zeweld W, Mezgebe K, Gebrekiros A (2010) Africa community resilience programme Tsaeda Amba Woreda, Eastern Tigray. Feinstein International Centre, Tufts University, USA, Ethiopia
- Mihretie F, Tsunekawa A, Bitew Y, Chakelie G, Derebe B, Getahun W, Beshir O, Tadesse Z, Asfaw M (2021) Teff [*Eragrostis tef* (Zucc.)] rainfed yield response to planting method, seeding density, and row spacing. *Agron J* 113(1):111–122. <https://doi.org/10.1002/agj2.20462>
- Morton JF (2007) The impact of climate change on smallholder and subsistence agriculture. *Proc Natl Acad Sci* 104(50):19680–19685. <https://doi.org/10.1073/pnas.0701855104>
- Moss SM, Ulug ÖM, Acar YG (2019) Doing research in conflict contexts: practical and ethical challenges for researchers when conducting fieldwork. *Peace Conflict J Peace Psychol* 25(1):86–99. <https://doi.org/10.1037/pac0000334>
- Müller TR, Read R (2021) Editors' introduction: humanity and solidarity. *J Humanit Affairs* 3(1):1–3. <https://doi.org/10.7227/JHA.053>
- Ncube N (2019) Measuring resilience in Somalia: an empirical approach. University of South Africa
- Nowell LS, Norris JM, White DE, Moules NJ (2017) Thematic analysis: striving to meet the trustworthiness criteria. *Int J Qual Methods* 16(1):1609406917733847
- Nyssen J, Naudts J, De Geyndt K, Haile M, Poesen J, Moeyersons J, Deckers J (2008) Soils and land use in the Tigray highlands (Northern Ethiopia). *Land Degrad Dev* 19(3):257–274. <https://doi.org/10.1002/ldr.840>
- Nyssen J, Govaerts B, Araya T, Cornelis WM, Bauer H, Haile M, Sayre K, Deckers J (2011) The use of the marasha ard plough for conservation agriculture in Northern Ethiopia. *Agron Sustain Dev* 31(2): 287–297. <https://doi.org/10.1051/agro/2010014>
- Nyssen J, Biruk B, Tesfamariam Z, Frankl A, Demissie B, Gebreyohannes T, Meaza H, Poesen J, Van Eetvelde V, Zenebe A (2017) Geographical determinants of inorganic fertiliser sales and of resale prices in north Ethiopia. *Agric Ecosyst Environ* 249:256–268. <https://doi.org/10.1016/j.agee.2017.07.037>
- Nyssen J, Tielens S, Gebreyohannes T, Araya T, Tekla K, Van de Wauw J, Degeyndt K, Descheemaeker K, Amare K, Haile M, Zenebe A, Munro N, Walraevens K, Gebrehiwot K, Poesen J, Frankl A, Tsegay A, Deckers J (2019) Understanding spatial patterns of soils for sustainable agriculture in northern Ethiopia's tropical mountains. *PLoS ONE* 14(10):e0224041. <https://doi.org/10.1371/journal.pone.0224041>
- Nyssen J, Negash E, Van Schaeybroeck B, Haegeman K, Annys S (2022) Crop cultivation at wartime – plight and resilience of Tigray's Agrarian Society (North Ethiopia). *Def Peace Econ*:1–28. <https://doi.org/10.1080/10242694.2022.2066420>
- Nyumba T, Wilson K, Derrick CJ, Mukherjee N (2018) The use of focus group discussion methodology: insights from two decades of application in conservation. *Methods Ecol Evol* 9(1):20–32. <https://doi.org/10.1111/2041-210X.12860>
- Ofori E, Kyei-Baffour N (2009) Agrometeorology and maize production. In: Guide on agricultural meteorological practices (GAMP), vol 134. World Meteorological Organisation/Technical Committee for Agro-Meteorology (WMO/CAGM), pp 1–19

- Oxford Analytica (2021) Ethiopia faces undiminished Tigray famine risk. Emerald Expert Briefings (oxan-es). <https://doi.org/10.1108/OXAN-ES262096>
- Oxford Analytica (2022) Prospects for East Africa in 2022. Emerald Expert Briefings. <https://doi.org/10.1108/OXAN-DB265348>
- Paravicini G, Hourelld K (2021) UN official accuses Eritrean forces of deliberately starving Tigray. Reuters
- Pellet P (2021) Understanding the 2020–2021 Tigray conflict in Ethiopia—background, root causes, and consequences, vol 39. KKI Elemzése
- Pender J, Gebremedhin B (2006) Land management, crop production, and household income in the highlands of Tigray, Northern Ethiopia: an econometric analysis. *Strategies for sustainable land management in the East African highlands*:107–139
- Plaut M (2021) The Tigray Famine. *RUSI J* 166(4):22–28. <https://doi.org/10.1080/03071847.2021.1981630>
- Quinlan RJ, Quinlan MB, Dira S, Caudell M, Sooge A, Assoma AA (2015) Vulnerability and resilience of Sidama enset and maize farms in Southwestern Ethiopia. *J Ethnobiol* 35(2):314–33 323
- Ramos M (2021) Tigray tragedy, a graphic essay. *Stichproben - Vienna. J Afr Stud* 41. [https://doi.org/10.25365/phaidra.310\\_01](https://doi.org/10.25365/phaidra.310_01)
- Redda A (2021) Maize farmers and climate change in Tigray. May Tsebr Agricultural Research Centre, Shire, Tigray, Ethiopia
- Richards P (1985) Indigenous agricultural revolution. Hutchinson, London
- Ringer JJ, Sallee J, Terry R, Brown N, Watters C, Blackwell S (2021) A phenomenological study of individual strategies for rebuilding food production ability in resource poor postconflict farming communities in Myanmar. *J Int Agric Ext Educ* 28(3):57–69. <https://doi.org/10.5191/JIAEE.2021.28357>
- Ruthenberg H (1980) *Farming systems in the tropics*. Clarendon Press, Oxford
- Schroeder RF (1985) Himalayan subsistence systems: indigenous agriculture in rural Nepal. *Mt Res Dev* 5:31–44
- Scoones I, Wolmer W (2003) Livelihoods in crisis: challenges for rural development in southern Africa. *IDS Bull* 34(3):1–14. <https://doi.org/10.1111/j.1759-5436.2003.tb00073.x>
- Semere T, Tsehaye Y, Westengen O, Fijellheim S (2019) Analysis of phenotypic diversity in Sorghum (*Sorghum bicolor* (L.) Moench) landraces in situ in Tigray, northern Ethiopia. Paper presented at the Plants, People, Planet Symposium, Royal Botanic Gardens, Kew, London
- Sew M (2022) Tigray's once-thriving agriculture sector has been purposely destroyed. *Ethiopia Insight*
- Sky News (2021) Ethiopia: hundreds executed, thousands homeless - the human cost of fighting in Tigray <https://news.sky.com/story/ethiopia-hundreds-executed-thousands-homeless-the-human-cost-of-fighting-in-tigray-12247307> (Accessed on 17/3/2021). 17 March 2021
- Sperling L, McGuire S (2010) Understanding and strengthening informal seed markets. *Exp Agric* 46(2):119–136. <https://doi.org/10.1017/S0014479709991074>
- Stratton RJ, Green CJ, Elia M (2003) Disease-related malnutrition: an evidence-based approach to treatment. Cabi, Wallingford, U.K. <https://doi.org/10.1079/9780851996486.0000>
- Svoboda M, LeComte D, Hayes M, Heim R, Gleason K, Angel J, Rippey B, Tinker R, Palecki M, Stooksbury D (2002) The drought monitor. *Bull Am Meteorol Soc* 83(8):1181–1190. <https://doi.org/10.1175/1520-0477-83.8.1181>
- Swearingen W, Bencherifa A (2000) An assessment of the drought hazard in Morocco. In: Wilhite DA (ed) *Drought: a global assessment*. Routledge, London, pp 279–286
- Tadesse D, Medhin ZG, Ayalew A (2014) Participatory on farm evaluation of improved maize varieties in Chilga district of North Western Ethiopia. *Int J Agric For* 4(5):402–407. <https://doi.org/10.5923/j.ijaf.20140405.09>
- Tesfay M, Shimelis H, Laing M, Assefa K (2017) Achievements and gaps in tef productivity improvement practices in the marginal areas of Northern Ethiopia: implications for future research directions. *Int J Agric Sustain* 15(1):42–53. <https://doi.org/10.1080/14735903.2016.1173990>
- Tghat (2021a) An August 21 NGO worker's raw notes of his visit to the Koraro village in Tigray. <https://www.tghat.com/2021/08/26/an-august-21-ngo-workers-raw-notes-of-his-visit-to-the-koraro-village-in-tigray/> (consulted on 2/9/2021)
- Tghat (2021b) Unprecedented migration, death, and famine unseen in this nation are coming to Tigray, says Tigray's Head of Agriculture and Rural Development. <https://www.tghat.com/2021/04/20/unprecedented-migration-death-and-famine-unseen-in-this-nation-are-coming-to-tigray-says-tigrays-head-of-agriculture-and-rural-development/> (20/4/2021, consulted 3/8/2021)
- Thurstone L (1928) Attitudes can be measured. *Am J Sociol* 33:529–554 <http://www.jstor.org/stable/2765691>
- Tittonell P, Giller KE (2013) When yield gaps are poverty traps: the paradigm of ecological intensification in African smallholder agriculture. *Field Crop Res* 143:76–90. <https://doi.org/10.1016/j.fcr.2012.10.007>
- Tsegay A, Abriha B, Hruy G (2019) Major crops and cropping systems in Dogu'a Tembien. In: *Geo-trekking in Ethiopia's tropical mountains*. Springer, pp 403–413. [https://doi.org/10.1007/978-3-030-04955-3\\_27](https://doi.org/10.1007/978-3-030-04955-3_27)
- Unwin T (2012) Terroir: at the heart of geography. In: Dougherty PH (ed) *The geography of wine*. Springer, pp 37–48. [https://doi.org/10.1007/978-94-007-0464-0\\_2](https://doi.org/10.1007/978-94-007-0464-0_2)
- USAID (2022) Ethiopia – Northern Ethiopia crisis, vol 4. Fact sheet. United States Agency for International Development
- Van De Fliert E, Asmunati R, Tantowijoyo W (2000) Participatory approaches and scaling-up. In: Paper presented at the CIAT Workshop “Working with farmers: the key to adoption of forage technologies”. CIAT, pp 1–12
- van der Veen A, Gebrehiwot T (2011) Effect of policy interventions on food security in Tigray, Northern Ethiopia. *Ecol Soc* 16(1):18. <https://doi.org/10.5751/ES-03895-160118>
- Vanden Bempt T, Annys S, Negash E, Ghekiere R, Nyssen J (2021) Tigray: one year of conflict – casualties of the armed conflict, 2020–2021 – Tigray (Ethiopia). Ghent University, Department of Geography & Every Casualty Counts, Ghent (Belgium) & London (U.K.)
- Von Maltzahn R, Van der Riet M (2006) A critical reflection on participatory methods as an alternative mode of enquiry. *New Voices Psychol* 2(1):108–128
- Walker B, Holling CS, Carpenter SR, Kinzig A (2004) Resilience, adaptability and transformability in social–ecological systems. *Ecol Soc* 9(2):5
- Wamer J, Stehulak T, Kasa L (2019) Woreda-level crop production rankings in Ethiopia: a pooled data approach. *Gates Open Res* 3(316). <https://doi.org/10.21955/gatesopenres.1115066.1>
- WeForest (2021) Securing the next harvest. [www.weforest.org](http://www.weforest.org)
- Weldemichel TG (2021) Inventing hell: how the Ethiopian and Eritrean regimes produced famine in Tigray. *Hum Geogr*: 19427786211061431. <https://doi.org/10.1177/19427786211061431>
- Westphal E (1975) *Agricultural systems in Ethiopia*. Centre for Agricultural Publishing and Documentation, Wageningen
- WFP (2022) Emergency food security assessment: Tigray Region, Ethiopia - January 2022. World Food Programme, Rome, Italy
- Wittman H (2011) Food sovereignty: a new rights framework for food and nature? *Environ Society* 2(1):87–105. <https://doi.org/10.3167/ares.2011.020106>
- World Peace Foundation (2021) *Starving Tigray*. The Fletcher School of Law and Diplomacy. Tufts University, USA
- Young D, Hinton R (1996) *An introduction to participatory appraisal techniques: sharing experience from China and Nepal*. VSO, London

- Zenebe A (2009) Assessment of spatial and temporal variability of river discharge, sediment yield and sediment-fixed nutrient export in Geba river catchment, northern Ethiopia. Ph.D. thesis. Department of Earth and Environmental Sciences, K.U.Leuven, Leuven
- Ziervogel G (2004) Targeting seasonal climate forecasts for integration into household level decisions: the case of smallholder farmers in Lesotho. *Geogr J* 170(1):6–21. <https://doi.org/10.1111/j.0016-7398.2004.05002.x>
- Zúñiga-Upegui P, Arnaiz-Schmitz C, Herrero-Jáuregui C, Smart SM, López-Santiago C, Schmitz M (2019) Exploring social-ecological systems in the transition from war to peace: a scenario-based approach to forecasting the post-conflict landscape in a Colombian region. *Sci Total Environ* 695:133874

**Publisher's note** Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.