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Drivers of agricultural profitability in GIZ-rehabilitated dry lands: Evidence from field research conducted in the Ethiopian Somali Region.

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CONTENT

List of Figures

List of Tables

LIST OF ACRONYMS

ADV	Amadle Dry Valley
CSA	Central Statistical Agency
DDP	Drylands Development Paradigm
DSES	Dryland social-ecological systems
DV	Dry valley
DVRPU	Dry Valley Rehabilitation and Productive use
DVUC	Dry Valley User Cooperatives
GIZ	Gesellschaft für Internationale Zusammenarbeit
GM	Gross margin
HDV	Harre Dry Valley
IDP	Internally Displaced Person
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IPCC	United Nations' Intergovernmental Panel on Climate Change
MCD	Masonry Check Dams
NGO	Non-governmental organisation
SDGs	Sustainable Development Goals
SES	Social-ecological system
SLM	Sustainable Land Management
UN	United Nations
UNCCD	UN Convention to Combat Desertification
WSW	Water-spreading weirs

1 INTRODUCTION

Having been designated as “existential threat”, “crisis multiplier”, “defining issue of our time” and “fundamental challenge” (UN, 2024), climate change represents one of the major problems humanity faces today. The latest report of the United Nations’ (UN) INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (IPCC) (2023) confirms that human activities are the reason for the changing climate, especially through greenhouse gas emissions in “industry, energy supply, transport, agriculture and buildings” (p. 44). The associated increasing global warming leads to partly irreversible effects such as biodiversity loss or extreme weather patterns making it indispensable to prevent this development in a very short time frame (IPCC, 2023).

The report further reveals that climate change related risks for all particularly worrying areas of concern[1] are much higher than presumed before (IPCC, 2023). Apart from that, the magnitude of effects associated with those risks is projected to be a lot more severe than previously assumed (ibid.). Being currently at a 1.1 degree increase of the planet’s temperature[2], a rise to 1.5 degrees implies, among others, an escalation in frequency and intensity of strong rainfall and flooding emergencies particularly in Asia and Africa, an expectation made with high confidence[3] (ibid.). A temperature rise of more than 1.5 degrees has increasingly harmful and cascading consequences for life on earth (ibid.). One of the ecosystems subject to disproportionately elevated risk are the planet’s drylands (ibid.). Those are particularly subject to climate change intensified land degradation (ibid.).

Several international contracts underline the relevance of degradation such as the UN Resolution 3054 recognizing the drought in the Sudano-Sahelian region in 1973 (UN, 2013), the UN Convention to Combat Desertification (UNCCD) from 1992 (UNFCCC, 2023) or the Sustainable Development Goals (SDGs) from 2015 (UN, 2015). Economic losses were associated with degraded land already in 1992, when the UNCCD aimed to increase land productivity (UN, 1994). Today, seven of the 17 SDGs, commonly referred to as Agenda 2030, recommend taking land resources into account (TÓTH ET AL., 2018). SDG 15 specifically aims

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[1] The framework describing the Reasons for Concern includes five categories related to distinctive and vulnerable systems, severe weather phenomena, spread of consequences, worldwide overall effects and major singular events (IPCC, 2023).

[2] “Global surface temperature was around 1.1°C above 1850–1900 in 2011–2020” (IPCC, 2023, p. 42).

[3] „A level of confidence is expressed using five qualifiers: ‘very low,’ ‘low,’ ‘medium,’ ‘high,’ and ‘very high.’ It synthesizes the author teams’ judgments about the validity of findings as determined through evaluation of evidence and agreement“ (IPCC, 2010, p. 3) while „increasing levels of evidence and degrees of agreement are correlated with increasing confidence“ (ibid.).

to “restore degraded land and soil, including land affected by desertification, drought and floods” (UN, 2015, p. 24).

Land degradation diminishes biomass productivity and is caused, among others, by human activities, loss of vegetation or soil erosion through water and wind (UN, 1994) which is exacerbated by floods and droughts (DESTRIJCKER ET AL., 2023). Droughts favour soil erosion by wind (FAO & ITPS, 2015) and diminish the water absorbing ability of the soil (WMO, 2023) while floods lead to soil erosion by water, a process in which topsoil and fertile sediments are lost rapidly through the overland water flow, which cuts channels or gullies into the land (FAO & ITPS, 2015). This in turn diminishes water holding ability and fertility further, which are crucial for plant growth as well as food and forage production (ibid.).

Many people affected by soil erosion are humans living in (agro-) pastoralist communities as this is the most common production system in drylands (GIZ, 2023c) which relies on livestock and agriculture (MOGES, 2021). The dependence on those already scarce resources (WORLD BANK, 2019a) renders (agro-) pastoralists particularly vulnerable to climatic conditions (MOGES, 2021) such as droughts which are occurring more and more often in Africa (MASIH ET AL., 2014). The Horn of Africa[4] is the driest part of the whole continent (MOGES, 2021) and among the regions in the world most susceptible to climate shocks (WFP, 2023a).

This area experienced three severe droughts since 2010 (OCHA, 2023b), the one lasting from 2020 to 2023 being the heaviest since 60 years (WFP, 2023a) resulting in 36.4 million affected people (OCHA, 2023b) and two million being displaced (IOM, 2022). High food insecurity was one of the consequences for about 23 million humans, with 4.4 million in Kenya, 6.7 million in Somalia, and 11.8 million in Ethiopia (WFP, 2023a). This period of drought was followed by abnormally large amounts of precipitation starting in April 2023 which lead to floods while drought-affected soils had lost water-absorbing capacities (WMO, 2023). Subsequent rains of October to December 2023 were 140 per cent more than average, again resulting in floods (WFP, 2023b).

Ethiopia, inhabited with the second highest population of Africa’s countries (WORLD BANK, 2019b) of which 80 per cent rely on agriculture as livelihood (FAO, 2017) while 75 per cent of the country’s surface area are classified as drylands (GEORGIS, 2015), is subject to floods and droughts occurring more frequently (BMZ, 2023; WORLD BANK, 2019b). While producing very

[4] This encompasses Somalia, Kenya and Ethiopia (OCHA, 2023b).

few amounts of greenhouse gas emissions (GEORGIS, 2010), with already six subsequent insufficient or rainless wet periods (WORLD BANK, 2023) and following extreme flooding events (ACTION AGAINST HUNGER, 2023), the nation faces a prospect of being severely hit by climate change effects (OCHA, 2024). It ranks 22nd out of the countries featuring highest vulnerability and least readiness to increase resilience to climate change (ibid.). The nation is already subject to severe land degradation (HURNI ET AL., 2015) with 25 per cent being degraded (GEORGIS, 2021), most pronounced in the country's drylands (MOA & PENHA, 2022), and aggravated by overgrazing, deforestation, inadequate production methods in agriculture as well as rapid population growth and, thus, rising demands of people (KASSA, 2021).

Numerous measures countering land degradation have been implemented and researched mainly in Ethiopia's highlands since 1970 (ABERA ET AL., 2020; HURNI ET AL., 2015; MEAZA ET AL., 2020) up to an assessment of the state of land degradation and potential economic gains of restoration impacts (HURNI ET AL., 2015). However, Ethiopia's lowlands, although covering 60 per cent of the country's surface area (WORLD BANK, 2019b), have not been treated and investigated in the same way (MEAZA ET AL., 2020). Its population, however, represents 12 to 14 per cent of Ethiopia's inhabitants (WORLD BANK, 2019b) and features considerably worse scores in economic and social indicators such as literacy or education access compared to national averages (ESS & WORLD BANK., 2023; WORLD BANK, 2019b). Livelihoods are based on rainfed small-scale livestock and arable production while grazing resources decline due to expanded crop production (GEORGIS, 2010). Traditionally low precipitation (GUMMADI ET AL., 2018) favours droughts (GEORGIS, 2010), while heavy rainfall events are common (GUMMADI ET AL., 2018), leading to numerous gully formations (RETTBERG ET AL., 2017) and, thus, compromising agricultural production (FAO & ITPS, 2015).

In the Ethiopian lowland region Somali, (agro-) pastoralism as the most important income source meets an arid and semi-arid climate, scarce cropland, low commercial value of produced crops and high population growth (DESTRIJCKER ET AL., 2023). Internally displaced persons (IDPs) due to conflict (ibid.) and high numbers of refugees (OCHA, 2024; TUFA, 2024) add to the population pressure. Droughts have a severe impact here, with 391,573 drought induced IDPs in December 2023 (IOM, 2024), decreasing crop production (REACH INITIATIVE, 2024) and resulting dependence on food aid (ACAPS, 2017). Floods caused by heavy rains decrease food security even more (DESTRIJCKER ET AL., 2023) as they impair planting and harvesting (REACH INITIATIVE, 2024) and cause further large-scale displacement (IDMC, 2024). Those climate hazards increase food insecurity (ibid., EAST AFRICA ENGINEERING AND GENERAL

CONSULTANT, 2018; UNEP, 2022) which is reflected in reports of international institutions (IFRC, 2022; IOM, 2023; OCHA, 2023a; WFP, 2020) and have led to constant humanitarian aid supply delivered to the region (WORLD BANK & UNITED KINGDOM'S DEPARTMENT FOR INTERNATIONAL DEVELOPMENT, 2019). The large-scale soil erosion is clearly visible, manifested in gully formations (GEBREMESKEL ET AL., 2019; GIZ, 2023c). A field excursion to the Somali region in July 2023 allowed direct observation of the severe degree of erosion involving various meter-deep gullies.

This situation is addressed, among others, by the German development cooperation represented by the Gesellschaft für Internationale Zusammenarbeit (GIZ). To reclaim dry zones and diversify income opportunities in a holistic, integrated and multidimensional fashion, GIZ designed the Dry Valley Rehabilitation and Productive Use (DVRPU) Approach (GIZ, 2022a, 2023c). It has been implemented first in the Ethiopian Afar region, subsequently in Somali and Oromia regions (GIZ, 2024a) and will be soon introduced in Southern Nations, Nationalities, and Peoples' region (GIZ, 2024b). The approach intends to improve drought resilience and living conditions for (agro-) pastoralists in Dry Valleys (DVs) considering apart from biological and technical aspects also social, economic, governmental and institutional dimensions (GIZ, 2023c). Those are taken into account through the seven steps (1) satellite identification and DV delineation, (2) suitability assessment, (3) community participatory planning, (4) DV user cooperative societies, (5) technical and budgetary planning, (6) land rehabilitation measures, mainly in the form of water spreading weirs (WSW), and (7) productive use which is designed to ensure an efficient utilization of the reclaimed land and establish market linkages (ibid.).

The DVRPU Approach demonstrated the potential to transform DVs into fertile landscapes (GIZ, 2023c, 2023b) with large areas already having been rehabilitated (GIZ, 2022a, 2023c, 2023b). Previously, WSW have been used predominantly in the Sahel (NILL ET AL., 2012). However, up to the time of writing, 508 WSW have been constructed as well in Ethiopia, eight of which located in Oromia region, 98 in Afar region and 402 in Somali region (GIZ, 2024a). One WSW rehabilitates 22 hectares (GIZ, 2023c, 2024b), translating into 11,176 hectares affected by the WSW across the country. While 77 WSW have been constructed by GIZ, the Ethiopian government upscales the approach and financed the majority of structures with 408 WSW in Somali and Afar regions (GIZ, 2024a). The Ethiopian Red Cross Society, Wetlands International and the World Bank financed the installation of the rest of constructions (ibid.).

Various studies document implications and effects of WSW in other African countries (NILL ET AL., 2012; SCHÖNING ET AL., 2012; WOCAT SLM DATABASE, 2012), the Afar region

(AMEDE, 2017; AMEDE ET AL., 2018; CALOW ET AL., 2018; GETNET ET AL., 2022; VAN DEN AKKER ET AL., 2015) and Somali region (FSIABD CONSULT, 2021; SORPARI, 2023, 2024). Positive effects of WSW relate to, among others, increased soil moistness (APARI, 2023B; SORPARI, 2023; TUINHOF ET AL., 2012) decreased erosion (AMEDE ET AL., 2022; GETNET ET AL., 2022), built up of rich soil (AMEDE, 2017; GETNET ET AL., 2022) and higher biomass productivity (GETNET ET AL., 2022; SORPARI, 2023). This allows a diversification of crop production (AMEDE ET AL., 2022) as well as higher crop yields (AMEDE ET AL., 2022; SORPARI, 2023; WOCAT SLM DATABASE, 2012). Implied potentials include an augmentation of food security (GETNET ET AL., 2022) and the creation of additional income opportunities in Somali region (FSIABD CONSULT, 2021) as well as increased community resilience (UNEP, 2022).

The existing literature leaves a research gap with regard to the productive use realized in the rehabilitated areas in the Somali region as well as economic returns obtained by (agro-) pastoralists cultivating crops in those areas. This is why the present research focussed on a closer examination of the current use of the rehabilitated zones, especially regarding crop choice in general, the WSW' effect on it as well as drivers impacting it. Further, the profitability of crops produced and factors influencing it were an area of interest. To shed more light on this, the present research aimed to address the following four questions in particular:
Do (agro-) pastoralists cultivate more vegetables after the construction of WSW than before?
Does the profitability differ across crop types?
Which drivers increase agricultural profitability?
Which factors influence the crop choice?

To investigate those, initially, in chapter 2, agricultural profitability is contextualised and the terms drylands, land degradation, (agro-) pastoralism as well as land rehabilitation are defined. Further, the chapter provides context information on the particularities of Ethiopia and the Somali region, summarizes the DVRPU Approach and conceptually frames the different topics. In chapter 3, the existent literature on effects of the rehabilitation technology in question and the chosen key indicator to measure agricultural profitability is summarized. Chapter 4 comprises the description of the study area, a summary of the process of data collection, an elaboration of the hypotheses to be examined and a specification of the methods employed to analyse the collected data. In chapter 5, main results are presented while chapter 6 contains a discussion of those as well as recommendations. Chapter 7 summarizes and concludes the work.

2 Conceptual Foundations

2.1 Contextualising agricultural profitability

The term profitability relates to economic performance (Gómez-Limón et al., 2023) which may be determined by a range of indicators (Eilon, 1985). Usually, ratios describing the interrelation of output to inputs are used to describe the economic state of the enterprise (ibid.). On the one hand, outputs may be defined in various ways, for instance as physical quantity produced or revenue (ibid.). On the other hand, inputs constitute the resources utilized for creating the output (ibid.). Examples are material or labour which may be quantified physically or in terms of expenses (ibid.). Which outputs and inputs exactly are taken into account depends on the individual case and analysis (ibid.).

According to Gómez-Limón et al. (2023), the economic strength is compiled of various facets, one of which constituting profitability. Thus, other decisive indicators such as efficiency or productivity are commonly considered as well when assessing economic performance (ibid.). Similarly, Latruffe et al. (2016), reviewing sustainability indicators in agriculture, argued that profitability is one of a few measurements of economic viability. However, profitability has been denoted as a crucial aspect used widely as it allows comparability (Gómez-Limón et al., 2023). Higher profitability can be attributed to more output (van den Berg et al., 2018). However, this only holds when other influencing factors are equal which rarely is the case (ibid.), as profitability in agriculture is affected by, among others, crop choice, technology employed, managerial decisions, geophysical and biological circumstances, resource availability, education, willingness to take risk, and market conditions as well as the political frame (Bowman & Zilberman, 2013).

Van den Berg et al. (2018) points out that the term profitability is not always utilized in a clear manner. It is a quantitative indicator setting revenue in relation to cost (Latruffe et al., 2016). It may be quantified either as a ratio (Balk, 2003) relating to other variables such as profit margin (van den Berg et al., 2018) like sales divided by expenses (Singh & Singh, 2023). It also may be expressed in absolute numbers mostly stated in currency values (Latruffe et al., 2016), for example the profit level (van den Berg et al., 2018), showing a difference from revenue and total expenses (Singh & Singh, 2023). In most cases, the indicator return on assets[5] is utilized to determine the profitability of a given business, particularly for big companies (GÓMEZ-LIMÓN ET AL., 2023).

As the present research does not aim for a general analysis of farms, the approach used is a more comprehensive one focussing on the different enterprises a farm comprises (MAFF, 1980, as cited in FIRTH, 2002) and enabling comparisons between those (SPRINGER-HEINZE, 2018) to get insights about the income contribution of a selected product (AGROMISA FOUNDATION, 2006). The key indicator chosen is the gross margin (GM), an essential profitability indicator used in economics, particularly in management (KRAUSE & ARORA, 2008). It represents a budgeting technique (ADEWUYI ET AL., 2010) and a basic model to calculate the economic viability of production in order to obtain an estimate of its profitability (BENU ET AL., 2010), commonly expressed in monetary terms (HA ET AL., 2015). Although it has been used for livestock production as well (ADEWUYI ET AL., 2010; NIELSEN ET AL., 2013; NKADIMENG ET AL., 2021), according to NKADIMENG ET AL. (2021), it was employed extensively in crop production due to the ease of calculation.

There are numerous examples of GM calculation being employed to explore the profitability of farms or single production lines which are elaborated on in chapter 3.2. Core variables for its estimation are revenue and cost (HA ET AL., 2015; PANDEY & GAUTAM, 2021). Total revenue, on the one hand, hereby may be defined as the monetarily valued yield of the farm, specifically the crop quantity produced multiplied by its price (ABU ET AL., 2011; DEMIR & GÖZÜBÜYÜK, 2020; HA ET AL., 2015; ODOEMENEM & INAKWU, 2011; PANDEY & GAUTAM, 2021) or revenue from sales (ALIYI ET AL., 2021; MELESSE, 2016; NKADIMENG ET AL., 2021). Cost, on the other hand, usually consists of fixed and variable elements, the former being related to overhead expenses, such as rent, maintenance and machinery and the latter being associated directly with the amount of production (ABU ET AL., 2011) including cost for, among others, fertilizer, seeds, machinery rental and labour (DEVKOTA & ATNAFE YIGEZU, 2020; HA ET AL., 2015; ODOEMENEM & INAKWU, 2011; PENOT ET AL., 2021).

The GM calculation only takes into account total variable expenses (NKADIMENG ET AL., 2021) and therefore shows which part of the income remains for the payment of profit and fixed expenses (PEDERSEN ET AL., 2005) over which the farmer has no control in the short-term

[5] Return on assets are „calculated as the ratio of earnings before interest and taxes (EBIT) to total assets“ (Gómez-Limón et al., 2023, p. 1305).

(DEMIR & GÖZÜBÜYÜK, 2020). The exclusion of fixed costs from the calculation makes conclusions faster and easier (AGROMISA FOUNDATION, 2006).

2.2 Drylands, land degradation, (agro-) pastoralism, & land rehabilitation

Dry lands constitute the planet's most extensive biome (SCHIMEL, 2010, as cited in WU ET AL., 2024), covering 41 per cent of the global terrestrial surface and being inhabited by 30 per cent of the planet's population (MILLENNIUM ECOSYSTEM ASSESSMENT, 2005A). They include hyperarid, arid, semiarid and dry subhumid areas[6], all having in common that evapotranspiration exceeds their levels of precipitation which in general are highly variable (UNEP, 1992). A further feature is a particular vulnerability regarding climate change (HUBER-SANNWALD ET AL., 2012; SMITH ET AL., 2019) and sensitivity to human action (REYNOLDS ET AL., 2007). In those zones "the production of crops, forage, wood and other ecosystem services are limited by water" (MILLENNIUM ECOSYSTEM ASSESSMENT, 2005a, p. 23). Drylands are especially subject to land degradation which is aggravated by climate change (IPCC, 2023).

(Land-) degradation[7] implies a reduction of resilience of an area (UNEP, 1992). It refers to a

> "reduction or loss "…" of the biological or economic productivity and complexity of rainfed cropland, irrigated cropland, or range, pasture, forest and woodlands resulting from land uses or from a process or combination of processes, including processes arising from human activities and habitation patterns, such as soil erosion caused by wind and/or water; deterioration of the physical, chemical and biological or economic properties of soil; and long-term loss of natural vegetation" (UN, 1994, pp. 4–5).

The decrease in quality and quantity of land causes a disruption of the provision of functions and services of ecosystems in part or in total (OKPARA ET AL., 2018). In line with this, the MILLENIUM ECOSYSTEM ASSESSMENT (2005a) connects land degradation to a decrease of human well-being due to the resulting reduction of provided ecosystem services. Those services comprise basic life supporting functions such as the formation of soil, photosynthesis or the cycling of nutrients, provisioning ones such as food, fuel or water, regulating benefits like the purification of water, pollination or control of erosion as well as cultural functionalities in the form of recreation or inspiration (MILLENNIUM ECOSYSTEM ASSESSMENT, 2005b). Land degradation impacts a share of 29 per cent of the global terrestrial area (LE ET AL., 2016) and expands by five to ten million hectares every year (STAVI & LAL, 2015) while impairing at least 3.2 billion humans (LE ET AL., 2014).

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[6] The Aridity Index, calculated as the ratio annual precipitation (P)/ Potential evapotranspiration (PET) is < 0.05 for hyperarid, < 0.20 for arid, < 0.50 for semiarid and < 0.65 for dry subhumid areas (UNEP, 1992).

[7] The terms degradation and land degradation will be used interchangeably in the present research.

Many of those impacted live in pastoral or (agro-) pastoral communities as this is the most prevalent form of cultivation in drylands (GIZ, 2023c). While pastoralism has been defined as "complex interaction of people, natural resources, and livestock" (CHANYALEW, 2015, as cited in GEBREMESKEL ET AL., 2019, p. 1), agro-pastoralism "combines extensive livestock production with crop cultivation for household consumption and income generation" (GEBREMESKEL ET AL., 2019, p. 2), thus, representing mixed farming (WORLD BANK, 2019b). This reliance on livestock and agriculture renders those production systems particularly vulnerable to climatic conditions (MOGES, 2021), with droughts such as the three last ones in the Horn of Africa having severe impacts (OCHA, 2023b) as outlined above.

Apart from those, droughts favour soil erosion by wind which mobilizes soil particles and deposes them in different locations (FAO & ITPS, 2015). They further lead to a loss of water-absorbing capacity of soils being flushed away in case of heavy rains, such as the ones in the Horn of Africa following the recent drought (WMO, 2023). This process exacerbates degradation as soil erosion by water occurs, a rapid loss of topsoil and fertile sediments, with the overland flow being able to cut distinct channels like rills or gullies into the land (FAO & ITPS, 2015). This process reduces rooting space, fertility and water holding ability essential for plant growth and contaminates water streams, thereby negatively affecting agricultural production (ibid.), also through the decrease of available fertile land (GIZ, 2023c).

The challenge of land degradation and its importance has been acknowledged globally and various international agreements try to address it as mentioned above. A range of measures exist to restore and rehabilitate affected areas (MILLENNIUM ECOSYSTEM ASSESSMENT, 2005a). Restoration hereby refers to the modification of a deteriorated site to recover the original condition of an ecosystem including provided services and functionalities (ibid.). Rehabilitation implies the correction of degraded or obstructed elements or segments of functionalities of an ecosystem to reestablish ecosystem productivity which is the main objective (ibid.).

> "Examples of measures to restore and rehabilitate include establishment of seed banks, restocking of soil organic matter and organisms that promote higher plant establishment and growth, and reintroduction of selected species. Other rehabilitation practices include investing in land through practices such as terracing and other counter-erosion measures, control of invasive species, chemical and organic nutrient replenishment, and reforestation. Policies that create incentives for rehabilitation include capacity building, capital investment, and supportive institutions. Community involvement in conceptualization, design, and implementation is essential for rehabilitation approaches" (MILLENNIUM ECOSYSTEM ASSESSMENT, 2005a, p. 16).

All approaches are targeting, among others, the reestablishment of lost ecosystem services (MILLENNIUM ECOSYSTEM ASSESSMENT, 2005a) while supporting the adjustment to and the reduction of climate change induced impacts as well as fostering the improvement of livelihoods and the alleviation of poverty (IPCC, 2023). This requires an interdisciplinary approach as well as the intense participation of local communities (MILLENNIUM ECOSYSTEM ASSESSMENT, 2005a). Both negative and positive environmental, social as well as economic consequences of rehabilitation efforts may be possible so that the effectiveness of measures depends on a variety of factors such as available technology, capital and labour (ibid.).

2.3 Ethiopia, the lowlands and the Somali region

For Ethiopia, the degradation of 25 per cent of its total surface area has been reported, impairing a third of the nation's inhabitants (GEORGIS, 2021). The zones where the majority of degradation and deforestation takes place are the country's drylands (MOA & PENHA, 2022) which account for around 75 per cent of the entire surface area (GEORGIS, 2015), encompassing the (agro-) pastoral lowlands and the dry midland and highland regions (MOA & PENHA, 2022). Most measures countering degradation are implemented in the Ethiopian highlands against the dominating form of land degradation, soil erosion (ABERA ET AL., 2020). As mentioned above, this phenomenon is exacerbated by droughts and floods, those being therefore also part of the main reasons for degradation of dryland in Ethiopia, next to invasive plant propagation, extensive deforestation, non-adequate farming practices and overgrazing (KASSA, 2021). This is aggravated by an increasing population, weak institutions and climate change (ibid.). Further influencing factors are limited movement of pastoralists due to fragmentation of land, rising demands related to growing settlements, resource-borne tensions, market shortfalls and climate variability (ibid.).

Immediate combating measures are crucial while those vulnerable ecosystems offer opportunities to support Ethiopia's sustainable development (MOA & PENHA, 2022) relating to faunal and floral variety as well as diversity of domesticated agricultural crops (GEORGIS, 2015), untouched subterranean water reserves as well as minerals (MOA & PENHA, 2022). Nevertheless, the already challenging living conditions in the drylands (ibid.) are reflected through poorest scores in numerous socio-economic indicators of development (UNDP ETHIOPIA, 2014). The dominant production system in drylands, (agro-) pastoralism (GIZ, 2023c), is most extensive in Ethiopia comparing to the rest of countries south of the Sahara with regard to number of people and livestock herd sizes as well as variety of resources and surface coverage (GEORGIS, 2015). It represents a share of the country's land mass of 57 per cent (UNDP Ethiopia, 2014) and provides livelihoods for more than 12 million Ethiopians (GEBREMESKEL ET AL., 2019).

Its farm animal component bears potential for economic development (Catley, 2017; Georgis, 2021; World Bank, 2019b) as to the (agro-) pastoral production system, 50 per cent of the nation's livestock is allocated (MoA & PENHA, 2022), integrated into trade connections between local markets and neighbouring nations (Catley, 2017) offering export potential also in light of rising demand for animal products (World Bank, 2019b). However, the production of crops yields little output and is realized with few inputs on a limited scale (MoA & PENHA, 2022) although an expansion of rainfed, irrigated, and water conservation agriculture is possible (World Bank, 2019b).

The lowland drylands of Ethiopia, origin of biodiversity for many crop and livestock species, comprise between 55 (Georgis, 2010) and 61 per cent of the country's land mass (Georgis, 2015) and are inhabited by a third of the nation's population mostly living from rainfed small-scale livestock and arable production realized in small land holdings of usually less than one hectare (Georgis, 2010). Grazing resources traditionally used for livestock are declining due to an extension of arable production and bush encroachment (ibid.) of invasive and native species (Georgis, 2021). Annual precipitation has been highly variable and traditionally very low (Gummadi et al., 2018). This leads to frequent droughts (Georgis, 2010) while rainfall events are usually heavy (Gummadi et al., 2018), resulting in bare soil and little vegetation (Georgis, 2010). The deterioration of natural resources in Ethiopia's lowlands is a cause of multiple challenges related to insufficient water resources, loss of soil, its fertility and flora (Georgis, 2010).

The further expanding erosion implies degradation of soil (GIZ, 2023c) and formation of gullies due to floods and droughts (Gebremeskel et al., 2019). A rising number of gullies has been reported for the Ethiopian lowlands, posing a significant challenge as, in consequence, flood emergencies increase while the water does not infiltrate the soil because it is diverted into the gullies (Rettberg et al., 2017). Apart from that, mounting deforestation in neighbouring highlands augment the possibility of severe flood occurrence (ibid.). This, in turn affect drainage systems and impact adversely the availability of water and agricultural productivity (GIZ, 2023c) while (agro-) pastoral farms close to the highlands are destroyed through the floods (Rettberg et al., 2017) all of which further intensifies the already alarming situation with regard to food security (GIZ, 2023c).

In the Ethiopian lowland region Somali, various governmental institutions like the Bureau of Livestock and Pastoral Development or the Bureau of Agriculture and Natural Resources are engaged in rehabilitation activities of dryland (Mohammed & Kenadid, 2020). Also non-state organizations such as the United Nations World Food Programme as well as globally present non-governmental organisations (NGOs) like Save the Children (ibid.) and Wetlands International (UNEP, 2022) are active in this area. Further, local NGOs such as Save the Environment of Ethiopia (SEE)PWO (MOHAMMED & KENADID, 2020) and Ethiopian Red Cross Society (ERCS, 2022) are involved next to academia and development cooperation organizations like GIZ (MOHAMMED & KENADID, 2020) and USAID (GIZ, 2024b).

Notwithstanding the variety of actors, only few restoration measures were realized in comparison to the highlands (ABERA ET AL., 2020) and sustainable, climate-smart soil protection and rehabilitation measures are not yet extensively implemented (GIZ, 2022b). However, cropland is already limited while the practiced rainfed agriculture results in products economically valued extremely low (DESTRIJCKER ET AL., 2023). Still, on this production, inhabitants rely as (agro-) pastoralism is the most important income source in the region (ibid.), although, in contrast to other regions, with more diversified income sources and a better market linkage (GEBREMESKEL ET AL., 2019). The whole region is one of the principal pastoral zones of Ethiopia and holds the largest pastoral community in the country (ibid.). Pastoralists in Somali region move depending on the season, thus, live in transhumance, possessing homesteads in addition (ibid.). Out of this livelihood systems follows a particular vulnerability to climatic impacts (DESTRIJCKER ET AL., 2023).

The semi-arid and arid climate in the region is already less predictable, more arid and hotter while more rising temperatures are expected (DESTRIJCKER ET AL., 2023). Although Somali region features subterranean water bodies with potential for irrigated farming (MOA & PENHA, 2022), droughts are consistently impairing nutrition and food security (FAO, 2017; REACH INITIATIVE, 2024) mainly due to water scarcity (DESTRIJCKER ET AL., 2023). Altered environmental conditions already made herders in Somali region switch from cattle, which requires more water, to sheep, goat and camel (GEORGIS, 2021). Nevertheless, droughts lead to large loss of livestock (MOA & PENHA, 2022). The share of people owning livestock for instance dropped from 43 per cent in 2020 to 18 per cent in December 2023[8], the main reason being drought[9] (REACH INITIATIVE, 2024).

[8] The reported share is based on the sample interviewed by the REACH Initiative comprising 2,633 households in nine of the 11 zones in Somali region (REACH Initiative, 2024).

[9] Drought was given as reason for livestock loss by 86 per cent of participants (REACH Initiative, 2024).

Apart from that, market functionalities decrease (REACH INITIATIVE, 2023b) and displacement occurs on large-scale (ACAPS, 2017). In 2022, 686,000 Ethiopians were displaced internally due to drought, the situation being most severe in Oromia and Somali regions (IDMC, 2024). As of December 2023, Somali region was the largest host of the country in terms of drought-induced IDPs with 391,573 people (IOM, 2024). Finally, agricultural production decreases, with for instance the REACH INITIATIVE (2024) documenting solely 6 per cent relying on crop farming as primary livelihood in December 2023 while pre-drought, 10 per cent reported this. Food access gets limited and a dependence on food aid develops (ACAPS, 2017) with the potential to negatively influence domestic agricultural production (GELAN, 2007).

Next to this, further changing weather patterns, more precipitation variability, and increasing numbers of heavy rainfall events are expected (DESTRIJCKER ET AL., 2023). This results in more water-induced erosion as well as river and flash floods, further aggravating food insecurity (ibid.) and displacement numbers. The most recent floods caused by heavy rains displaced thousands (IOM, 2023). By the end of 2023, Ethiopia accounted for 550,000 IDPs due to floods, Somali region being hardest hit (IDMC, 2024). The floods caused 23,000 livestock deaths in the region (FAO GIEWS, 2023), hindered recovery from the previous drought and negatively affected planting and harvesting (REACH INITIATIVE, 2024). More disease and pest occurrences are forecasted for the region (DESTRIJCKER ET AL., 2023), an expectation mirrored in the recent flood-induced cholera outbreak (SAVE THE CHILDREN, 2023). In addition, security concerns arise due to local conflicts caused by food insecurity and access to natural resources as a consequence of this vulnerability to climatic conditions (DESTRIJCKER ET AL., 2023).

Apart from that, the Somali region is subject to extreme population growth and demographic pressures resulting from internal displacement (DESTRIJCKER ET AL., 2023) which overstresses the limited carrying capacity of the land (GEORGIS, 2010). By the end of 2023, Ethiopia accounted for 2.9 million IDPs due to conflict and violence (IDMC, 2024), 102,000 being reported to reside in Somali region (TUFA, 2024). Further, asylum applicants and refugees number to more than 916,000 in the country with Ethiopia ranking as the third biggest host within African countries (OCHA, 2024) while 300,000 are documented for Somali region (TUFA, 2024). The already vulnerable livelihood system, droughts, floods and the population pressure against the background of limited resources leads to a particular need for humanitarian aid (ACAPS, 2017). Of about 6.2 million inhabitants of the Somali region (DESTRIJCKER ET AL., 2023), 2.6 million are in need of humanitarian assistance in 2024 (OCHA, 2024) while 24 per cent of households in Somali region assessed by the REACH INITIATIVE (2024) in

December 2023 reported having received humanitarian aid in the 12 months before data collection, 79 per cent of which considered the quantity received as insufficient.

Summarizing, (agro-) pastoralist communities in Somali region are facing multiple challenges. While they rely on natural resources for their livelihoods, the already overgrazed pasture spaces for livestock are declining further due to population growth and expansion of arable production. Population growth leads to more settlements which limits the movement of pastoralists due to land fragmentation and increases the demands of the population, thus, favouring resource-borne tensions. Crop production is realized with non-sustainable practices, while the available land for this is already limited. The sensitive environment is particularly prone to land degradation, resulting not only from the just mentioned development, but from other factors such as invasive plant propagation and weak institutions while being exacerbated by climate change.

The already dry area favours drought occurrences which lead to water scarcity, thus, also to large losses of livestock and decreasing arable production. This aggravates nutrition and food security. A dependence on food aid develops, further decreasing agricultural production. Apart from that, wind erosion occurs and the water absorbing capability of the soil diminishes. Changing precipitation patterns cause more heavy rains, which, in conjunction with deforestation in neighbouring highlands lead to more frequent floods, compromising recovery after drought as well as planting and harvesting patterns. The quantity of water cannot infiltrate the soil and increased water erosion degrades it further as fertile sediments are flushed away and gullies are cut into the land. This further decreases available fertile land while water holding and drainage capacity as well as soil fertility are reduced, leaving little vegetation and bare soil, thus, decreasing agricultural production and contributing to more food insecurity. Finally, extreme weather patterns lead to large numbers of IDPs, adding even more population pressure and overstressing the carrying capacity of the system further.

2.4 Dry Valley Rehabilitation and Productive Use Approach

Those challenges resulting from degradation which particularly (agro-) pastoral communities are facing are addressed, among others, by the GIZ with the development of the DVRPU Approach, tailored to the particularities of the Ethiopian lowlands, but with the potential to be applied in other drylands across the globe (GIZ, 2023c). Targeting drought resilience, it is designed to improve living conditions for (agro-) pastoralists in an integrated manner taking into account not only biological and technical dimensions, but also social, economic, governmental and institutional aspects (ibid.). The key construction used are cascading water-spreading weirs (WSW), accompanied by dry stone and biological measures which reduce the speed of floods, leading to increased water penetration, groundwater levels and sedimentation (ibid.). The fertile areas created allow for cultivation of forage and food crops strengthening resilience and food security (ibid.).

Initially, various criteria are used to evaluate whether in a DV the necessary requirements are met for it to be suitable for the DVRPU Approach (GIZ, 2023c). Environmental and landscape criteria relate, among others, to the annual occurrence of seasonal floods originating in the highlands and the suitability of the soil for crop cultivation (ibid.). Community criteria include, among others, the existence of a community living within a three-kilometre radius of the DV and the absence of conflict (ibid.). Access criteria refer, among others, to the reachability with a car and the presence of stones and sand within three kilometres (ibid.). Stakeholder criteria comprise for instance that the Woreda is willing to provide financial and technical support to the DVs community exceeding a five years' time span (ibid.)[10].

The process of DVRPU implementation following when those requirement criteria are met consists of seven steps, starting with (1) satellite identification and DV delineation (GIZ, 2023c). Image analysis and remote sensing are used to determine whether a site is biophysically and socially appropriate, taking into account, among others, slope, terrain and flood occurrence (ibid.). With the use of Digital Elevation Model data, DVs can be delineated to determine river networks and channels which for Ethiopia has been done by the Ministry of Agriculture (ibid.). The next (2) step involves the suitability assessment of a prospective DV, making use of a suitability matrix, a rapid field appraisal method, filled out by experts (ibid.). Aspects like land rights, institutional agreements, plant density, soil as well as hydrological and topographical factors are evaluated, informing the decision about the type of rehabilitation measure to be installed (ibid.). Then, key informants provide insights about prospects and difficulties (ibid.).

Subsequently, the (3) community participatory planning follows which informs native communities represented by the users of the DV and generates understanding about every aspect of the intervention (GIZ, 2023c). To ensure ownership and engagement, a representative community planning team is elected from the local population (ibid.). This is guided by a Woreda planning team including experts and a Kebele planning team including among others the Kebele chairman and local Development Agents while in all teams women's contribution is secured (ibid.). Frequently conducted meetings within and between the teams which are filled with visual first-hand experience about the rehabilitation are intended to facilitate information,

[10] A complete list of evaluation criteria used can be found in table A.1 in appendix II.

exchange, participation and consensus (ibid.). In the process, community-elected representatives have the opportunity to visit rehabilitated DVs while finally bylaws are developed regarding maintenance work provided by the communities' individuals (ibid.).

If the community commits, (4), Dry Valley User Cooperatives (DVUCs), in Ethiopia following the model and regulations outlaid by Proclamation No. 1223/2020, are founded to administer, secure and exploit the restored DV based on democratic decision-taking (GIZ, 2023c). This also includes a cooperative agency which subsequently provides capacity-building to the members and audits to analyse compliance and finances of the DVUC (ibid.). The (5) technical and budgetary planning, created with the close and detailed advice of Kebele and Woreda teams, is designed for the long term and comprises in-depth objectives, tasks and key milestones for each year while community involvement is ensured through one planning meeting per year to evaluate the progress and revise the roadmap for the next year (ibid.). The communities' knowledge is used to assess available resources of the area which provides a base for outlining the construction of physical and biological means and subsequent use of the DV (ibid.).

The (6) construction phase engages the local community based on the bylaws agreed on before and makes use of local insights (GIZ, 2023c). The main technologies used involve WSW, dry stone measures and check dams[11], all of which reduce speed of floodwaters and divert them, leading to the above-mentioned effects (ibid.). WSW stretch over the complete dry river bank including the gully to distribute the water over the surrounding land while channelling excess water to the next structure (ibid.). Biological measures[12] complement physical constructions to more efficiently prevent erosion (ibid.). The combination of those measures reduces the speed of seasonal floods which allows the water to infiltrate the soil, thereby recharging subterranean water and depositing rich soil which refills the gully (ibid.). Consequently, extremely productive land is formed offering opportunities to produce food as well as fodder (ibid.).

[11] Dry-Stone Measures are built in cascades with loose stones utilized to fill up gullies up to 1.5 metre deep (GIZ, 2023c, p. 31). Check dams encompass the following measures. Masonry check dams (MCDs) are built into mostly stony gullies until a depth of four metres using cement (GIZ, 2023c) and are counted as well as WSW (GIZ, 2024b). Gabion check dams, stabilised by durable wire mesh called gabion, work in a similar way to MCDs (GIZ, 2023c). They are installed and fixed into gullies, are built lower than MCDs and especially useful for securing deeper gullies and regulating water flow (ibid.).

[12] Biological measures include grass strips and live check dams. The former are planted following the contours of the constructed measures with a width of one to three metres. Among others, they enforce and support the physical structure while also generating biomass which can be used as forage (GIZ, 2023c). The latter are a cost-effective measure to reduce erosion (ibid.). They consist of a strategic mix of various grasses and other plant species placed horizontally in the gully to decrease the speed of water (ibid.).

This leads to the last step of the DVRPU Approach, the (7) productive use (GIZ, 2023c). It allows to introduce Flood-Based Farming practices in the rehabilitated DVs (ibid.). This offers opportunities to plant a diverse range of grasses, trees and crops suited to the individual DV zones differing in their moistness to enable the community to benefit in terms of food security and income diversification while preventing further erosion, improving water availability and increasing biodiversity (ibid.). As (agro-) pastoral communities frequently do not have the necessary skills to use the rehabilitated land in the most optimal way, the last step further involves local capacity development, particularly regarding agroecological production approaches which are essential for an effective utilization (ibid.).

A diverse range of short and long-term, direct and indirect advantages are envisaged through the approach (GIZ, 2023c). With regard to water and soils, benefits include the formation of fresh arable land, augmenting groundwater levels, carbon capture and alleviation of damages caused by flooding (ibid.). From an agricultural lens, the approach, among others, facilitates multiple harvests with the use of few inputs, allows the cultivation of a broader crop range including cash crops, prevents oversalted and acidified soils and augments system resilience (ibid.). Apart from this, social cohesion is enhanced through community collaboration while the prevention of flood damages and augmented agricultural productivity including implied health benefits result in diversified livelihood opportunities and, thus, less migration (ibid.).

DVRPU exhibited a potential to convert drylands into vegetation rich landscapes (GIZ, 2023c, 2023b). Large areas have already been rehabilitated (GIZ, 2022a, 2023c, 2023b) with the construction of 508 WSW in total up to date, comprising eight structures in the Ethiopian Oromia region, 98 in Afar region and 402 in Somali region[13] (GIZ, 2024a), affecting up to 11,176 hectares across the country (GIZ, 2023c, 2024b). Of those structures, 77 have been built by GIZ while the Ethiopian government, upscaling the technology, financed 408 weirs (GIZ, 2024a). The rest of constructions has been set up by various organizations mentioned above (ibid.). The structures are complemented by further rehabilitation measures (GIZ, 2022a). The entire DVRPU Approach has not been applied to its full extent in all sites due to its recent development (GIZ, 2024b). In Afar, GETNET ET AL. (2022) found a huge productivity increase and, thus, a considerable potential to augment food security in the region, even during dry periods. In Somali region, WSW benefitted households in the surroundings and exhibited

[13] Those figures include the MCDs which are counted as WSW as well. Of the 98 structures in Afar region, three are MCDs. Of the 402 structures in Somali region, 42 are MCDs. In Oromia region, only WSW were constructed.

potential to create additional income opportunities (FSIABD CONSULT, 2021), among others through augmented yields (SORPARI, 2024) while increasing community resilience (UNEP, 2022). Further research regarding the effects of WSW is provided in chapter 3.1.

2.5 Social-ecological systems

The afore-mentioned topics of drylands, land degradation, (agro-) pastoralism and land rehabilitation as well as the DVRPU Approach can be conceptualized from a social-ecological systems (SES) perspective. As defined by the INTERGOVERNMENTAL SCIENCE-POLICY PLATFORM ON BIODIVERSITY AND ECOSYSTEM SERVICES (IPBES), SES

> "are complex adaptive systems in which people and nature are inextricably linked, in which both the social and ecological components exert strong influence over outcomes. The social dimension includes actors, institutions, cultures and economies, including livelihoods. The ecological dimension includes wild species and the ecosystem they inhabit" (*IPBES*, 2024).

Thus, the SES itself consists of the two dimensions biological ecology and people's society including their economy (CHAPIN, III ET AL., 2009). The usefulness of such an approach regarding the alteration of land systems has been, among others, acknowledged by LESLIE ET AL. (2015) as it offers a frame for interconnected natural and human systems, centring around the fact that humans rely on nature (FISCHER ET AL., 2015) and are responsible for it (CHAPIN ET AL., 2010). This perspective, viewing humans as an element of the natural world, has also been proposed by OKPARA ET AL. (2018) who argued that a SES lens is indispensable as it has an informative and guiding effect to achieve the above mentioned SDG 15.3.

To analyse sustainability and outcomes of such complex networks, various frameworks were developed, one example of which is the well-known SES framework created by OSTROM (2009). It is a concept incorporating four subsystems, namely "resource systems", "resource units", governance systems" and "users" (OSTROM, 2009, p. 420), each of which being described by sets of variables (ibid.). OSTROM'S framework was deemed appropriate to be applied to the phenomenon of degradation and landscape restoration for the purpose of examining progress made as it does not only consider ecological outcomes but considers socio-economic impacts (DUGUMA ET AL., 2015). Resource systems and their resource units represent the ecological dimension while governance systems and users capture the social side (ibid.).

For drylands with their particular environment being described as dryland social-ecological systems (DSES) which are "the most diverse yet highly vulnerable" (HUBER-SANNWALD ET AL., 2012, p. 3158), a different framework has been used in large parts of dryland literature (STRINGER ET AL., 2017) and remarkably influenced the discourse around dryland development

(FU ET AL., 2024). For this specific type of system, where nature, culture and society is closely interlinked (HUBER-SANNWALD ET AL., 2012), the Drylands Development Paradigm (DDP) was created (REYNOLDS ET AL., 2007). Although it, unlike OSTROM'S approach (2009), does not specifically point to the way institutional, political, cultural, economic and societal interrelating grids can be interwoven (STRINGER ET AL., 2017), the DDP can guide rehabilitation and mitigation specifically of degraded or deserted drylands (HUBER-SANNWALD ET AL., 2020), as it provides a holistic frame for analysing dryland ecosystems to determine problems and seize opportunities in favour of development (REYNOLDS ET AL., 2007).

It is an adequate concept as it takes into account the intricacy, variety as well as instability of DSES (HUBER-SANNWALD ET AL., 2020) and incorporates key elements such as certain variables, connections of stakeholders and different information sources (REYNOLDS ET AL., 2007). The DDP is characterised by five principles (ibid.) laid out in the following.
(1) DSES represent the dynamical, co-adaptive result of the interrelations between human subsystems such as economies or institutions and biophysical subsystems like climate or soil across time and space (REYNOLDS ET AL., 2007). Those interconnected systems do not feature an equilibrium point as continuous alterations are caused by external drivers like prices or climate and internal factors such as smallholders' decisions regarding land use (ibid.). Both socioeconomic and biophysical spheres are equally important (ibid.).
(2) In contrast to "fast" (REYNOLDS ET AL., 2007, p. 849) and highly volatile variables, for instance precipitation or crop yield, the dynamic development of DSES is mainly influenced by "slow" (ibid.) socioeconomic and biophysical variables such as soil fertility and household wealth worth of investigation as they indicate the degree of degradation and resource depletion as well as upcoming potentials (REYNOLDS ET AL., 2007).

(3) The state of DSES may be transformed when the different thresholds of the range of slow variables are crossed, affecting the systems economic, social or ecological dimensions and leading to potentially nonlinear repercussions in all of them (REYNOLDS ET AL., 2007).
(4) DSES are nested, interlinked, multidimensional and incorporated into a hierarchical order, involving multiple stakeholders with varying objectives across space and time with variables at one scale impacted by variables of another scale (ibid.).
(5) To facilitate an efficient coadaptation of DSES, a continuously updated knowledge base incorporating scientific research, policy experiences and local environmental knowledge is necessary (ibid.).

Applied to the present research, the investigated DVs can be thought of a DSES vulnerable to degradation and constitute, thus, a product of the numerous past and present alterations in nearby as well as distant interconnected socio-economic and ecologic systems and subsystems influencing them. A strongly interfering human subsystem is represented by (agro-)pastoralism as a cultivation method which also affects the biophysical dimension. An external driver impacting the interconnected grid is manifested in the phenomenon of climate change as it alters weather patterns and exacerbates droughts and floods. Also, market prices are changing the system as external influential factors as they may induce changes in agricultural practice or land use alterations. Contrasting this, the internal factor soil quality may be altered due to heavy machines employed by inhabitants to reach efficient production possibilities.

Fast variables such as precipitation and crop yield highly influence the lives of (agro-) pastoralist communities living in those DVs in the short-term while soil fertility or water availability constitute slow variables having a longer-term effect. Floodwater, previously being distributed overland, but at some point redirected to erosion gullies represent a nonlinear change connected to a crossed threshold (REYNOLDS ET AL., 2007) strongly affecting social, economic and ecological dimensions of the DVs. Stakeholders of the DV are not only local (agro-) pastoral communities, but also a range of local and national state and non-state actors as well as international institutions as described before which all are influencing fast and slow variables. Governmental donation programmes for fertilizer and pesticides for instance may have an effect on fast variables such as crop yield. As another example, food aid, on which people depend for their livelihoods, might decrease incentives for domestic agricultural production (GELAN, 2007; GIZ, 2024b). (Agro-) pastoralists' local knowledge about their environment coupled with local and non-local research as well as expertise from various active organizations and institutions may contribute to the sustainable development of those DVs.

The DVRPU Approach may well be linked to all five principles featuring REYNOLD'S ET AL. (2007) DDP framework. DVRPU, alongside governmental stakeholders and international actors as well as local NGOs, is intended to holistically rehabilitate the DVs under investigation within the present research while assessing and recognizing the highly interwoven human and natural subsystems as well as external and internal drivers. The approach, among others, particularly tackles water availability and soil fertility which represent slow variables having been described within the DDP as decisive to address degradation. Determining variables already have crossed at least one important threshold manifested in meter-deep gully erosion. Another important threshold may be the uncontrolled proliferation of invasive species. The hierarchy surrounding the DV is acknowledged as the various actors such as regional government, Woreda and Kebele authorities as well as local (agro-) pastoralists are involved, which provides opportunities for synergies to evolve and uses various bodies of knowledge.

The main focus of the present research was laid on WSW as dominant rehabilitation measure and one of the human subsystems of the DSES, the (agro-) pastoralist communities, while in particular their agricultural practices, crop choice and drivers impacting it as well as agricultural profitability and factors influencing this were of special interest. Therefore, when relating the investigation to the DDP framework depicted before, the study envisaged the examination of the rather fast variable of agricultural profitability affecting the system in the short-term. While some interview questions also related to slow variables such as water availability, the majority of data collected in the frame of the present research does not necessarily allow inference on the long-term development of the rehabilitated DVs. However, it creates a comprehensive snapshot of and insights into the actual local living conditions (agro-) pastoralists experience currently and therefore serves the purpose of the research objective.

3 LITERATURE REVIEW

3.1 Water-spreading weirs as rehabilitation technology

Despite the some stakeholders and actors interested and engaged in land restoration in the lowlands in general and in Somali region in particular (GIZ, 2024a; MOHAMMED & KENADID, 2020), the investigation of rehabilitation efforts is a lot less than in the highlands as in higher altitude zones a lot more measures have been implemented (ABERA ET AL., 2020). Also, studies relating to the particular technology of WSW in Ethiopia are scarce. WSW have been installed in the Sahel already in the 1990s (NILL ET AL., 2012; VAN DEN AKKER ET AL., 2015; WOCAT SLM DATABASE, 2012), however, the method there still requires further development in terms of maintenance and community ownership (NILL ET AL., 2012).

Looking at Ethiopia’s Afar region, the traditional measures the country implemented against land degradation were adopted only at very low to low rates (MOTUMA ASSEN & ASHEBO, 2018). WSW represent a more recent and innovative intervention method which has been introduced in Afar region by GIZ (DOUTHWAITE & GETNET, 2019; GETNET ET AL., 2022) in 2014 (GIZ, 2024a). After verifying the potential WSW also offers regarding an implementation in Somali region (AMEDE ET AL., 2018; DOUTHWAITE & GETNET, 2019), the technology has been installed there as well (GIZ, 2023b; UNEP, 2022), starting from 2018 (GIZ, 2024a).

WSW represent a more recently developed means of soil and water harvesting (VAN DEN AKKER ET AL., 2015) to decrease, hinder and recover degradation, particularly the erosion of soil caused by water and degradation of water bodies (WOCAT SLM DATABASE, 2012). WSW constitute a physical water buffering technique (TUINHOF ET AL., 2012) inspired by traditional flood management systems (AMEDE ET AL., 2018, 2022; GETNET ET AL., 2022) which, constructed in cascades (CALOW ET AL., 2018), stretches over the entire river bank and distributes the water on the neighbouring land (AMEDE, 2017). Low retention walls constructed with natural stones and cement comprise a spillway within the bed of the river, flanking restraints and wing walls (AMEDE ET AL., 2018, 2022; NILL ET AL., 2012; VAN DEN AKKER ET AL., 2015; WOCAT SLM DATABASE, 2012), an illustration of which is demonstrated in figure 1 in appendix I. The induced flooding can lead to different outcomes (WOCAT SLM DATABASE, 2012) laid out in the following.

Knowledge about WSW is concentrated among a few countries (WOCAT SLM DATABASE, 2012). The effects of those rehabilitation measures have been studied in the Sahel (NILL ET AL., 2012; SCHÖNING ET AL., 2012; WOCAT SLM DATABASE, 2012) and in the Afar region of Ethiopia (AMEDE, 2017; AMEDE ET AL., 2018, 2022; CALOW ET AL., 2018; GETNET ET AL., 2022; VAN DEN AKKER ET AL., 2015) after GIZ introduced them there (DOUTHWAITE & GETNET, 2019). Agricultural practices in zones rehabilitated with WSW in Afar have been demonstrated (AMEDE, 2017; DOUTHWAITE & GETNET, 2019). For Somali region, effects of WSW have been studied as well (SORPARI, 2023, 2024; UNEP, 2022). Apart from this, more insights regarding the topic may be offered by studies of other land restoration methods such as investigations of floodwater use in spate irrigation systems in Eritrea and Iran (MESBAH ET AL., 2016; TESFAI, 2001; TESFAI & STERK, 2002; TESFAI & STROOSNIJDER, 2001).

The purpose of WSW placed at the valley floor is to collect, retain and redirect excess water from unpredictable precipitation and intense floods originating in the highlands while slowing the velocity of the water (AMEDE ET AL., 2018, 2022; GETNET ET AL., 2022; KETTER & AMEDE, 2017; WOCAT SLM DATABASE, 2012). The effect is augmented water infiltration (FSIABD CONSULT, 2021; KETTER & AMEDE, 2017; TUINHOF ET AL., 2012; VAN DEN AKKER ET AL., 2015; WOCAT SLM DATABASE, 2012) and distribution of sediments (GETNET ET AL., 2022; TUINHOF ET AL., 2012; VAN DEN AKKER ET AL., 2015), resulting in improved soil moistness (AMEDE ET AL., 2018, 2022; APARI, 2023B; SORPARI, 2023; TUINHOF ET AL., 2012; WOCAT SLM DATABASE, 2012) and groundwater replenishment (GIZ, 2023C, 2023B; MESBAH ET AL., 2016; TUINHOF ET AL., 2012; VAN DEN AKKER ET AL., 2015; WOCAT SLM DATABASE, 2012).

Water availability in general rises (AMEDE, 2017; GIZ, 2023B; SORPARI, 2023; WOCAT SLM DATABASE, 2012) while overflow is channelled onwards (AMEDE, 2017) and the creation of water storage is possible to sustain livestock (SORPARI, 2024). WSW decrease erosion (AMEDE ET AL., 2018, 2022; GETNET ET AL., 2022; GIZ, 2022B; NILL ET AL., 2012; SORPARI, 2023, 2024; WOCAT SLM DATABASE, 2012), safeguard the riverbank (VAN DEN AKKER ET AL., 2015), stabilize the gullies (SORPARI, 2023) and place sediments into them refilling them ultimately (AMEDE ET AL., 2022; GETNET ET AL., 2022; KETTER & AMEDE, 2017; NILL ET AL., 2012; SORPARI, 2024; VAN DEN AKKER ET AL., 2015; WOCAT SLM DATABASE, 2012).

They expand the fertile part of the land (GIZ, 2023C; NILL ET AL., 2012; SORPARI, 2023; WOCAT SLM DATABASE, 2012) and enhance built-up of rich soil (APARI, 2023B; GETNET ET AL., 2022; GIZ, 2022B; KETTER & AMEDE, 2017; VAN DEN AKKER ET AL., 2015; WOCAT SLM DATABASE, 2012) which alters the quality of the land (AMEDE, 2017). Soil organic carbon stock is improved which is important for productivity and health of the soil (SORPARI, 2024). Sedimentation of fertile soils may augment water holding ability as well as improve physical and chemical soil properties resulting in fewer necessary inputs (GETNET ET AL., 2022; TESFAI, 2001; TESFAI & STERK, 2002; TESFAI & STROOSNIJDER, 2001) which reduces production costs (TESFAI & STERK, 2002).

Enhanced crop and forage productivity (GIZ, 2023b) and multiple harvests are likely (GIZ, 2023c) as well as higher crop yields (GETNET ET AL., 2022; GIZ, 2022B; NILL ET AL., 2012). Raised production of biomass has been documented (AMEDE, 2017; AMEDE ET AL., 2022; APARI, 2023B; GETNET ET AL., 2022; GIZ, 2023B; SORPARI, 2023, 2024; WOCAT SLM DATABASE, 2012), backed up by investigations using remotely sensed data (KOHLING & HOLTER, 2022). This opens up opportunities to utilize the rehabilitated areas for food and forage production (KETTER & AMEDE, 2017) which has been reported for rehabilitated sites previously non-suitable for the cultivation of crops (AMEDE ET AL., 2022) in Afar through the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT).

There, four differing crop management zones have been identified in which specific plants may be particularly suitable (AMEDE, 2017; AMEDE ET AL., 2022) while food and forage productivity differ significantly depending on the location of the field within the DV catchment and, thus, its water content (GETNET ET AL., 2022). A differentiation of crop production in the direction of vegetables is possible (GIZ, 2023c). In Afar region, a diversification has been reported including more grain types, various legumes and forage grasses (AMEDE ET AL., 2022) while for Somali region, the production of vegetables as well as multiple harvests has been documented (FSiAbd Consult, 2021; SoRPARI, 2024).

In the Sahel, a considerably higher yield was documented for millet in Chad (WOCAT SLM Database, 2012). A rise in cultivated area, production as well as yield were observed in Niger (Betifor, 2010 cited in Schöning et al., 2012). The yield of crops has been studied also for sites in Afar (Amede, 2017; Amede et al., 2018, 2022). An increase in the output in cereal production has been found on experimental plots in that region (Amede, 2017; Amede et al., 2018, 2022; Getnet et al., 2022; Ketter & Amede, 2017). Chemical fertilizers were reported to be obsolete due to the richness of the soil (Amede et al., 2022; Getnet et al., 2022) and weeds were documented only in limited numbers (Amede et al., 2022). Another study found crop cultivation of maize and sorghum compared to no arable production at all in control sites, either being due to the consequences of the recent conflict (APARI, 2023b) or entirely to be attributed to the effects of the WSW (APARI, 2023a). For Somali region, yield increases were documented as well (SoRPARI, 2022). SoRPARI (2024) reported significant maize and sorghum yield increases in rehabilitated DVs, in addition to introduced double cropping.

3.2 Gross margin analysis globally, in Ethiopia and Somali region

As mentioned in chapter 2.1, GM calculations are used frequently for crop production and can be found for many parts of the world. They were employed for instance for wheat in Australia (Flower et al., 2017), various cropping patterns of potatoes in Europe (Pedersen et al., 2005), comparison of tillage systems in Turkey (Demir & Gözübüyük, 2020), mung beans in West Timor (Benu et al., 2010), various vegetables in Nepal (Pandey & Gautam, 2021), wheat and maize in China (Ha et al., 2015), wheat in Morocco (Devkota & Atnafe Yigezu, 2020), the financial performance assessment of food security projects in arable farming in South Africa (Baloyi & Mautjana, 2018), sesame (Abu et al., 2011), cassava (Ebukiba, 2010), cereals and legumes (Sumaka, 2017) rice (Odoemenem & Inakwu, 2011) as well as soybeans in Nigeria (Ogbanje, 2023), oil palm in Ghana (Djokoto & Zigah, 2021), beans in Malawi (Kasonga, 2018) and rice in Cameroon (Djomo Choumbou et al., 2015).

Nevertheless, the brief literature review for the present research indicated that especially for Ethiopia studies involving the calculation of GMs seem to be rare. Examples of the few studies include a GM study for various enterprises such as crops and livestock as well as honey production having been conducted for Tigray, Oromia and Amhara to evaluate the impact of the governmental sustainable land management programme supported by various donors (Große-Rüschkamp, 2015). Apart from that, for Oromia, factors influencing the commercialisation of potatoes (MELESSE, 2016), drivers affecting the GM of the same crop (MERSHA ET AL., 2017) and market performance as well as profitability of vegetable crops (ALIYI ET AL., 2021) have been assessed, all of which use also GM calculations. For Somali region, respective studies comprise an investigation of the livestock market (TADESSE ET AL., 2022), and a fodder market assessment conducted for GIZ (EAST AFRICA ENGINEERING AND GENERAL CONSULTANT, 2018).

While the assessment of factors influencing output has been employed more numerously (NKADIMENG ET AL., 2021), for instance in Nigeria (ODOEMENEM & INAKWU, 2011; SUMAKA, 2017) or Swaziland (XABA & MASUKU, 2013), investigations of drivers of GMs are seldomly found. Few examples include KASONGA (2018) who studied the influence of sex, age, marital status, income, experience, farm size, extension services, seed used, fertilizer, labour, total variable cost, cooperative membership and total harvest on GM of beans in Malawi. SUMAKA (2017) assessed the impact of age, education, household size, output and mode of farming[14] on GMs of legumes and cereals in Nigeria. XABA & MASUKU (2013) researched about the effect of age, experience, education, sex, access to credit, access to extension service, access to market information, land under vegetables, number of dependants and distance to market on the GM of vegetables in Swaziland. Apart from that, SAMUEL & IDRIS (2021) examined how amount of credit, experience, savings, farmland, sales, investment, expenses for agrochemicals, cost of machinery and distance affect the profitability of soybeans in Nigeria. Drivers influencing the GM of livestock have been researched as well (NKADIMENG ET AL., 2021).

Regarding Ethiopia, MERSHA ET AL. (2017) researched about factors affecting GMs of potatoes and included gender, age, household size, level of education, cultivated area, production expenses, access to irrigation, credit, extension service and information about the market as well as livestock ownership as potential drivers. Thematically similar research include the examinations of determinants of production inefficiencies in crop cultivation in Amhara (MUSSA ET AL., 2012), studies of technical efficiency in wheat production in the same region (GEBRIE, 2018), exploration of technical efficiency in the cultivation of crops in Tigray (SHUMET, 2011), an investigation of economic efficiency in barley cultivation in Amhara (WOLLIE ET AL., 2018) and an assessment of economic efficiency in onion production in Somali region (YASIN, 2020). Apart from that, also studies not using regression analysis to investigate

[14] The mode of farming refers to full or part time.

drivers of GMSs (DJOMO CHOUMBOU ET AL., 2015; KEBA & MILKIAS, 2020; ODOEMENEM & INAKWU, 2011) provide insights regarding potentially influential factors for GMs.[15]

This compilation of the investigated literature regarding the topic of GMs and their drivers is complemented by data regarding area, production and yield of various crops being provided by the Central Statistical Agency (CSA) (2021b), although those lack various values for Somali region. Calculated yields complemented in parts by estimations of production costs and GMs are also provided by further studies (EAST AFRICA ENGINEERING AND GENERAL CONSULTANT, 2018; HEDBEZ BUSINESS & CONSULTANCY PLC, 2018; MOHAMMED RESHID CONSULTANCY, 2018; SORPARI, 2023, 2024). Nevertheless, the lack of studies regarding the calculation of GMs as well as the assessment of influencing factors point to a considerable research gap particularly for Somali region while this, due to the livestock production system the region is based on (EID, 2014; GIZ, 2023C; MERCY CORPS, 2020) is not surprising at least regarding the crop production part.

4 RESEARCH DESIGN, MATERIALS & METHODOLOGY

For the present research, a mostly quantitative approach was envisaged, being based on the review of documents and reports related to the DVRPU Approach as well as other literature available related to the topic[16].

4.1 Description of study area

The study site is situated in Somali region, in its Fafan zone (FSIABD CONSULT, 2021) within the upper catchment (WETLANDS INTERNATIONAL, 2016) and close to the regional and zone capital Jigjiga. Somali is the second biggest region of Ethiopia, divided into nine zones and further separated into around 100 Woredas (GEBREMESKEL ET AL., 2019) subdivided into Kebeles (DESTRIJCKER ET AL., 2023). The dominant ethnicity is Somali (MOHAMMED RESHID CONSULTANCY, 2018) and the area is identified as (agro-) pastoralist (GEBREMESKEL ET AL., 2019), owning the largest livestock population compared to other regions (SORPARI, 2023).

[15] A compilation of potential socio-economic, environmental, institutional and financial drivers of GMs as well as influencing factors related to agricultural practices and the GM calculation itself can be found in tables A.2 to A.6 in appendix II. Table A.7 shows potential factors influencing the sold share of crops produced. Some of the studies mentioned in this chapter and in the tables originate from low ranked, not ranked at all and even predatory journals as the research coverage is slim regarding the topic. Nevertheless, they should be mentioned to allow for a complete picture.

[16] Relevant literature was searched using academic databases such as Google Scholar, ResearchGate, Science Direct or JSTOR and platforms such as Academia, Wiley as well as online libraries of World Bank, IMF and FAO. Journal rankings were monitored and publishers were compared to Beall´s list. The searching language was English.

The majority of scores in socio-economic indicators are worse compared to average values achieved for the country (MOHAMMED RESHID CONSULTANCY, 2018; WORLD BANK, 2019a). For instance, the Multidimensional Poverty Index for Somali region lies at 80.1 (WORLD BANK, 2019a). Ethiopian Somali women give birth to 7.2 children on average (ibid.). Literacy rates reach 48.1 per cent for men and 36.9 per cent for women, while the national mean lies at 61.1 and 47.0 per cent (ESS & WORLD BANK., 2023). The share of men without education comprises 44.8 per cent and 75.3 per cent for women (GEBREMESKEL ET AL., 2019).

A percentage of 80 per cent of Somali region's surface area belongs to the lowlands, the rest being hilly and mountainous (ZERFU ET AL., 2010, as cited in MOHAMMED & KENADID, 2020). The altitude varies between approximately 300 and 1600 metres (MOHAMMED & KENADID, 2020). While precipitation levels move from 300 to 500 millimetres per year, evapotranspiration varies between 1750 and 3100 millimetres annually (ibid.). This lack of moisture classifies the region as dryland according to the information laid out in chapter 2.2. The semi-arid and arid climate features temperatures between 20 and 45 degrees Celsius (MOHAMMED & KENADID, 2020). The region experiences irregular precipitation and flood events (GEBREMESKEL ET AL., 2019), originating in the highlands (NLRC & ERCS, 2018).

Animals kept include camel, small ruminants and cattle (ESS, 2022; GEORGIS, 2010), mules, donkeys, poultry (ESS, 2022) and bees (EAST AFRICA ENGINEERING AND GENERAL CONSULTANT, 2018; ESS, 2022; FIELD TRIP, 2023; FSIABD CONSULT, 2021; GIZ, 2023A). Cereals produced in Somali region comprise maize, sorghum, wheat, barley, teff, rice, oats and millet while also vegetables such as onion, tomato, garlic, carrot, potato, beetroot, cabbage, watermelon, pepper and pumpkin are cultivated. Further, pulses like chickpea, different types of beans and peas can be found. Apart from that, forage such as Sudan and elephant grass, in addition to oilseeds like sesame, ground nut and wild sunflower and other crops such as khat[17] and greenleaves are grown. Finally, tree fruits like banana, orange and avocado are produced[18]. The mean landholding size is 1.1 hectares of which on average 0.1 hectares are cultivated (ESS & WORLD BANK., 2023).

Fafan zone has been classified as a mixed agro-ecological environment (SORPARI, 2023). Soils in its upper catchment include "vertisols, cambisols, luvisols, and leptisols" (ibid., p.13) leading

[17] Khat represents a plant-based drug (Hurni et al., 2015) competing with food production (Destrijcker et al., 2023).

[18] A detailed list with agricultural and horticultural products from Somali region including their mentioning in the literature is provided in table A.8 in appendix II.

to the conclusion that the majority of the zone is not or only moderately fertile (SoRPARI, 2023). Reasons for the lack of soil fertility are, among others, soil erosion and invasive species (ibid.). Nevertheless, 56 per cent of the total surface is used for crop cultivation (ibid.). The year is split into the wet season Gu'u lasting from March to September which includes the growing season from March to June, and the dry season Jilal extending from September to March (ibid.)[19]. Most crops are cultivated during Gu'u season (March to September) which provides the base for mostly rainfed crop production being dominated by cereals with 68 per cent of the entire area and 85 per cent of total production (ibid.).

In Fafan, a change from pastoralist to agro-pastoralist (HEDBEZ BUSINESS & CONSULTANCY PLC, 2018; SoRPARI, 2023) and sedentary way of life can be observed (SoRPARI, 2023). This means that for instance the land around Jigjiga is possessed exclusively by farmers being able to exert all rights coming with ownership in contrast to the traditional land ownership in Somali region which is related to being a clan member (HEDBEZ BUSINESS & CONSULTANCY PLC, 2018). Households own two hectares on average, controlled mostly through men (SoRPARI, 2023). Farm activities and decisions are also mainly undertaken by men (ibid.). This includes everything relating to camel and cattle, while women are more in charge for sheep and goats (MOHAMMED RESHID CONSULTANCY, 2018; SoRPARI, 2023). The family as well as neighbours within work-sharing agreements provide the majority of labour (SoRPARI, 2023).

In the area, arable production dominates livestock herding and crops are cultivated mainly for home consumption (SoRPARI, 2023). Prevailing and continuously cultivated grains are sorghum and maize, further pulses like groundnuts or chickpeas are grown, as well as vegetables such as tomato or onion using irrigation while fruit production is scarce (ibid.). Access to extension service, markets, improved crop varieties and labour is limited and usage of pest control and fertilizer is scarce while heavy machinery recently is utilized often due to the difficulties to keep oxen because of frequent droughts (ibid.). This results in low

[19] Gu'u season is separated further into "dira' (late March - late May), Hagaa (late May - late July), and Karan (late July - late September)" (SoRPARI, 2023, p. 81). Jilal season is split into "deyr (late September - late November) and kalil (late November - late March)" (ibid.). While during the data collection, the Gu´u season timing was confirmed, implying that planting for Gu'u takes place in March and harvesting in June, CSA reports differently in their surveys. CSA separates survey reports into main and short rain season named Meher and Belg (CSA, 2022b). Meher refers to a larger rainy season lasting from June to September while Belg extends from February to May (ibid.). "Belg Season Crops are defined as crops that are harvested during the months of March to August, while crops that are harvested during September to February are considered as Meher season crops" (CSA, 2022b, p. 7). This creates confusion as larger yields are reported through CSA for Meher, although this constitutes the less important season for Somali region. Exemplary sources for this are provided in chapter 5.3.

productivity (ibid.) while perceived core challenges are “limited access to improved crop technologies, recurrent drought, pest damage and limited access to mechanization services” (SORPARI, 2023, p. 18).

Two DVs situated in Jigjiga South and rehabilitated within DVRPU were selected for the study due to their similar geographical and agrophysical conditions. Amadle and Harre respectively cover around 9033 and 47458 hectares and are located 20 and 30 kilometres from Jigjiga (FSIABD CONSULT, 2021). Both feature a relatively flat surface with a gentle slope between 1.3 and 1 per cent for Amadle and Harre respectively (ibid.). Altitudes in Amadle vary between 1485 and 1785 metres, in Harre between 1470 and 1890 metres and both DVs are characterised by a subtropical highland climate with precipitation levels between 600 and 700 millimetres per year (ibid.). Both DVs feature gullies, pasture, cropland and settlements (ibid.). While in Harre ten WSW are constructed, in Amadle 12 were installed[20]. The majority of soils are luvisols and cambisols which, when properly treated, are usable for crop production (FSIABD CONSULT, 2021). Both DVs are inhabited mainly by (agro-) pastoralists (ibid.). The sample on which the present research is based solely includes those (agro-) pastoralists directly benefitting from the WSW, that is, directly cultivating on the rehabilitated land in front of, behind or next to the structures.

4.2 Method of data collection

Data used for the present research consist of secondary and primary type. Secondary data were used to conduct a brief literature review centring around the topic and its conceptual foundations as laid out in chapter 2. Further, those data were utilized to summarize studies investigating effects of WSW as demonstrated in chapter 3.1. Finally, secondary data were also used to create the questionnaire to collect primary data. Crucial information for this was, on the one hand, related to which crops are produced in Somali region, Fafan zone and the selected DVs. To collect as much information as possible, it has been decided to include all crops cultivated in Somali region as mentioned in chapter 4.1 into the questionnaire. On the other hand, information obtained from secondary sources was important to create the questionnaire itself which was supposed to allow detailed GM calculations as well as the investigation of factors influencing GMs as described in chapter 3.2. Consequently, the studies mentioned which

[20] The exact number of weirs was determined during the data collection. GPS lines were taken from them in addition.

include GM calculations as well as examinations of drivers affecting GMs were used as guidelines.

The final questionnaire contained mostly closed-ended questions related to information indispensable for the proper calculation of GMs obtained such as expenses for labour, machinery and inputs like seeds, fertilizer, pesticides, fungicides, insecticides and herbicides. Further, some questions referred to factors[21] which, according to the reviewed literature, may influence GMs such as socio-economic parameters[22]. The primary data were collected in November 2023 in collaboration with GIZ Ethiopia through face-to-face interviews conducted with a structured survey questionnaire developed with Kobo Toolbox. The investigated period comprised the Gu'u season 2023 (March to September) as well as the Jilal season 2022/2023 (September to March). A five day pilot phase was used for an extensive briefing and training of the enumerator, testing and adjustment of the survey ensuring comprehensibility of all questions and a smooth interview process. In the following ten days interviews were conducted with a GIZ staff translating into the local Somali language.

According to information obtained through Kebele Officials, the direct beneficiaries of the WSW include 48 (agro-) pastoralist household heads, more specifically 22 in Amadle and 26 in Harre. Due to the small number of potential participants and in order to compile a picture of the situation on the ground as detailed as possible, it has been decided not to sample randomly but rather collect data from all beneficiaries. This was successful due to the help of local GIZ staff, Development Agents, Kebele Officials and participants themselves. Only four members of the population were not available for an interview, resulting in a final dataset covering Amadle and Harre with 21, respectively 23 participants.

4.3 Hypotheses

Hypotheses were developed based on the review of existing studies regarding effects and implications of WSW for the biophysical environment as well as agricultural practices and performance as laid out in chapter 3.1. Further, existing research investigating GMs and their influencing factors as described in chapter 3.2 guided the formulation of the hypotheses to be examined. Finally, the particularities of Somali region and the study area as well as the investigated local (agro-) pastoralist communities were taken into consideration. All together

[21] Tables A.2 to A.6 in appendix II show a compilation of potential factors influencing GMs and provide information which were included in the questionnaire.

[22] A shortened version of the questionnaire used is provided in table A.9 in appendix II.

facilitated the creation of the following hypotheses to be tested in the course of the research work.

1: After the construction of water spreading weirs (WSW), agro-pastoralists in the Somali region, Ethiopia, cultivate more vegetable types then before.

2: The profitability differs across crop types.

2.1: The profitability is higher for vegetables than for cereals.

3: Overall profitability increases with agricultural experience, the use of fertilizer, the use of pest control mechanisms and the availability of water.

4: Mainly cereals are cultivated compared to vegetables because of risk aversion of the family heads, easier storage possibility, drought resilience, subsistence agriculture and the dual-use benefit for livestock production.

Note: Vegetables (including legumes and fruits) constitute tomato, onion, garlic, carrot, potato, pumpkin, watermelon, beetroot, cabbage, pepper, beans, field pease, chickpea and greenleaves. Cereals constitute teff, barley, wheat, sorghum, maize and millet.

Hypothesis 1 refers to diversification of crop production in direction of vegetables, one of the effects envisaged by the DVRPU Approach. Vegetable farming in those DVs has been reported (FSIABD CONSULT, 2021) while according to SORPARI (2023), vegetables were not produced continuously and only in low numbers in the years 2013 to 2016 and 2017 to 2018, that is, until the start of the intervention. Accordingly, the topic was worth of further examination in the present research. Hypothesis 2 attempts a similar analysis as has been done in some of the literature such as PANDEY & GAUTAM (2021) to determine which crops are significantly higher than others regarding their profitability. Hypothesis 2.1 addresses the question whether vegetables in general would be a recommendable crop in the described setting.

Variables included in hypothesis 3 are based on the literature (KASONGA, 2018; NKADIMENG ET AL., 2021; SUMAKA, 2017; XABA & MASUKU, 2013)[23]. In case of fertilizer, although soil fertility is assumed to be increased in the surrounding of the WSW as described in chapter 3.1, it is presumed as well that additional inputs have a significant augmenting effect (KEBA & MILKIAS, 2020; SHUMET, 2011; WOLLIE ET AL., 2018). Pest control was selected as pests were reported

[23] In this context, tables A.2 to A.6 in appendix II show a compilation of potential socio-economic, environmental, institutional and financial drivers of GMs as well as influencing factors related to agricultural practices and the GM calculation itself. They provide additional information for each variable related to significance in other studies, whether they were reflected in the survey for the present research, whether they were included in the modelled regressions and the expected sign of the effect.

already during the fieldtrip in July and constitute a common risk in crop production in general (KAHAN, 2008), leading to lower yields (ODOEMENEM & INAKWU, 2011; WOLLIE ET AL., 2018). Pest control is expected to have an increasing effect. Experience is expected to lead to a better understanding of all processes connected to crop production (YASIN, 2020) and, therefore, is assumed to increase the GM as well. Water availability was included with particular reference to one of the main functionalities of the WSW as described in chapter 3.1. It is expected to increase yields (WOLLIE ET AL., 2018).

Hypothesis 4 attempts to give a starting point for further analysis about factors influencing whether vegetables or cereals are produced, therefore providing insights around the topic of income diversification with vegetable production. As grains like maize and sorghum are most important in the study area, they represent a meaningful starting point for such analysis. Cereals are assumed to be associated with less investment and less risk, as vegetables are more perishable (MEZGEBE ET AL., 2016; MOHAMMED RESHID CONSULTANCY, 2018); therefore, risk averse (agro-) pastoralists are expected to produce more cereals. Further, vegetables are expected to be stored less easily (MEZGEBE ET AL., 2016), and therefore, worse storage opportunities are expected to lead to an increased cereal production. Cereals, particularly sorghum, feature drought resilience qualities (DERESE ET AL., 2018) which is why they may be increasingly produced in dryland settings. Vegetables are expected to provide income opportunities (SCHREINEMACHERS ET AL., 2018) rather than being consumed large-scale at home, like cereals such as sorghum and maize (SORPARI, 2023); in consequence subsistence producers are expected to produce mainly cereals. Finally, cereals, through straw and leaves, provide also forage for livestock (EAST AFRICA ENGINEERING AND GENERAL CONSULTANT, 2018), making those crops particularly preferable for (agro-) pastoralists.

4.4 Methods of data analysis

The collected data were processed and analysed using RStudio. After data cleaning, they were investigated with descriptive methods, statistical tests and regression analyses as well as GM calculation. The examination of frequencies, means, standard deviations and percentages was used in the present research to explore particularly socio-economic features of participating (agro-) pastoralists as well as particularities of practiced agriculture and perceptions about crops produced, a descriptive approach following the example of various studies mentioned in chapter 3.2. Further, the data collected was used to calculate output as well as GMs per hectare as a proxy of profitability of the different crops produced within the two DVs. Subsequently, averages were obtained. The GM was calculated employing a basic equation (1) used in various reviewed studies (DEMIR & GÖZÜBÜYÜK, 2020; ODOEMENEM & INAKWU, 2011).

$$GM = TO * P - TVC \tag{1}$$

where:

GM = Gross margin per hectare in birr

TO = Total output per hectare in kilogram

P = Price per kilogram in birr

TVC = Total variable cost per hectare in birr

The formula was decomposed into several parts and adapted to the case of the present research. Output was defined as amount produced instead of amount sold as has been done also by EAST AFRICA ENGINEERING AND GENERAL CONSULTANT (2018) and, similarly, by DEVKOTA & ATNAFE YIGEZU (2020). Thus, the entire produced quantity was considered in the equation so that home consumption was equally valued like sold produce. Output counted in bags produced was divided by the amount of Qodi cultivated and further divided by four as one Qodi translates to 0.25 hectares. This was multiplied by the average of the farmgate prices per bag reported by the (agro-) pastoralists, similar to the approach used by DEVKOTA & ATNAFE YIGEZU (2020). From the output per hectare in this way valued monetarily in birr, total variable cost per hectare in birr was deducted. Following the recommendation of PENOT ET AL. (2021), an attempt was made to include all variable expenses for labour and inputs in the calculation. In case of this research, those costs are composed by the rental cost for machinery, input expenses for seeds, fertilizer and pesticides as well as labour costs[24] for all stages including land preparation, sowing, weeding, spraying and harvesting.

[24] The cost for labour was proxied through questions posed occasionally to survey participants. People indicated having received or paid 500 birr and 300 birr for an eight-hour working day. The average of those were taken for the calculation corresponding to 50 birr per hour.

Table 1: Scheme for gross margin calculation

Output (per ha in birr)	$\left(\frac{\text{Bags produced}}{\left(\frac{\text{Qodi cultivated}}{4}\right)}\right) * \text{Average farmgate price (per bag)}$
-Total variable cost (per ha in birr) consisting of:	
Preparation (birr/ha)	Labour hrs * average hourly wage * people + Oxen hrs * rental cost + Total tractor cost + (labour hrs * average hourly wage * 1)
Sowing (birr)	Labour hrs * average hourly wage * people + Bought seed bags * bag cost + Government seed bags * bag cost + NGO seed bags * bag cost
Fertilizer (birr/ha)	Labour hrs * average hourly wage * people + Labour hrs spraying person * hourly wage sprayer + Fertilizer units used * unit cost
Pesticides (birr/ha)	Labour hrs * average hourly wage x people + Labour hrs spraying person * hourly wage sprayer + Pesticide units used * unit c Labour hrs * average hourly wage * people + Labour hrs spraying person * hourly wage sprayer + Pesticide units used * unit cost ost
Harvest (birr/ha)	Labour hrs * average hourly wage * people + Tractor cost per harvested bag * bags produced

Remark: More information regarding the calculation of farmgate prices is provided in table A.10 in appendix II. The calculation scheme was only used to quantify the GM of the main product, leaving out by-products such as straw from grain crops.

Source: Own calculation scheme developed based on all relevant literature considered as indicated in the text.

After this process, statistical tests were employed to investigate hypotheses 1 for which the significance of the difference in the number of vegetables produced before and after installation of WSW was tested. As the data did not fulfil the assumptions required for a paired T-Test, the Wilcoxon signed rank test was chosen for this setting with one dependent variable and two groups dependent of one another (UCLA, 2021b). This is the case here as participants were asked twice about which crops they produce requiring an answer once for the cultivation before WSW were constructed and once more about production in the Gu'u season 2023 (March to September); thus, observations were not independent. For the application of the test to the data it is assumed that the distributions of both groups of values are symmetric which allows the test to be an assessment of the medians (MANGIAFICO, 2016).

Hypothesis 2 relates to the differences in GMs obtained for various crops. The significance of this difference can be tested employing various statistical measures (UCLA, 2021b). The GM represents one dependent variable of, in this case, more than two groups which points, among others, to a one-way ANOVA as test approach (ibid.). This has been used for instance by PANDEY & GAUTAM (2021) to test differences in GMs. However, in contrast to their approach, for the present research, the Kruskal-Wallis-Test was employed offering another approach for hypothesis testing (UCLA, 2021b) which may be used in case the data, among others, do not comply with requirements of parametric tests or the sample is small (PLANING, 2022) both of which is the case for the GM data obtained within the present research.

The non-parametric Kruskal-Wallis-Test, the alternative to the one-way ANOVA, assesses the significance of differences in the mean ranks of two or more groups (PLANING, 2022). For the present research it is assumed that the groups' distributions have the same spread as well as shape. In this setting, the medians of the groups are tested as described by MANGIAFICO (2016). As the test only shows the existence of a difference between at least two groups, but does not specify which ones differ, a post-hoc test is needed to get more insights, the most common of which is the Dunn's Test (MANGIAFICO, 2016; PLANING, 2022) showing which of the groups differ from each other (MANGIAFICO, 2016). Hypothesis 2.1 only requires a test of significance of the difference of GMs of vegetables and cereals. As this hypothesis only considers two independent groups with again one dependent variable, the Wilcoxon-Mann Whitney Test is the appropriate method (UCLA, 2021b). It can be employed as well under the assumption that spread and shape of both groups' distributions are similar, allowing the test to be an assessment of medians according to MANGIAFICO (2016). In addition to that, mean ranks can be assessed subsequently (PLANING, 2022).

To generate insights regarding hypothesis 3, the data were used to model multiple linear regressions. This method predicts the values of a dependent variable while using information of independent variables (RASCH ET AL., 2014). It is widely applied for a range of statistical assessments while making some assumptions, for instance that effects can be combined in a linear manner and that the response variable is continuous (MANGIAFICO, 2016) which is the case for the present research. The method gives insight into the relative effect of each predicting variable in the context of the rest of independent variables (RASCH ET AL., 2014) which allows the assessment of the effect of a change in one predictor on the response variable while all other factors included in the model are held constant at their sample mean (DEVKOTA & ATNAFE YIGEZU, 2020). The multiple linear regression model to investigate hypothesis 3 was created guided by the few examples having been found in the literature such as KASONGA (2018),

SUMAKA (2017), XABA & MASUKU (2013), SAMUEL & IDRIS (2021) AND MERSHA ET AL. (2017)[25].

In order to assess hypothesis 4, a linear mixed model was created which allows the assessment of observations not independent of each other (UCLA, 2021e). For this hypothesis, all produced crops were considered which renders the observations dependent of one another as one participant produced more than one crop, that is, there are more than one observation from the same participant. A linear mixed model is the appropriate approach for this setting, following the descriptions of MANGIAFICO (2016) and YING & SCOTT (2023). This type of model consists not only of fixed but also random effects (MANGIAFICO, 2016) and uses all the available data instead of aggregating them in order to produce independent observations (UCLA, 2021e).

5 RESULTS

5.1 Participants' socio-economic status, agricultural practices & perceptions

Of the inhabitants of the two DVs, 48 were classified as (agro-) pastoralist household heads cultivating on the rehabilitated land directly in front of, behind or next to the WSW, meaning that between one and four households are using one single WSW. Of those, constituting the direct beneficiaries, 44 were interviewed. Beneficiaries of Harre DV (HDV) comprise 23 interviewees, the rest cultivates Amadle DV (ADV). Only four women participated as can be seen in table A.11 in appendix II which shows a summary of social parameters. In both DVs, the majority of (agro-) pastoralists have between six and ten family members organized mostly in one to two households, of which a similar count is male (4.26 and 4.1 on average for ADV and HDV). Families in Amadle have a higher average count of adults (5.33 in ADV compared to 3.65 in HDV) and more literate adult family members (on average 2.48 in ADV and 0.82 in HDV). The highest grade achieved in school by those adult literate family members was for Amadle most frequently primary school (confirmed by 38.10 per cent of participants). A share of 14.29 per cent of participants in Amadle had only illiterate family members while for Harre, the majority of 65.22 per cent reported no literate adult family members and, thus, no formal education.

As demonstrated in table 2, all participants in both DVs practice agriculture, while livestock is kept by more participants in Amadle than in Harre (85.71 per cent in ADV compared to 60.87

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[25] The tables A.2 to A.6 in appendix II provide further information regarding the covariates chosen for the regression models predicting the GMs.

per cent in HDV). Generation of non-farm income is similar in both DVs while apiculture is solely practiced by one person in Amadle. In Harre, agriculture is the most important livelihood for 91.3 per cent of participants, while in Amadle, other livelihoods are also essential for the people in comparison, leaving agriculture for 71.43 per cent as the most important one. From the table is visible that in both DVs, a large share of participants have a considerable amount of experience in agriculture. In Amadle, 52.38 per cent have 20 to 29 years of experience, in Harre this share amounts to 43.48 per cent. More than 40 years of experience were reported by 28.57 per cent in ADV and 21.74 per cent in HDV. All interviewees were engaged in agricultural production already before the WSW were constructed. The mean total land size owned is similar in both DVs (47.42 Qodi[26] (11.86 hectares) in ADV and 45.36 Qodi (11.34 hectares) in HDV). With on average of 24.95 Qodi (6.24 hectares) in ADV and 25.57 Qodi (6.39 hectares) in HDV, the size of the cultivated area is also comparable. All participants cultivated in Gu'u season 2023 (March to September) while only four of them planted in Jilal season 2022/2023 (September to March).

In ADV and HDV, 42.86 per cent respectively 39.13 per cent used loans to finance the crop production of the agricultural year 2022/2023 which includes Gu'u and Jilal seasons. Of those utilizing loans, 77.78 per cent in both ADV and also HDV received them through friends. The share of those who received agricultural advice is 57.14 per cent in ADV and 47.83 per cent in HDV. The main sources of advice for Amadle were family, NGOs and GIZ (each mentioned by 25 per cent), while for Harre, family as advice source was mentioned by 36.36 per cent, Woreda experts by 27.27 per cent and GIZ by 18.18 per cent. Cooperatives were more important in Harre, with 39.13 per cent of participants confirming a membership (in comparison 23.81 per cent confirmed membership in Amadle).

Further, willingness to take risk was evaluated using an 11-point Likert scale from zero meaning completely unwilling to ten indicating very willing. The interviewees rated themselves on average at 8.3 on the scale with the majority of participants (36.36 per cent) reporting a ten. Using the same scale ranging from very difficult to very easy, market access was rated at a mean of 4.59. The interviewees reported going to the market on average 2.23 times during the year 2022/2023, taking a mean of 0.54 hours to reach it. The majority used a rented vehicle for

[26] The Somali region land unit size Qodi translates into 0.25 hectares.

that[27] and had to pay on average 197 birr one way. Cost and the availability of public transport were major challenges regarding market access, mentioned by 54.54 and 34.09 per cent[28].

Table 2: Economic parameters of participants

Variable		Amadle			Harre		
		Frequency	Percentage	Mean	Frequency	Percentage	Mean
Livelihood	Agriculture	21	100	-	23	100	-
	Livestock	18	85.71	-	14	60.87	-
	Non-farm	3	14.29	-	4	17.39	-
	Bee-keeping	1	4.76	-	-	-	-
Agriculture most important	yes	15	71.43	-	21	91.3	-
Experience	0-9	-	-	-	4	17.39	-
	10-19	2	9.52	-	3	13.04	-
	20-29	11	52.38	-	10	43.48	-
	30-39	2	9.52	-	1	4.35	-
	40+	6	28.57	-	5	21.74	-
	Total	21	100	26.81	23	100	22.78
Land size (Qodi) (hectares)	0-10	1	4.76	-	3	13.04	-
	11-25	5	23.81	-	4	17.39	-
	26-50	8	38.10	-	8	34.78	-
	51-99	3	14.29	-	5	21.74	-
	100+	4	19.05	-	2	8.7	-
	Refuse to answer	-	-	-	1	4.35	-
	Total	21	100	47.42 (11.86)	23	100	45.36 (11.34)
Agricultural area in Qodi (hectares)	0-10	6	28.57	-	4	17.39	-
	11-25	10	47.62	-	13	56.52	-
	26-50	2	9.52	-	4	17.39	-
	51-99	2	9.52	-	2	8.7	-
	100+	1	4.76	-	-	-	-
	Total	21	100	24.95 (6.24)	23	100	25.57 (6.39)
Usage of loans	Yes	9	42.86	-	9	39.13	-
	No	12	57.14	-	14	60.87	-
Agricultural advice	Yes	12	57.14	-	11	47.83	-
	No	9	42.86	-	12	52.17	-
Cooperative	Yes	5	23.81		9	39.13	-
	No	16	76.19		14	60.87	-

Remark: The table shows frequencies and percentages and means where applicable related to economic parameters of participants, displayed for Harre and Amadle separately.
Source: Own calculations based on collected data.

The investigated period was described with drought by 13.64 per cent of participants. Using an 11-point Likert scale ranging from very short to very long, participants rated water availability on average with 2.98. As shown in table A.12 in appendix II, participating (agro-) pastoralists cultivated maize, sorghum, onion, wheat, khat, chickpea, barley, tomato, carrot, beetroot and

27 This was mentioned by 31 participants out of 42 in total having reported market visits.

28 Additionally, one person mentioned the lack of an identity card as obstacle to go to the market.

Sudan grass, the first three occurring most frequently with 39, 34 and 27 participants growing them. The majority (47.73 per cent) combined a grain with onion[29]. Table A.12 also shows the mean area size cultivated per crop. Maize, wheat and sorghum cover most of the surface area with on average 3.41, 2.5 and 1.86 hectares, followed by khat and onion with a mean area size of 1.58 and 1.44 hectares[30]. Table 3 shows the reasons for crop choice for the three most frequently cultivated crops. Maize and sorghum were most often connected to dual use as they are used as food and forage. Onion was cultivated mostly to earn additional income[31].

Table 3: Reasons for crop choice

Crop	Reason for choice	Frequency	Percentage
Maize	Dual use	35	89.74
	Additional income	9	23.08
	Stable market demand	3	7.69
	Other	5	12.82
Sorghum	Dual use	31	93.94
	Additional income	9	27.27
	Stable market demand	2	6.06
	Other	2	6.06
Onion	Dual use	4	14.81
	Additional income	21	77.78
	Stable market demand	4	14.81
	Other	3	11.11

Remark: The table shows reasons for crop choice for maize, sorghum and onion. For maize, other includes soil quality, storage and yield (each mentioned by 2.56 per cent) as well as preference and tradition (both mentioned by 2.56 per cent). For sorghum, other includes tradition and safe animals from drought (each mentioned by 3.03 per cent). For onion, other includes soil quality, no weeds disturbing the crop and tradition (each mentioned by 3.70 per cent).

Source: Own calculations based on collected data.

Table 4 demonstrates how the produced crops were used. It is visible that from 39 maize producers, 82.05 percent harvested but only 10.26 per cent sold some of their production while 15.38 per cent donated a part and 23.08 per cent saved a share of the production to use them as seeds for the next season. Although sorghum was planted numerously, the majority lost the

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29 Wheat was only included by two participants (4.55 per cent of total interviewees) in those combinations, the rest combined onion with maize or sorghum or both. Further, 20.45 per cent produced only grains, most of them cultivating maize and sorghum, only one participant combined maize with wheat. A share of 15.91 per cent produced only maize or sorghum in monocropping. A share of 13.64 per cent combined a grain and onion with further crops. The remaining participant (2.27 per cent) combined grains with chickpea.

30 The four participants cultivating in Jilal season 2022/2023 (September to March) produced only maize, sorghum and onion.

31 Apart from that, for wheat, dual use was named by 100 per cent of cultivators as reason for crop selection while additional income was mentioned by 25 per cent. Khat was cultivated by 33.33 per cent for additional income; 66.67 per cent grew it to for consumption to increase motivation for work in the fields. Chickpea was associated to dual use and stable prices (both mentioned by 50 per cent) and food diversification (mentioned by 50 per cent) while tomato and barley were connected to dual use (mentioned by 100 per cent each); carrot and beetroot to stable market demand (mentioned by 100 per cent each).

harvest. However, from the onion cultivators, 81.48 per cent got a harvest from their plots and a considerable share of 77.78 per cent sold their produce. Maize and sorghum cultivators sold their produce mostly in the market (confirmed by 75 and 100 per cent). Of the onion producers who sold their produce, most sold to intermediaries, followed by the market and wholesalers (66.67, 42.86 and 14.29 per cent). Wheat, tomato and carrot cultivators sold to the market while Khat was sold to the market and intermediaries. Average prices obtained per kilogram and bag are visible as well in table 4. It shows that Khat has an exceptionally high price, although only the onion price is representative as for the rest, the observations are very few. The average price estimated for onion is subject to considerable variability with a standard deviation of 1216 birr and a price range from 500 to 5000 birr per bag. Looked at separately, on the market, onion growers obtained a mean price of 2159 birr per bag, while intermediaries paid on average 1952 birr and wholesalers 1917 birr[32].

Table 4: Usage of produced crops in absolute numbers & percentages

Crop	Planted	Harvested	Donated	Saved	Sold	Mean price per kilogram (bag) in birr
Maize	39	32 (82.05)	6 (15.38)	9 (23.08)	4 (10.26)	24.66 (1,233)
Sorghum	33	7 (21.21)	3 (9.09)	5 (15.15)	3 (9.09)	43.34 (2,167)
Onion	27	22 (81.48)	6 (22.22)	-	21 (77.78)	37.56 (1,878)
Wheat	4	3 (75)	-	1 (25)	1 (25)	50 (2,500)
Khat	3	2 (66.67)	1 (33.33)	-	2 (66.67)	12,000 (3,000)
Chickpea	2	2 (100)	-	-	-	-
Barley	1	1 (100)	-	-	-	-
Tomato	1	1 (100)	-	-	1 (100)	25 (300)
Carrot	1	1 (100)	-	-	1 (100)	40 (2,000)
Beetroot	1	-	-	-	-	-
Sudan grass	1	1 (100)	-	-	-	-

Remark: The table shows how many participants planted a specific crop in absolute numbers. Further, it is displayed how many people harvested, donated, saved and sold their produce in absolute numbers. The corresponding percentage share relative to the total number of participants producing this crop is shown in parentheses. For Khat, only two producers are counted as having harvested because the third person could not quantify production. Further, the table shows the average price in birr obtained by participants per kilogram while the bag price is shown in parentheses. For maize and sorghum, the price mean is based on three observations each. For onion, 21 observations were considered. For wheat, tomato and carrot, the value originates in one observation each. The Khat price is based on two observations. Chickpea and barley were not sold. One person cultivating beetroot lost the harvest. For Sudan grass, no unit size and price could be obtained.

Source: Own calculations based on collected data.

As displayed in table 5, pests were frequently reported, with bugs mentioned by 66.67 per cent of maize cultivators, 36.36 per cent of sorghum growers and 77.78 per cent of onion producers, birds mentioned by 10.26 per cent of maize cultivators and 69.70 per cent of sorghum growers and grasshoppers named by 7.69 per cent of maize cultivators, 9.09 per cent of sorghum growers

[32] This information is provided in addition in table A.13 in appendix II.

and 25.93 per cent of onion producers. Participants used this question also to point to drought. This was mentioned by 12.82, 9.09 and 14.81 per cent of participants cultivating maize, sorghum and onion. When looking only at those participants having lost the harvest, of the seven maize cultivators for which this is the case, 71.43 per cent reported drought or lack of rain and 14.29 per cent mentioned birds. Of the 26 participants having lost their sorghum, birds, bugs and grasshoppers were reported by 80.77, 38.46 and 7.69 interviewees. A share of 11.54 per cent also mentioned drought. Of the five interviewees having lost the onion harvests, drought and bugs were each mentioned by 60 per cent and 20 per cent reported grasshoppers. A direct question investigating reasons for crop loss was not included in the questionnaire[33].

Table 5: Pests reported in absolute numbers & percentages

	Cultivated				Lost harvest			
Crop	**Bugs**	**Birds**	**Grasshoppers**	**Drought**	**Bugs**	**Birds**	**Grasshoppers**	**Drought**
Maize	26 (66.67)	4 (10.26)	3 (7.69)	5 (12.82)	-	1 (14.29)	-	5 (71.43)
Sorghum	12 (36.36)	23 (69.70)	3 (9.09)	3 (9.09)	10 (38.46)	21 (80.77)	2 (7.69)	3 (11.54)
Onion	21 (77.78)	-	7 (25.93)	4 (14.81)	3 (60)	-	1 (20)	3 (60)

Remark: The table shows the number of participants mentioning bugs, birds, grasshoppers and drought on the question asking for pests. Data are displayed for all participants having planted and all participants who lost the harvest subsequently. Percentage shares relative to the total number of cultivators, respectively the total number losing the harvest are shown in parentheses.
Source: Own calculations based on collected data.

However, regarding the inputs used, the collected data show that for maize, fertilizer as well as pest control were used only by 5.13 per cent of producers. For sorghum, no one used fertilizer and only 6.06 per cent of cultivators applied pest control mechanisms. In onion production, however, 40.74 per cent of the 27 cultivating participants used fertilizer and 29.63 per cent made use of pest control mechanisms[34]. In table A.14 in appendix II, inputs desired by participants for the production of the currently cultivated crops are listed. Answers include machinery, seeds, water, fertilizer, labour and insecticides while the picture for maize, sorghum and onion is very similar. More machinery and seeds are perceived as being most necessary for all of them.

Table A.15 in appendix II shows the seed origin and costs for all produced plants ordered from high to low mean seed prices. While it is visible that some seeds had been saved from the last

[33] The participant planting beetroot and losing the harvest mentioned bugs as well.

[34] Fertilizer used for maize and onion were chemical. Pest control mechanisms used for maize were manual removal of insects and chemicals. For sorghum, all participants using pest control manually removed insects. Chemical pest control was used by 18.52 per cent of onion cultivators and manual removal by 7.40 per cent while 3.70 per cent mechanically removed insects.

season, particularly for the cultivation of maize and sorghum with respectively 33.33 and 29.21 per cent of cultivators reporting seed saving, it is clearly evident that most of the seeds are obtained on the market. Regarding the average per unit cost, the table shows that seed prices for sorghum, carrot, beetroot and maize are rather similar, ranging from 3,020 to 2,976 birr, while the mean onion unit seed price with 2,372 birr is lower. However, only maize, sorghum and onion feature sufficient observations to provide a representative picture.

To get insights regarding perceptions of (agro-) pastoralists about their crops, questions referring to an 11-point Likert-scale ranging from zero to ten were used. Due to the low prevalence of all other produced crops, results are presented here only for maize, sorghum and onion. Table 6 shows an overview of the number of participants having selected the different scale points as well as the mean values regarding various topics for some of which the scale was defined differently. It is visible that for demand, assessed on the scale from very low to very high, averages are lowest for maize and highest for onion with 17 participants reporting very high demand for the crop. Perceptions about the level of prices show a similar picture, lowest for maize and highest for onion, reaching a mean of nine on the scale for onion.

With regard to stability of prices, assessed from fluctuating to stable, onion prices were rated on average the most stable in comparison, reaching a mean of 6.55 on the scale. For storage, graded from very difficult to very easy, onion was evaluated the worst, with an average of 2.44 on the scale and ten onion producers selecting one on the scale. Financial access to inputs, evaluated as well from very difficult to very easy, is perceived as rather difficult with an average of 3.33, 3.35 and 3.8 on the scale for onion, maize and sorghum while physical access to inputs is evaluated as being rather easy with a mean of 8.77, 9.07 and 9.31 on the scale for sorghum, onion and maize and the vast majority of 20, 17 and 27 participants rating this with ten on the scale.

From 44 participants all confirmed the wish to also produce other crops than the ones they were cultivating in the investigated period of time. When asked for factors necessary to produce crops different from the currently grown ones, 31 interviewees, that is, 70.45 per cent of all participants, mentioned physical access to inputs, followed by 11 (agro-) pastoralists constituting a share of 25 per cent pointing out the financial access to inputs. Water was named seven times (15.90 per cent), followed by advice or training with two mentions (4.55 per cent) while five participants (11.36 per cent) referred to different necessities[35].

Table 6: Perceptions of participants regarding crops cultivated

	Crop	Mean	0	1	2	3	4	5	6	7	8	9	10
Demand	Maize	6.82	-	-	1	5	2	3	6	3	8	5	6
	Sorghum	7.34	-	1	2	-	-	6	3	2	6	8	7
	Onion	9.16	-	-	-	-	-	-	2	2	2	4	17
Level of prices	Maize	5.38	1	1	2	7	3	8	4	6	1	2	4
	Sorghum	6.66	-	1	2	-	3	9	2	2	5	5	6
	Onion	9	-	-	-	-	-	-	1	3	4	6	13
Stability of prices	Maize	5.03	1	4	1	2	6	13	3	2	2	3	2
	Sorghum	5.51	1	2	2	3	6	4	3	3	6	3	2
	Onion	6.55	-	-	3	5	2	3	-	-	2	3	9
Storage	Maize	3.89	1	5	6	5	14	1	2	-	-	3	2
	Sorghum	3.97	3	1	9	8	2	3	1	3	1	2	2
	Onion	2.44	2	10	5	4	2	2	-	-	2	-	-
Financial access to inputs	Maize	3.35	3	6	6	7	6	6	1	2	-	2	-
	Sorghum	3.8	2	6	4	9	-	4	3	4	2	-	1
	Onion	3.33	2	3	8	4	5	1	1	-	-	2	1
Physical access to inputs	Maize	9.31	-	-	-	-	-	1	3	-	2	6	27
	Sorghum	8.77	-	-	-	-	1	3	1	1	6	3	20
	Onion	9.07	-	-	-	-	1	-	1	2	3	3	17

Remark: The table shows perceptions of participants about different topics regarding their produced crops. All variables were assessed using an 11-point Likert scale ranging from zero to ten. For demand and level of prices the scale ranges from very low to very high. For stability of prices the scale extends from very fluctuating to very stable. For storage, financial access to inputs and physical access to inputs the scale runs from very difficult to very easy.

Source: Own calculations based on collected data.

5.2 Water-spreading weirs and vegetable production

Hypothesis 1 states that (agro-) pastoralists produce more vegetables after the construction of WSW. To investigate this, initially, the number of vegetables produced per participant was counted, once before the construction of WSW and once for the Gu'u season 2023 (March to September). A simple comparison between the average count of produced vegetables[36] for both points in time shows that before construction of WSW participants' vegetable production comprised on average 40.91 per cent while in the examined Gu'u season 2023, interviewees cultivated an average share of 72.73 per cent vegetables relative to total production. In addition, medians of the counts were assessed. The median for crops produced before construction of WSW was zero, while the one for Gu'u season 2023 was one.

The significance of this difference can be tested statistically employing the Wilcoxon signed rank test. With the assumptions made in chapter 4.4, in this case, the test examines the null

[35] Mentioned different necessities were a motorbike to buy inputs with one mention (2.27 per cent) as well as fertilizer and tractors with two mentions each (4.55 per cent each).

[36] Vegetables are classified here as tomato, onion, carrot, beetroot and chickpea.

hypothesis stating that the medians of both groups are identical, in contrast to the alternative one stating that they are not. The test was applied to the data using the one-sided method which specifies the alternative hypothesis further. This states not only inequality of medians but that vegetable counts before the construction of WSW are lower than in Gu´u season 2023. The result of the test is a p-value lower than the set alpha level of 0.05 which allows to reject the null hypothesis (MANGIAFICO, 2016) and confirm the alternative hypothesis that vegetable counts were indeed lower before the construction of WSW[37] (V = 66, p-value = 0.008227). In summary, hypothesis 1 can be verified as indeed more vegetables were produced in the assessed Gu'u season 2023, that is, after the construction of WSW, compared to the number of vegetables cultivated before.

5.3 Gross margin analysis

The GMs of the crops produced by participating (agro-) pastoralists were calculated initially for Gu'u season 2023 (March to September) as this is the main growing season and because participants cultivated very little in Jilal season 2022/2023 (September to March) as mentioned in chapter 5.1[38]. For the calculation, the collected data was used while the scheme as laid out in table 1 in chapter 4.4 was applied. GMs were intended to be calculated for all main crop products found to be grown by (agro-) pastoralists in the two investigated DVs while by-products such as straw were excluded. As has been mentioned in chapter 5.1, participants cultivated maize, sorghum, onion, wheat, Khat, chickpea, barley, tomato, carrot, beetroot and Sudan grass and only the first three in sufficient numbers to provide representative results.

Initially, the output in kilogram per hectare was calculated to get a first insight. This was done by first dividing the output counted in bags by the amount of Qodi cultivated, further divided by four, and then multiplying it with the average bag size[39]. Table 7 shows averages and standard deviations as well as minimum, maximum and median of output per hectare in kilogram for all crops produced ordered from high to low mean output. Calculations of averages

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[37] As recommended by Planing (2022), in addition to that, the mean ranks were assessed as well. They show no difference (for both the mean is 22.5). However, it was concluded that mean ranks may be equal, even though differences in the distributions of the ranks of the two groups exist. Further, it was assumed that the result of the statistical test employed provides the most meaningful and significant result. Apart from that, also a one-sided paired T-Test was applied to the data. This also confirms the significance of differences in vegetable counts at a p-value of 0.01456, indicating the mean difference of -31.81 per cent.

[38] Nevertheless, calculations were conducted in addition for Jilal season 2022/2023 as well as for both seasons together.

[39] The bag size was obtained through occasional additional questions posed to (agro-) pastoralists and market traders. More information is provided in table A.10 in appendix II.

were made considering also those participants who planted but lost the harvest. Carrot and tomato are in addition to onion the crops with the highest output, however the first two being based only on one observation. For this reason, the standard deviation is missing for those crops which output does not feature any variability.

Onion shows a noticeably high output as well. However, it also features considerable dispersion around the mean and values ranging from 50 to 6,000 kilogram per hectare, while being based on data collected from 27 participants. Maize, also based on a reasonable amount of data of 39 participants, achieved a far lower average, with less pronounced variability, although minimum values start at 67 kilogram per hectare and maximum values lie at 1,500 kilogram per hectare. While based on figures reported from 33 interviewees, sorghum shows a very high dispersion with values extending from 40 to 1,300 kilogram per hectare as well as a very low average output. This is caused by the widespread harvest loss for sorghum in the investigated season. Of 33 people who planted sorghum, only 7 (21.21 per cent) were able to harvest in the end. People indicated during the interviews that leaves and straw was used nevertheless as forage for animals. This was not quantified within the present study as mentioned before. Beetroot was cultivated by only one person who lost the harvest and for Sudan grass, no unit size could be obtained so that calculations could not be applied. The medians, which are more robust to extreme values, are in most applicable cases, that is, cases based on more than one observation, lower than the mean; in the case of sorghum laying even at zero.

Table 7: Average output per hectare in kilogram

Crop	Number cultivating	Mean	St.dev.	Minimum	Maximum	Median
Carrot	1	2,000	NA	2,000	2,000	2,000
Onion	27	1,456	1,487	50	6,000	1,167
Tomato	1	960	NA	960	960	960
Maize	39	418	361	67	1,500	333
Barley	1	120	NA	120	120	120
Sorghum	33	113	329	40	1300	0
Chickpea	2	97	52	60	133	97
Wheat	4	94	103	67	240	67
Khat	3	8	8	2	13	8
Beetroot	1	0	NA	0	0	0
Sudan grass	1	NA	NA	NA	NA	NA

Remark: The table shows the number of participants cultivating the different crops, the average output per hectare in kilogram, its standard deviation as well as minimum, maximum and median.
Source: Own calculations based on collected data.

Subsequently, GMs were calculated following the scheme shown in table 1. In order to do this, the costs of every step of the process from preparation to completed harvest were calculated separately first to later sum them to obtain total variable cost. Table 8 shows the cost per hectare incurred for the different steps of the agricultural production process as well as total variable cost ordered from highest total variable cost represented for onion to lowest associated with Khat. From the table is visible that the strongest cost drivers were different for the various crops. Regarding the cultivation of carrot, onion and beetroot, most variable expenses were used in the sowing phase with 54, 52 and 75 per cent of total variable costs incurred.

Contrasting this, for barley, maize, sorghum, Sudan grass and chickpea, the harvesting phase is most costly for producers. In this phase, for the first two crops, 88 and 52 per cent of total variable costs are invested and for sorghum and Sudan grass 50 per cent of expenses are used while for chickpeas this share amounts to 35 per cent. For tomato, the cost is balanced between land preparation, sowing and fertilizer, for wheat most expenses incur during preparation and Khat, a special case, needs most of costs for fertilizer application. For this last one, land preparation and sowing costs were classified as fixed costs and excluded due to the perennial character of the crop. As has been mentioned before, only onion, maize and sorghum were cultivated by a sufficient number of participants to provide a representative picture.

Table 8: Mean cost per production step & in total per hectare in birr (per cent)

Crop	Land preparation	Sowing	Fertilizer application	Pesticide application	Harvest	Total variable cost
Onion	3,644 (16)	11,892 (52)	1,008 (4)	177 (0.8)	6,115 (27)	22,836
Carrot	10,200 (45)	12,200 (54)	-	-	200 (0.9)	22,600
Sorghum	3,515 (26)	2,857 (21)	-	491 (4)	6,805 (50)	13,668
Barley	1,560 (12)	40 (0.3)	-	-	11,200 (88)	12,800
Wheat	5,820 (49)	2,385 (21)	40 (0.3)	-	3,600 (30)	11,845
Sudan grass	5,200 (46)	500 (4)	-	-	5,600 (50)	11,300
Tomato	3,400 (32)	3,400 (32)	3,400 (32)	200 (2)	200 (2)	10,600
Maize	2,343 (26)	1,468 (16)	499 (5)	44 (0.5)	4,756 (52)	9,109
Beetroot	2,000 (25)	6,000 (75)	-	-	-	8,000
Chickpea	500 (14)	754 (22)	954 (28)	54 (2)	1,200 (35)	3,460
Khat	-	-	1,831 (58)	1,182 (38)	133 (4)	3,147

Remark: The table shows average costs for land preparation, sowing, fertilizer and pesticide application, harvest as well as total variable cost for the different crops produced. Absolute numbers with percentages in parentheses are displayed. Absolute and percentage values might not add up completely due to rounding differences and because means of the different steps are displayed.

Source: Own calculations based on collected data.

In the process, total variable cost was deducted from total output. Table 9 shows average total outputs, average total variable costs, the resulting mean GMs as well as their standard deviations and minimum and maximum GM values for the different crops in birr per hectare, ordered from high to low mean GM. A higher resulting GM hereby indicates a higher profitability (Abu et al., 2011) and negative values signal an economic loss. Although GMs obtained for vegetables are high in general here as well, similar to the output data, they have to be considered with care as they are based on very few observations with the exception of onion. The table shows for instance that onion has a mean total output of 54,669 birr per hectare from which on average 22,836 birr total variable cost per hectare were deducted, leaving a considerable mean GM of 31,832 birr per hectare. However, the variability around the mean for onion is very high and values range from -36,500 to 184,760 birr per hectare. Maize and sorghum, with GMs of 1,190 and -8,765 birr per hectare are associated as well with high variability. Khat is shown with an exceptionally high GM based on the low variable cost it needs after it has once been planted[40].

Table 9: Mean total output, total variable cost & gross margin per hectare in birr

Crop	Mean total output	Mean total variable cost	Mean gross margin	Minimum gross margin	Maximum gross margin	Standard deviation of gross margin	Median gross margin
Khat	90,000	3,147	87,800	19,600	156,000	96,449	87,800
Carrot	80,000	22,600	57,400	57,400	57,400	NA	57,400
Onion	54,669	22,836	31,832	-36,500	184,760	53,646	21,460
Tomato	24,000	10,600	13,400	13,400	13,400	NA	13,400
Chickpea	5,440	3,460	1,980	857	3,104	1,589	1,980
Maize	10,308	9,109	1,190	-17,380	33,565	8,842	878
Barley	6,514	12,800	-6,286	-6,286	-6,286	NA	-6,286
Wheat	4,666	11,845	-7,178	-10,667	-640	4,580	-8,704
Beetroot	0	8,000	-8,000	-8,000	-8,000	NA	-8,000
Sorghum	4,903	13,668	-8,765	-88,400	45,342	23,737	-6,150

Remark: The table shows averages of total output, total variable cost and GMs of crops produced. Further, minimum and maximum values of GMs, their standard deviations and their medians are displayed. All values are shown in birr per hectare. Values might not add up completely due to rounding differences and because means are displayed. Values are based on all available observations which means that for instance, output and cost for Khat is based on three observations but GM only on two as one participant could not quantify his harvest. Calculations were made only for the main product, while straw and leaves for grain crops were not taken into account. Sudan grass could not be valued as unit sizes and prices could not be obtained.

Source: Own calculations based on collected data.

5.4 Differences in gross margins

Hypothesis 2 claims that the profitability of crops differs. Table 9 demonstrates that the means as well as the medians of GMs of the various crops are considerably distinct. As described in chapter 4.4, this difference can be tested using the Kruskal-Wallis test. To produce meaningful results, the analysis was conducted taking into account only maize, sorghum and onion as all other crops were cultivated in very limited numbers. Based on the assumptions made in chapter 4.4, the null hypothesis for this test is that all groups do not have significantly different medians, the alternative stating that for at least one group this is not true.

40 In Jilal season 2022/2023 (September to March), only maize, sorghum and onion were cultivated, with an average GM of -1,730, -3,990 and -12,240 birr per hectare. For the whole year encompassing Jilal season 2022/2023 and Gu'u season 2023 (March to September), average GMs for maize, sorghum and onion are 1,053, -8,742 and 31,379 birr per hectare.

The Kruskal-Wallis Test, applied to the data, yielded a p-value less than the set alpha level of 0.05 which allowed to reject the null hypothesis and confirmed the existence of significant differences in the GMs of the three compared crops (Kruskal-Wallis chi-squared = 16.934, df = 2, p-value = 0.0002103). The Dunn's test[41] was applied post-hoc to the data and revealed that significant differences exist solely between the GMs of sorghum and maize (p-value = 0.0035) and sorghum and onion (p-value = 0.0001). Test variations yielded the same result[42]. Accordingly, hypothesis 2 can only partly be verified as not all GMs of the crops produced differ significantly from each other. The GM of maize does not differ significantly from the one of onion. However, the GM of sorghum is significantly different from the ones of maize and onion.

Hypothesis 2.1 proposes that the profitability, that is, the GM of vegetables, is higher than the one of cereals. This was examined as well considering solely maize, sorghum and onion for the same reasons as indicated above. The data for those three crops was grouped into cereals and vegetables. Initially, mean GMs were compared for a first insight. The average GM of cereal crops was -3,437 birr per hectare while the one for vegetable crops was 31,832 birr per hectare. Medians were -2,240 birr per hectare for cereals and 21,460 birr per hectare for vegetables. Similar to above, the Wilcoxon-Mann Whitney Test, a two-sample test, conducts a comparison of observations of two independent groups. With the assumptions made, the null hypothesis is that medians are equal and the alternative one states the opposite.

The test was applied to the two groups cereals and vegetables using the one-sided test method which specifies the alternative hypothesis to state not only inequality of medians, but that the cereals group has lower values than the vegetables group. The test shows that both groups differ significantly from each other as the p-value is lower than 0.05 (W = 610, p-value = 0.002827). Thus, the null hypothesis can be rejected and the alternative hypothesis that the cereals group has lower values than the vegetable group can be confirmed. Mean ranks assessed additionally

[41] The Dunn's Test was applied using the Bonferroni correction for multiple comparison adjustments.

[42] For this test, outliers were initially kept in the data. In addition, the same tests were applied to the data with excluded outliers, showing the same results regarding significance. In addition, the same test and post-hoc test was applied to the GMs obtained from Gu'u 2023 (March to September) and Jilal season 2022/2023 (September to March) considered together. This also yielded the same results regarding significance while taking out outliers and running the tests again also did not change the results. Further, a one-way ANOVA, additionally conducted with the same data obtained from Gu'u season including outliers yielded the same result regarding significance pointing also to differences in the GMs of the groups with a p-value of 1.07e-05. The post-hoc employed Tukey test showed p-values below 0.05 and significant differences only for the GMs of sorghum and maize as well as sorghum and onion.

show that average ranks of GMs of cereals are lower (56.65) than the ones of vegetables (86.20). In conclusion, hypothesis 2 can be verified as GMs of vegetables in this dataset are higher than cereals.

5.5 Drivers influencing gross margins

Hypothesis 3 states that profitability increases with agricultural experience, the use of fertilizer, the use of pest control mechanisms and the availability of water. As described in chapter 3.2, regression analysis has not been found numerously during the literature review. This type of modelling is seldomly used to analyse factors influencing GMs, but more often to assess drivers of output (NKADIMENG ET AL., 2021). Nevertheless, a few researchers applied it as explained above. For the same reasons as stated above, this analysis was focussed on maize, sorghum and onion. Within the process of analysis, for all three crops, different equations were formed similar to the general model (2) based on NKADIMENG ET AL. (2021) to assess the influence of various factors.

$$Y = \beta_0 + \beta_1 X_1 + \ldots + \beta_n X_n + U \quad (2)$$

Where:

Y	is the GM, denoted with $_m$ for maize, $_s$ for sorghum and $_o$ for onion
β_0	is the constant
β_1 to β_n	are the coefficients of the predictor variables
X_1 to X_n	are the predictor variables
U	is the variation not explained by the model

Following this model, six different equations were built to assess drivers influencing the GM of maize as laid out hereafter.

$$Y_m = \beta_0 + \beta_1 \text{ experience} + U \quad (3)$$

$$Y_m = \beta_0 + \beta_2 \text{ perceived water availability} + U \quad (4)$$

$$Y_m = \beta_0 + \beta_3 \text{ pest control} + U \quad (5)$$

$$Y_m = \beta_0 + \beta_4 \text{ fertilizer} + U \quad (6)$$

$$Y_m = \beta_0 + \beta_1 \text{ experience} + \beta_2 \text{ perceived water availability} + \beta_3 \text{ pest control} + \beta_4 \text{ fertilizer} + U \quad (7)$$

$$Y_m = \beta_0 + \beta_1 \text{ experience} + \beta_2 \text{ perceived water availability} + \beta_3 \text{ pest control} + \beta_4 \text{ fertilizer} + \beta_5 \text{ female} + \beta_6 \text{ primary education or higher} + \beta_7 \text{ agriculture=most} \quad (8)$$

important + β_8 nr of literate family members + β_9 family size + β_{10} nr of male family members + β_{11} perceived market access + β_{12} loan usage + β_{13} willingness to take risk + U

While formula (7) relates to the stated hypothesis, equation (8) was created additionally to examine the effect of various other socio-economic factors for which data has been collected as well. The results of the multiple linear regression used to explain the variation in the GM of maize per hectare valued in Ethiopian birr are provided in table 10. The explanatory factors chosen are the binary variables pest control, fertilizer, female, primary education or higher, agriculture as most important livelihood and loan usage as well as the discrete variables experience, number of literate family members, family size and number of male family members. Further, scale variables are included, all measured on an 11-point Likert scale ranging from zero to ten. The scale used for perceived water availability extends from very short to very long, the one for perceived market access ranges from very difficult to very easy while the scale used for willingness to take risk ranges from unwillingness to very willing.

Their coefficients are accompanied by their standard errors shown in parentheses and, in case of a significant effect, with one star showing marginal significance, two stars representing a significant effect at the alpha level of five per cent and three stars indicating significance at an alpha level of one percent. The different number of observations for instance in model (5) and (6) results from missing values and the fact that for regression analysis, only complete data rows are used[43]. The first measure to be looked at is the R^2 value indicating the share of the response variable's variability being explained by the regression model (MANGIAFICO, 2016).

Looking at table 10, the low R^2 values indicate that all models with their predictors do not explain the variation in the response variable very well. The higher R^2 value of 44 per cent of model (8) is due to the high number of included predicting variables. This is visible through the adjusted R^2, which takes into account the number of predictors. Here, the values of all models are quite low. The F-statistic showing whether the response variable is reliably predicted by the explanatory variables used (UCLA, 2021a) indicates that only model (6) is statistically significant compared to a model without predictors. In addition to model (7) and (8), model (6)

[43] The unequal number of missing values is caused by the conditionality of some questions in the survey questionnaire. For instance, in case a participant denied the question whether pests were present in the field, the question for pest control mechanisms being applied was not posed, resulting in a missing value in the dataset. The maximum number of observations is 38 instead of 39 as one maize cultivator could not quantify his harvest, leading to a missing GM.

also presents the only significant coefficient at an alpha level of five per cent, indicated by two stars, which is fertilizer.

It is associated with a strong negative effect showing that the application of fertilizer reduces the predicted GM by 13,863.81 birr, holding all other independent variables constant. The underlying reason for this result is that fertilizer was used only by two participants, both of which achieved a strongly negative GM (-11,773 birr and -12,115 birr) very far from the mean GM of 1,190 birr for maize. Further, this amount of data points is seen as insufficient for a meaningful result so that the effect associated with fertilizer has to be treated with caution. Another variable, pest control, has, although not significant, also a negative sign in models (5), (7) and (8), but this is as well based on only two participants using pest control. One more remarkable result is the negative coefficient associated with perceived water availability in models (4), (7) and (8). The assumption laid out in chapter 4.3 was that more water availability may be correlated with higher GMs, which makes the coefficient’s sign counterintuitive.

Apart from that, the table shows that one year more of experience is associated with an increase in the predicted GM of maize by 117.27 birr in model (3), holding all other variables covariates constant, although this is not a significant effect. Further, according to the results in the table, the variables primary education or higher and number of male family members have marginally significant positive effects shown in model (8). Female has a negative coefficient in model (8). However, this effect is not significant and again based on limited data as only four participants were female. While the variables agriculture as the most important livelihood, perceived market access and loan usage are associated with positive coefficients, number of literate family members, family size and willingness to take risk are represented with negative coefficients in model (8). None of those, however, show a significant effect. In summary, hypothesis 3 can be rejected with regard to maize as none of the coefficients chosen for the hypothesis have a significant and meaningful effect.

Table 10: Regression results – gross margin of maize

	Dependent variable:					
	Gross margin of maize per hectare in birr as predicted by formula (3) to (8)					
	(3)	(4)	(5)	(6)	(7)	(8)
Experience	117.27 (135.49)				176.92 (156.17)	184.38 (178.73)
Perceived water availability		-1,053.96 (871.34)			-1,223.95 (949.08)	-1,003.85 (1,014.94)
Pest control			-167.20 (6,828.21)		-3,260.59 (6,559.46)	-10,532.16 (7,900.84)

Fertilizer				-13,863.81** (6,088.81)	-13,497.78** (6,434.18)	-23,405.90** (8,358.89)
Female						-5,315.56 (5,486.25)
Primary education or higher						9,622.12* (4,927.38)
Agriculture=most important						5,934.07 (5,941.63)
Nr of literate family members						-1,290.53 (890.21)
Family size						-1,105.50 (1,160.14)
Nr of male family members						3,114.37* (1,720.52)
Perceived market access						520.49 (881.89)
Loan usage						1,907.74 (4,324.13)
Willingness to take risk						-193.48 (977.23)
Constant	-1,778.63 (3,719.82)	4,157.87 (2,837.59)	576.20 (1,707.05)	1,919.81 (1,396.87)	809.85 (4,689.09)	-12,797.96 (10,766.70)
Observations	38	38	32	38	32	32
R^2	0.02	0.04	0.0000	0.13	0.21	0.44
Adjusted R^2	-0.01	0.01	-0.03	0.10	0.09	0.04
Residual Std. Error	8,872.58 (df = 36)	8,787.62 (df = 36)	9,349.91 (df = 30)	8,381.21 (df = 36)	8,769.97 (df = 27)	9,033.48 (df = 18)
F Statistic	0.75 (df = 1; 36)	1.46 (df = 1; 36)	0.001 (df = 1; 30)	5.18** (df = 1; 36)	1.77 (df = 4; 27)	1.09 (df = 13; 18)

Note: This table shows results from the multiple linear regression using the collected data in Somali region. The dependent variable is the GM of maize per hectare valued in birr. Experience is a discrete variable measured in years. Pest control, fertilizer, female, primary education or higher, agriculture=most important and loan usage are binary variables. Nr of literate family members, family size and nr of male family members are discrete variables. Perceived water availability, perceived market access and willingness to take risk were assessed using an 11-point Likert scale ranging from 0 to 10. For perceived water availability, the scale ranges from very short to very long. For perceived market access, it extends from very difficult to very easy. For willingness to take risk, it ranges from unwillingness to very willing. Standard errors are shown in parentheses. Significance indications: * p < 0.1, ** p < 0.05, *** p < 0.01.

Source: Own calculations based on collected data.

In order to investigate hypothesis 3 regarding sorghum, as explained above, regression models similar to the case of maize were set up, while Y is denoted with $_s$

$$Y_s = \beta_0 + \beta_1 \text{ experience} + U \tag{9}$$

$$Y_s = \beta_0 + \beta_2 \text{ perceived water availability} + U \tag{10}$$

$$Y_s = \beta_0 + \beta_3 \text{ pest control} + U \tag{11}$$

$$Y_s = \beta_0 + \beta_4 \text{ fertilizer} + U \tag{12}$$

$Y_s = \beta_0 + \beta_1$ experience + β_2 perceived water availability + β_3 pest control + β_4 fertilizer + U (13)

$Y_s = \beta_0 + \beta_1$ experience + β_2 perceived water availability + β_3 pest control + β_4 fertilizer + β_5 female + β_6 primary education or higher + β_7 agriculture=most important + β_8 nr of literate family members + β_9 family size + β_{10} nr of male family members + β_{11} perceived market access + β_{12} loan usage + β_{13} willingness to take risk + U (14)

Table 11 contains the results obtained for the regression investigating factors potentially influencing the GM of sorghum per hectare valued in Ethiopian birr. The covariates chosen are the same as for maize and the structure and elements such as standard errors in parentheses and stars to indicate significance are identical to the case of maize. The number of observations varies for similar reasons as for maize[44]. Also comparable to the maize case, it is visible from the R^2 and adjusted R^2 values that the chosen explanatory variables do not predict the variability in the GM of sorghum properly. The F-statistic shows that only model (11) is overall significant. This model, in addition to model (13) and (14) also contains the only significant coefficient in the whole table which is marginally significant in model (11) and (13) and significant at the five per cent alpha level in model (14). This negative coefficient represents the effect of the variable pest control and indicates that the usage of it leads to a 29,280.14 birr decrease in the predicted GM of sorghum in model (11), holding all other predictors constant.

This may be explained in a similar way like for maize above in the case of fertilizer. Pest control mechanisms were used only twice for sorghum. One of those participants utilizing pest control lost the harvest while the other one produced only two units resulting in considerably negative GMs of -16,246 birr and -62,900 birr, both far from the mean GM of -8765 birr. Similar to what has been stated above, a meaningful result cannot be reported due to the small amount of data. Apart from this, the table also shows that no coefficient for the use of fertilizer was reported. This is due to the fact that none of the participants used it. Experience as well as perceived water availability are associated with positive coefficients, although not significant.

Female is again presented with a negative coefficient in model (14), although this is not meaningful due to the reasons stated above. While primary education or higher, number of

[44] In this case, the number of observations varies as well due to missing observations for pest control. Further, for model (14), one observation is missing for number of adult literate family members as this question was conditional on the answer of the preceding question about number of adults which one participant responded with zero. In consequence, the question about number of literate adults was not posed.

literate family members, number of male family members, perceived market access and loan usage are associated with positive coefficients, the remaining covariates agriculture as the most important livelihood, family size and willingness to take risk are shown with negative effects in model (14). However, none of those variables is reported with a significant coefficient. Summarizing, also for the case of sorghum, hypothesis 3 cannot be verified as none of the coefficients associated with the selected covariates show a significant and meaningful effect.

Table 11: Regression results – gross margin of sorghum

	Dependent variable:					
	Gross margin of sorghum per hectare in birr as predicted by formula (9) to (14)					
	(9)	(10)	(11)	(12)	(13)	(14)
Experience	261.16 (378.42)				79.79 (338.63)	237.74 (373.45)
Perceived water availability		34.01 (1,975.90)			846.56 (1,793.43)	363.52 (1,947.05)
Pest control			-29,280.14* (14,323.54)		-28,020.44* (15,092.08)	-40,359.92** (14,909.98)
Fertilizer						
Female						-16,523.79 (11,354.64)
Primary education or higher						8,550.33 (12,318.09)
Agriculture=most important						-2,158.56 (10,891.45)
Nr of literate family members						2,198.10 (4,039.46)
Family size						-3,650.68 (2,454.04)
Nr of male family members						2,851.03 (3,268.30)
Perceived market access						2,860.87 (1,820.16)
Loan usage						12,092.68 (8,275.61)
Willingness to take risk						-1,586.46 (2,048.96)
Constant	-14,969.17 (9,908.72)	-8,865.69 (7,214.95)	-10,292.86*** (3,698.32)	-8,764.70** (4,132.03)	-14,817.04 (9,535.87)	-6,783.99 (21,724.34)
Observations	33	33	30	33	30	29
R^2	0.02	0.0000	0.13	0.00	0.14	0.52
Adjusted R^2	-0.02	-0.03	0.10	0.00	0.04	0.15
Residual Std. Error	23,933.38 (df = 31)	24,116.42 (df = 31)	19,569.68 (df = 28)	23,736.73 (df = 32)	20,178.18 (df = 26)	18,946.47 (df = 16)
F Statistic	0.48 (df = 1; 31)	0.0003 (df = 1; 31)	4.18* (df = 1; 28)		1.42 (df = 3; 26)	1.42 (df = 12; 16)

Note: This table shows results from the multiple linear regression using the collected data in Somali region. The dependent variable is the GM of sorghum per hectare valued in birr. Experience is a discrete variable measured in years. Pest control, fertilizer, female, primary education or higher, agriculture=most important and loan usage are binary variables. Nr of literate family members, family size and nr of male family members are discrete variables. Perceived water availability, perceived market access and willingness to take risk were assessed using an 11-point Likert scale ranging from 0 to 10. For perceived water availability, the scale ranges from very short to very long. For perceived market access, it extends from very difficult to very easy. For willingness to take risk it ranges from unwillingness to very willing. Standard errors are shown in parentheses. Significance indications: * p < 0.1, ** p < 0.05, *** p < 0.01.

Source: Own calculations based on collected data.

Finally, the same approach was taken for onion, with Y is denoted with $_o$.

$$Y_o = \beta_0 + \beta_1 \text{ experience} + U \tag{15}$$

$$Y_o = \beta_0 + \beta_2 \text{ perceived water availability} + U \tag{16}$$

$$Y_o = \beta_0 + \beta_3 \text{ pest control} + U \tag{17}$$

$$Y_o = \beta_0 + \beta_4 \text{ fertilizer} + U \tag{18}$$

$$Y_o = \beta_0 + \beta_1 \text{ experience} + \beta_2 \text{ perceived water availability} + \beta_3 \text{ pest control} + \beta_4 \text{ fertilizer} + U \tag{19}$$

$$Y_o = \beta_0 + \beta_1 \text{ experience} + \beta_2 \text{ perceived water availability} + \beta_3 \text{ pest control} + \beta_4 \text{ fertilizer} + \beta_5 \text{ female} + \beta_6 \text{ primary education or higher} + \beta_7 \text{ agriculture=most important} + \beta_8 \text{ nr of literate family members} + \beta_9 \text{ family size} + \beta_{10} \text{ nr of male family members} + \beta_{11} \text{ perceived market access} + \beta_{12} \text{ loan usage} + \beta_{13} \text{ willingness to take risk} + U \tag{20}$$

In table 12, the regression results for the factors influencing the GM of onion per hectare valued in Ethiopian birr are presented similarly to the cases before. Numbers of observations differ regarding pest control due to the same reasons as above. The R_2 and adjusted R_2 values suggest also here a bad model fit. The F-statistic indicates that model (18) is overall significant. This model also contains the only coefficient significant at the five percent alpha level, which is fertilizer. Also here, fertilizer is associated with a strong, but this time positive effect, indicating that the use of it is associated with an increase in the predicted GM of onion by 43,447.51 birr, holding all other explanatory variables constant. The result is based on a more balanced number of observations with 16 participants (59.26 per cent) not applying fertilizer and 11 (40.74 per cent) utilizing it.

Nevertheless, the effect is not significant anymore when considered together with other covariates as in model (19) and (20). Model (16) and (19) again like in case of maize show a negative effect of perceived water availability while it is positive in model (20), all of those not significant. Pest control is presented with a high magnitude positive but non-significant effect in model (17); in model (19), the magnitude is a lot less and it is negative in model (20). Further, in model (20), similar as in the case of maize, primary education or higher is indicated to have a marginally significant positive effect, here with very high magnitude of 66,231.37 birr. In this model, experience, agriculture as the most important livelihood, family size and willingness to take risk are associated with positive coefficients while female, number of literate family members, number of male family members, perceived market access and loan usage are reported with negative effects, all of them not significant. In summary, for onion, hypothesis 3 can only partly be verified. Solely the expected factor fertilizer use was found to have a significant positive and meaningful effect on the GM of onion.

Table 12: Regression results – gross margin of onion

	Dependent variable:					
	Gross margin of onion per hectare in birr as predicted by formula (15) to (20)					
	(15)	(16)	(17)	(18)	(19)	(20)
Experience	1,578.74 (997.51)				794.87 (1,253.77)	453.62 (1,616.87)
Perceived water availability		-3,921.75 (6,988.56)			-3,289.01 (7,283.18)	1,329.25 (10,803.13)
Pest control			30,722.84 (23,509.39)		2,214.13 (31,918.01)	-13,352.20 (55,152.59)
Fertilizer				43,447.51** (19,586.72)	36,296.27 (32,517.38)	80,535.59 (51,637.59)
Female						-19,866.51 (43,455.85)
Primary education or higher						66,231.37* (36,774.22)
Agriculture=most important						34,657.25 (60,012.63)
Nr of literate family members						-10,703.87 (8,080.62)
Family size						5,584.51 (11,812.56)
Nr of male family members						-1,082.07 (12,540.59)
Perceived market access						-10,364.73 (7,931.46)
Loan usage						-29,781.86 (35,346.02)
Willingness to take risk						2,155.82 (9,047.83)
Constant	-1,847.66 (23,528.71)	41,999.64* (20,922.51)	21,131.41 (13,298.92)	14,131.31 (12,501.90)	7,749.51 (32,325.78)	-56,173.81 (99,543.13)
Observations	27	27	25	27	25	25
R^2	0.09	0.01	0.07	0.16	0.19	0.46
Adjusted R^2	0.05	-0.03	0.03	0.13	0.03	-0.17
Residual Std. Error	52,157.33 (df = 25)	54,366.60 (df = 25)	54,832.84 (df = 23)	50,007.61 (df = 25)	54,923.85 (df = 20)	60,228.30 (df = 11)

F Statistic	2.50 (df = 1; 25)	0.31 (df = 1; 25)	1.71 (df = 1; 23)	4.92** (df = 1; 25)	1.16 (df = 4; 20)	0.73 (df = 13; 11)

Note: This table shows results from the multiple linear regression using the collected data in Somali region. The dependent variable is the GM of onion per hectare valued in birr. Experience is a discrete variable measured in years. Pest control, fertilizer, female, primary education or higher, agriculture=most important and loan usage are binary variables. Nr of literate family members, family size and nr of male family members are discrete variables. Perceived water availability, perceived market access and willingness to take risk were assessed using an 11-point Likert scale ranging from 0 to 10. For perceived water availability, the scale ranges from very short to very long. For perceived market access, it extends from very difficult to very easy. For willingness to take risk it ranges from unwillingness to very willing. Standard errors are shown in parentheses. Significance indications: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$..

Source: Own calculations based on collected data.

5.6 Drivers of cereal cultivation

Hypothesis 4 claims that more cereals are cultivated compared to vegetables due to risk aversion of the family heads, easier storage possibility, drought resilience, subsistence agriculture and the dual-use benefit for livestock production. To assess this, a binary variable was created, taking the value one when the cultivated crop is a cereal and zero if this is not the case[45]. This represents the dependent variable in the subsequently created linear mixed model, chosen, as stated in chapter 4.4 due to the lack of independent observations. Similar to the approach used in chapter 5.5, different models were created from the general equation (21) based on YING & SCOTT (2023) to assess the influence of various factors on cereal cultivation.

$$Y = X_1\beta_1 + \ldots + X_n\beta_n + \alpha + \varepsilon \qquad (21)$$

Where:

Y	is the binary response variable taking the value one when a cereal is cultivated
X_1 to X_n	are the predictor variables
β_1 to β_n	are the fixed-effects regression coefficients of the explanatory variables
α	represents the random effects
ε	is the error term

The final equations are laid out in the following. The factor drought resilience had to be dropped from the equation as no participant mentioned this as a reason for crop choice.

$$Y = \text{subsistence agriculture}\ \beta_1 + \alpha + \varepsilon \qquad (22)$$

$$Y = \text{dual use of crop}\ \beta_2 + \alpha + \varepsilon \qquad (23)$$

$$Y = \text{willingness to take risk}\ \beta_3 + \alpha + \varepsilon \qquad (24)$$

45 Vegetables were defined as tomato, onion, carrot, beetroot and chickpea. Cereals constitute barley, wheat, sorghum and maize.

Y = ease of storage $\beta_4 + \alpha + \varepsilon$ (25)

Y = subsistence agriculture β_1 + dual use of crop β_2 + willingness to take risk β_3 + ease of storage $\beta_4 + \alpha + \varepsilon$ (26)

Y = subsistence agriculture β_1 + dual use of crop β_2 + willingness to take risk β_3 + ease of storage β_4 + female β_5 + primary education or higher β_6 + agriculture=most important β_7 + nr of literate family members β_8 + family size β_9 + nr of male family members β_{10} + perceived market access β_{11} + loan usage $\beta_{12} + \alpha + \varepsilon$ (27)

Y = subsistence agriculture β_1 + dual use of crop β_2 + willingness to take risk β_3 + ease of storage β_4 + female β_5 + primary education or higher β_6 + agriculture=most important β_7 + nr of literate family members β_8 + family size β_9 + nr of male family members β_{10} + perceived market access β_{11} + loan usage β_{12} + perceived demand for crop β_{13} + perceived stability of market prices β_{15} + perceived level of prices β_{16} + perceived financial access to inputs β_{17} + perceived physical access to inputs β_{17} + perceived water availability β_{18} + additional income possibility $\beta_{19} + \alpha + \varepsilon$ (28)

While equation (26) relates to the stated hypothesis, formula (27) was created additionally to examine the effect of the other socio-economic factors for which data has been collected and model (28) has the purpose to investigate further potential covariates. Table 13 demonstrates the mixed model results. The dependent variable cereal cultivation is binary and takes the value one if a cereal is cultivated and zero if not. The explanatory factors chosen are the binary variables subsistence agriculture, dual use of crop, female, primary education or higher, agriculture as most important livelihood, loan usage and additional income possibility[46] as well as the discrete variables number of literate family members, family size and number of male family members. Further, the following scale variables are included, all measured on an 11-point Likert scale ranging from zero to ten.

For willingness to take risk the scale extends from unwillingness and to very willing. For ease of storage, perceived market access, perceived financial access to inputs and perceived physical access to inputs it ranges very difficult to very easy. For perceived demand for crop and perceived level of price, it extends from very low to very high. For perceived stability of market prices it ranges from very fluctuating to very stable while the one used for perceived water availability ranges from very short to very long. Similar to the regressions demonstrated in

[46] Additional income possibility takes the value one when additional income was mentioned as reason for crop choice and it takes the value zero if this is not the case.

chapter 5.5, the coefficients of the variables are accompanied by their standard errors in parentheses and, in case of a significant effect, with one star showing marginal significance, two stars representing a significant effect at the alpha level of five per cent and three stars indicating significance at an alpha level of one percent. However, the interpretation of the coefficients is not only dependent, like in common linear multiple regression models, on holding all other explanatory variables constant, but also on holding constant the random effect which reduces the relative influence of the fixed effect (UCLA, 2021d).

The numbers of observations vary again due to similar reasons as in chapter 5.5[47]. Looking at table 13, model (26) which represents hypothesis 4 features the highest Log Likelihood value, indicating the best fit compared to the other models in the table (UCLA, 2021c). It also has the lowest values for the Akaike and Bayesian Criterions indicating as well that it has, in comparison, the best goodness of fit (MOHAMMED ET AL., 2015). This model demonstrates various significant coefficients. All those are interpreted holding the other variables as well as random effects constant. Subsistence agriculture, for instance, increases the predicted probability that a cereal is cultivated by 51 per cent. The dual use property of a crop is associated with a 37 per cent of that probability. Both coefficients are highly significant at an alpha level of one per cent. A rise of willingness to take risk of one point on the Likert scale is related to a four per cent decrease of the same predicted probability, significant at a five per cent alpha level. Finally, a perceived easier storage possibility of one point on the scale is correlated with a three percent increase of the predicted probability of cereal cultivation, significant at a 10 per cent alpha level.

While subsistence agriculture and dual use of crop are also significant in the other models, willingness to take risk is only significant in model (26) and (27) and ease of storage is significant only in models (25) to (27). Another marginally significant effect is shown by the coefficient associated with loan usage. The utilization of loans is related to an increase in the predicted probability of cereal cultivation by 15 per cent in model (27), significant at a ten per cent alpha level in this one and model (28). Finally, a perceived easier physical access to inputs of one point on the Likert scale is also reported as being marginally significant in model (28), associated with a six per cent decrease in the predicted probability of cereal cultivation.

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[47] The binary variable subsistence agriculture was created out of the variable units sold. The corresponding question was posed only when participants had produced something. Because lots of participants lost the harvest as shown in table 4, many missing values were created.

Apart from that, although there are no more significant coefficients, female is presented with a negative one in model (27) and (28), indicating an associated decrease in the probability of cereal cultivation, although females are underrepresented in the data as mentioned before. The same is the case for agriculture as most important livelihood and additional income possibility in model (27) and (28). All three variables show an effect magnitude higher than the rest of variables. Of those remaining, primary education or higher, number of literate family members, number of male family members, perceived demand for crop, perceived level of prices and perceived financial access to inputs are associated with negative coefficients in model (28), while the opposite is true for family size, perceived market access, perceived stability of market prices and perceived water availability, all of those not being significant and with a very low magnitude of effect between minus 0.3 and two per cent. In total, hypothesis 4 can be verified with regard to almost all expected factors as subsistence agriculture, dual use benefit, ease of storage and willingness to take risk are associated with significant effects in the model while only drought resilience was not mentioned at all by the participants and had to be dropped from the equation.

Table 13: Model results – drivers of cereal cultivation

	Dependent variable:						
	Cereal cultivation as predicted by formula (22) to (28)						
	(22)	(23)	(24)	(25)	(26)	(27)	(28)
Subsistence agriculture	0.68^{***} (0.09)				0.51^{***} (0.08)	0.57^{***} (0.09)	0.46^{***} (0.10)
Dual use of crop		0.71^{***} (0.06)			0.37^{***} (0.09)	0.30^{***} (0.10)	0.32^{***} (0.11)
Willingness to take risk			0.01 (0.02)		-0.04^{**} (0.02)	-0.05^{**} (0.02)	-0.04 (0.03)
Ease of storage				0.04^{***} (0.02)	0.03^{*} (0.02)	0.04^{**} (0.02)	0.03 (0.02)
Female						-0.14 (0.15)	-0.10 (0.17)
Primary education or higher						-0.03 (0.11)	-0.01 (0.12)
Agriculture=most important						-0.10 (0.13)	-0.06 (0.15)
Nr of literate family members						-0.02 (0.02)	-0.02 (0.02)
Family size						0.002 (0.03)	0.01 (0.03)
Nr of male family members						0.01 (0.04)	-0.003 (0.04)
Perceived market access						0.03 (0.02)	0.02 (0.02)
Loan usage						0.15^{*} (0.09)	0.17^{*} (0.09)

Perceived demand for crop							-0.01 (0.02)
Perceived stability of market prices							0.01 (0.01)
Perceived level of prices							-0.02 (0.02)
Perceived financial access to inputs							-0.003 (0.02)
Perceived physical access to inputs							-0.06* (0.03)
Perceived water availability							0.01 (0.02)
Additional income possibility							-0.10 (0.10)
Constant	0.24*** (0.06)	0.22*** (0.05)	0.63*** (0.19)	0.54*** (0.07)	0.33** (0.16)	0.34 (0.23)	0.94*** (0.34)
Observations	71	114	114	114	71	71	71
Log Likelihood	-30.52	-36.89	-78.60	-75.60	-24.69	-39.00	-53.98
Akaike Inf. Crit.	69.04	81.78	165.20	159.20	63.39	107.99	151.97
Bayesian Inf. Crit.	78.09	92.72	176.14	170.14	79.22	141.93	201.74

Note: This table shows mixed model estimates using the collected data in Somali region. The dependent variable cereal cultivation is binary and takes the value of 1 if a cereal is cultivated and 0 if not. Subsistence agriculture, dual use of crop, female, primary education or higher, agriculture=most important, loans usage and additional income possibility are binary variables. Additional income possibility takes the value 1 when additional income was mentioned as reason for crop choice and it takes the value 0 if this is not the case. Nr of literate family members, family size, nr of male family members are discrete variables. The remaining variables were assessed using an 11-point Likert scale ranging from 0 to 10. For willingness to take risk the scale ranges from unwillingness to very willing. For ease of storage, perceived market access, perceived financial access to inputs and perceived physical access to inputs it extends from very difficult to very easy. For perceived water availability it ranges from very short to very long. For perceived demand for crop and perceived level of price it extends from very low to very high. For perceived stability of market prices, it ranges from very fluctuating to very stable. Standard errors are shown in parentheses. Significance indications: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Source: Own calculations based on collected data.

6 DISCUSSION AND RECOMMENDATIONS

In the frame of this research, data were collected from 44 (agro-) pastoralists cultivating two GIZ-rehabilitated DVs in Fafan zone, situated in Ethiopia's Somali region. As described in chapter 4.1, both DVs feature similar geographical and agrophysical conditions. The harvesting seasons Jilal 2022/2023 (September to March) and Gu'u 2023 (March to September) were investigated, particularly regarding the profitability of crops produced as well as reasons for crop choice. Conceptualised within a DSES thinking, the DVs present an ecological system subject to degradation driven to a considerable part by the external factor climate change aggravating droughts and floods.

Various stakeholders undertake rehabilitation efforts to positively influence slow variables like water availability and soil fertility while the (agro-) pastoralist communities constitute socio-economic systems influencing their natural surroundings, themselves being influenced as well, not only through the slow variables mentioned above, but also, particularly in the short term, through fast variables such as crop yield which is crucial for the profitability of their produce and, thus, their livelihoods. The investigation of the GM, the chosen indicator to measure profitability, allowed to gain some insight about the living conditions (agro-) pastoralists face in the DVs investigated. The following chapters discuss the results of the analysed data.

6.1 Participants' socio-economic status, agricultural practices & perceptions

The collected data revealed that both examined DVs are quite similar regarding most social parameters. The majority of participants in both study sites were male. This mirrors the finding of other studies (SORPARI, 2023, 2024) about mainly men controlling a household's land as well as conducting farm activities and taking decisions. However, one feature varying remarkably is education. In Harre, 65.22 per cent of participants indicated that their adult family members are illiterate and without education while in Amadle, only 14.29 per cent reported this. This value for Harre is also a lot higher than the regional average of men without education of 2016 which was 44.8 per cent, although this included men from the age of 15 years (GEBREMESKEL ET AL., 2019). After data collection, GIZ regional staff shared the information that Harre does not have a school within the village, while the primary school in Amadle is less than one kilometre from the village centre, leading to the recommendation that establishments of schools within DVs should be promoted.

Regarding economic characteristics, the DVs are also comparable. All participants practice agriculture, in both DVs people own the same mean amount of land and cultivate on average an almost equal share of this land. Further investigation could explore how participants utilize the rest of land they own as on average only around half of the owned land was used agriculturally. It is worth mentioning that the reported amount of land owned and cultivated is a lot larger than the average for Somali region of 1.1 hectares and 0.1 hectares estimated by ESS & WORLD BANK (2023). Mean land sizes in ADV and HDV are found to be on average 11.86 and 11.34 hectares while a mean of 6.24 and 6.39 hectares of these are cultivated in ADV and HDV. SORPARI (2024) reported that 80 per cent of respondents in rehabilitated DVs in Somali region own one to three hectares, two being the average in Fafan according to SORPARI (2023), which is more consistent with the figures documented by ESS & WORLD BANK (2023). The reasons for the larger size owned and cultivated reported in the present research remain unclear and would need further investigation as a response bias is possible, although there is no obvious reason to report larger land sizes[48].

In both DVs, the experience measured in years is as well comparable and an alike number of participants used loans and received agricultural advice. The naming of GIZ as a source of agricultural advice has to be interpreted with caution as a response bias here is possible, leading study participants to answer in a way they perceive as favourable in the context. Cooperative membership is more prevalent in Harre than in Amadle. Apart from that, agriculture is more essential for the participants cultivating HDV, with 91.3 per cent confirming it as the most important livelihood. In ADV, only 71.43 per cent reported this and in addition, a larger share practices livestock herding than in Harre which indicates a slightly more diversified income structure. This, considered together with a higher number of literate adults in the families in Amadle, represents an interesting field for further research also with regard to income diversification as it is an envisaged goal of the DVRPU Approach. The low shares of participants generating income also off-farm (14.29 per cent in ADV and 17.39 per cent in HDV) are similar to the 14 per cent reported by SORPARI (2023) for Fafan. The concentration of perceived challenges regarding market access on cost and lack of public transport mirrors observations documented by SORPARI (2023).

In this research, the Gu'u season (March to September) was found to be the main cultivating season with people being surprised when asked about cultivation in Jilal season 2022/2023 (September to March)[49]. This is consistent with SOPARI (2023). However, SORPARI'S (2024) study investigating second plantings in late 2023 suggests that also cultivation in Jilal is possible including the obtainment of comparably high yields. This points to the achievement of one objective of the DVRPU Approach relating to multiple harvests (GIZ, 2023c) backed by FSIABD CONSULT (2021). Further research to verify whether this is an exception or a trend would be desirable. With regard to crops produced, it has been found that the participating (agro-) pastoralists cultivated maize, sorghum, onion, wheat, khat, chickpea, barley, tomato,

[48] Within the pilot phase of the study, land was measured with GPS devices and compared to land size estimations of the respondents. As estimations were quite exact and measurements consume lots of time, fields were not measured during data collection. SORPARI'S (2024) reported values are also based on interviews, not on measurements. A response bias is possible in case participants were particularly conscious about the way output and GMs are calculated, as larger field sizes reduce output and GM per hectare. This initially seems unlikely due to the rather low education levels of participants; however, these calculations are easy to understand and people may have received training for this before.

[49] Only four participants cultivated maize, sorghum and onion in Jilal season 2022/2023 (September to March), all three crops featuring negative GMs for this season.

carrot, beetroot and Sudan grass. SORPARI (2024) reported also the cultivation of pepper from their assessment of second plantings, indicating an adaptation of cropping patterns to the season. In the present research, the crops maize, sorghum and onion occurred noticeably more frequently, consistent with SORPARI (2023, 2024). The majority (47.73 per cent) of participants combined a grain such as maize, sorghum and wheat with onion.

While a wider range of crops is grown in Somali region[50], the general variety of crops found implies despite low frequencies for some of them a diversification including in the direction of vegetables, which is intended as well with the DVRPU Approach as it may open up opportunities to engage in various income and nutrition streams, adding to food security. Further research about the continuity of this development is recommended. A general diversification of crops contribute to soil health (WANG ET AL., 2022) and should be promoted further while SORPARI (2024) points specifically to additional benefits connected to an introduction of more legume crops as they improve soil quality.

The assessment of reasons for crop choice proved that maize and sorghum are mostly cultivated due to their dual use benefit for food and forage while onion is used to generate additional income. Interestingly, SORPARI (2024) reports drought resistance of crops to be the most important factor, which was expected to be found in the present research as well, but was not mentioned by participants. The reasons for the inconsistency are not exactly clear, although the assumption is made that this result relates to the wording of the question. SORPARI (2024) asked distinctively for reasons for crop selection and purpose of cultivation of specific crops, which seems to be a more feasible approach to get correct information.

Interpreting the results for maize and onion regarding amount produced and sold, those indicate that maize is used mainly for subsistence while onion is produced to generate cash. SORPARI (2023) reports the same for irrigated crops in Fafan and SORPARI (2024) backs this finding. According to the collected data, the highest average price for onion was obtained in the market compared to prices paid by intermediaries and wholesalers. Due to the frequent losses of harvests, for sorghum a clear indication is missing, although it is assumed that it serves the same purpose as maize. The deliberate cultivation of onion to earn additional income which is also largely achieved as the majority of producers indeed sold their produce shows without doubt a successful generation of income through crop production, pointing as well to

[50] Table A.8 in appendix II provides further information.

achievements of desired DVRPU effects which may improve (agro-) pastoralists livelihoods, although also here, further research is recommended.

An interesting result is the considerable number of participants donating parts of their produce. This may be connected to social and cultural (GIZ, 2024b) as well as religious values prevalent in the region and points to interesting research fields regarding social structures in the DVs. Those may, among others, have an impact on productivity, as help from other community members for instance during the harvest may increase efficiency and facilitate optimal timing while donation of produce points to a contribution to food security of poorer community members.

Looking at the lost part of the harvest, pests and drought reported may give an indication of reasons. For onion, five participants losing the harvest reported bugs and drought most frequently (each reported by 60 per cent). Seven participants lost maize with drought reported most often among them (by 71.43 per cent). With regard to the 26 people losing their sorghum harvest, bugs and birds were mentioned most frequently by 38.46 and 80.77 per cent of them. This indicates that the main reason for the loss of the sorghum grain is caused by birds. Harvest losses due to birds mainly during harvesting were reported also by SORPARI (2023) while they also pointed to one sorghum variety used in Fafan, dangi, being particularly tolerant to birds (ibid.). They also mentioned another variety, Cilmi-jamac, being the most popular in the region which is caused by its increased head numbers, tillering ability, biomass production and drought tolerance (ibid.). However, improved seeds are rarely accessible in the area (ibid.). This represents a field for further research investigating which varieties are used for which specific reasons in the rehabilitated DVs and which should be recommended.

With regard to agricultural practices, the scarce use of fertilizer and pest control is no surprise as Somali ranks as one of the regions with lowest application rates of those inputs (CSA, 2022b). More machinery and seeds were mentioned as most necessary inputs for currently produced crops. Also, SORPARI (2023) reported that limited mechanization is perceived as core challenge. Most seeds were obtained on the market with maize and sorghum featuring a higher average seed price per unit than onion while financial access was not named as key necessity. The classification of onion as the crop with highest demand is consistent with the high rating regarding the perceived level of prices and onion being used to generate additional income. Also, the bad rating of storage is a logical result as vegetables are more perishable than cereals (MOHAMMED RESHID CONSULTANCY, 2018).

While physical access to inputs is rated very well for the crops currently produced, the majority reported this access to be very bad regarding different crops they would wish to produce. It is a field for further research to investigate which crops would be most desired by (agro-) pastoralists cultivating rehabilitated DVs as this has not been covered in the present research. The lack of physical access to inputs was mentioned a lot more frequently than financial access in the present research, indicating that a diversification of crop production finds an obstacle here. Also SORPARI (2024) reports that access to seeds for the production of crops different from maize and sorghum is missing. Further investigation, for instance through controlled experiments with different crops and varieties, is recommended in this context. During the pilot phase of the data collection, this was already observed in small-scale. In Harre, several fruit trees were planted close to the WSW, encompassing eucalyptus, papaya and mango trees. Further investigations should document the development of this initiative. SORPARI (2024) started this already reporting apart from the above mentioned trees also guavas and avocados not only for Harre, but also for Amadle.

6.2 Water-spreading weirs and vegetable production

The statistical analysis allowed to confirm hypothesis 1 as (agro-) pastoralists were producing significantly more vegetables in the Gu'u season 2023 (March to September) looked at for this test than before the construction of WSW. This indicates a diversification of livelihood and income opportunities over the course of the intervention which is envisaged by the DVRPU Approach (GIZ, 2023c). However, as only one year, respectively, one main season was investigated within the frame of this hypothesis, further research regarding past or future harvest seasons would be useful to confirm whether the vegetable share was exceptionally high or even low. In this regard, SORPARI (2023) provides a hint with an analysis of crops having been produced in Fafan across a ten year time span utilizing data provided by CSA. This shows that onion has been produced only between 2013 and 2016, tomato has been produced only between 2017 and 2018, both covering only small surface areas while cereals such as maize and sorghum were cultivated with greater continuity and larger surface areas covered between 2012 and 2020/2021[51] (ibid.).

Subsequent studies may investigate the exact reasons for why the change occurred as it could be due to a variety of circumstances such as, among others, increased extension services provided through the government, less risk aversion, fewer pests (GIZ, 2024b), improved

[51] The original source shows this referring to the Ethiopian calendar. This has been adapted for this research.

availability of water and/or labour, better financial and physical access to inputs or higher market demand and soil fertility. This may have been improved, among others, through the described sedimentation and moisture increasing effect the WSW have on the land. As this enhances biomass productivity and, thus, crop residues, more organic matter may be present in the soil, increasing fertility (EKYALIGONZA ET AL., 2022). Apart from that, a more biodiverse crop production may, if managed correctly, have a similar enriching effect as a higher variety of plants implies differing root structures and organic matter, also attracting insects which may enhance the quality of the soil further (MIR ET AL., 2022). Investigation and optimization of current cropping patterns are recommended in this context.

Out of this research, a hint regarding the reasons for the diversification is provided only through the examined causes for crop choice of participating (agro-) pastoralists demonstrated in chapter 5.1 which show that particularly the vegetable onion was cultivated to benefit from additional income opportunities which can be due to, among others, higher market demand and prices, easier financial and physical access to inputs or fewer required inputs. Obsolete inputs in the catchment area of WSW have been reported before (AMEDE ET AL., 2022; GETNET ET AL., 2022) which reduces production cost (TESFAI & STERK, 2002). Thus, more research regarding the topic is strongly recommended.

6.3 Gross margin analysis

The data demonstrated that the main crops grown are maize, sorghum and onion. Sudan grass was planted by one participant, but could not be measured as it was not possible to obtain unit sizes and amounts of units produced. As the fodder produced is very important for (agro-) pastoralists to feed their livestock, this, including the analysis of the forage component of maize and sorghum, the straw, represents a topic where further research apart from the one already conducted by EAST AFRICA ENGINEERING AND GENERAL CONSULTANT (2018) and SORPARI (2024) is recommendable.

Regarding output produced, averages were higher for most vegetables than cereals. Unfortunately, the restricted number of observations does not allow a meaningful interpretation here for all crops produced. Still, high mean values for carrot, onion and tomato indicate a higher productivity of vegetables. More research is desirable to verify whether those crops should be promoted to facilitate envisaged DVRPU effects relating to food security, income diversification and improved livelihoods. When compared to the limited available literature, yields of maize, sorghum and onion seem remarkably low. While average outputs per hectare in the present research were estimated at 1,456 kilogram, 418 kilogram and 113 kilogram for onion, maize and sorghum, other average estimates for Fafan zone for 2023 amount to 7,600 kilogram for onion, 2,000 kilogram for maize and 1,800 kilogram for sorghum under rainfed production (ZONAL OFFICE OF AGRICULTURE, 2023, as cited in SORPARI, 2023). The productivity of maize was assessed as far below the national average, representing less than half of the country's mean (SORPARI, 2023). The study was created in the same year as the present research, making the large difference surprising. However, neither exact information about the sample location is provided nor the exact method how yield estimates were obtained.

A second study conducted by SORPARI (2024) calculated yields for maize and sorghum for second plantings in rehabilitated DVs in Somali region in 2023 using the crop-cut method[52]. They documented an average maize and sorghum yield of 3,562 and 3,348 kilogram per hectare (ibid.)[53]. Rains in Fafan were less from October to December 2023 than from March to May 2023 (REACH INITIATIVE, 2024), the former period assumed to correspond to the yield calculated by SORPARI (2024) and the latter corresponding to the results of the present research. Yields may be less as rains from March to May lead to flooding (FEWS NET, 2024; OCHA, 2024), resulting in postponing the planting (REACH INITIATIVE, 2024), although crops in general were reported to be healthy in most areas by June 2023 (FEWS NET, 2024).

Further, SORPARI (2024) investigated second plantings while the present study assessed the first ones. A more obvious reason for the yield gaps here, however, seem to be based on the measurement method applied by SORPARI (2024). The present research relies on the memory and reporting behaviour of the participants. This may lead to biases grounded in non-exact figures provided by interviewees and expectations of participants regarding potential consequences of the interview. From their perspective, lower reported figures, for instance, may lead to more support in the future. Further, land sizes found within the present research are a lot larger than values obtained in other studies (ESS & WORLD BANK., 2023; SORPARI, 2023, 2024), a result indicating the possibility of incorrectly reported land sizes, thus, influencing output and GM calculations.

52 The crop-cut method involves the usage of several small parts of the original plot representative for high, medium and low crop performance (SORPARI, 2024). Grain yield is weighed after having been adjusted to optimal moisture (ibid.). Yield is calculated through dividing production by area and is subsequently expressed in kilogram per hectare (ibid.). The straw yield was also estimated by cutting, weighing the fresh yield and subsequently drying it in the oven to obtain the dry weight (ibid.).

53 The reported maize yield for ADV is included in this average (SORPARI, 2024). The value estimated for Amadle amounts to a mean of 4165 kilogram per hectare (ibid.).

The Ethiopian governmental statistics institution, CSA, in general as well reported higher yield values for maize and onion for Fafan zone in 2020/2021, although documented yields were decreasing in the years after[54]. The drop in the yields reported by CSA makes sense when taking into account the start of the drought in late 2020, being aggravated in the subsequent years (REACH INITIATIVE, 2024). More recent figures corresponding to the end of the drought in 2023 are not published yet through CSA. While the gaps in yields reported by CSA compared to the ones in the present research are astounding, different reasons for this are possible, such as related to the sample or the year as well as the fact that CSA interviewed peasants, not (agro-) pastoralists, which, although having a lot in common, nevertheless have been treated different in research as pointed out by SCOONES (2021). Further, as mentioned in chapter 4.1, it is not exactly clear which season reported by CSA corresponds to the Gu'u season (March to September) in Somali region. Apart from that, CSA uses varying methods and tools to measure the yield as individual interviews, measuring tape, measuring software for tablets (CSA, 2022b) and crop cutting were applied (CSA, 2022a).

Although, also for other Somali region zones like Godey Woreda in Shebelle zone, for maize a yield of 2,500 kilogram per hectare was observed while for onion a yield of 15,000 kilogram per hectare was to be expected in 2018/2019 (MOHAMMED RESHID CONSULTANCY, 2018), constituting much higher figures than the ones obtained in this study, however being based on irrigation (ibid.). Another study assumed a maize yield of 3,000 kilogram per hectare, but produced under irrigation in Godey (EAST AFRICA ENGINEERING AND GENERAL CONSULTANT, 2018). Further, a different study reported maize, sorghum and onion yields for the year 2016/2017 and calculated for Jigjiga South respectively 512 and 502 kilogram per hectare for maize and sorghum under rainfed production as well as between 2,102 and 4,897 kilogram per hectare for onion under irrigation in various Woredas of Shebelle and Siti zones while

[54] The estimated maize yield for the main season 2020/2021 was 2,467 kilogram per hectare for Fafan zone (2021b) while in 2021/2022, the yield was only 1,250 kilogram per hectare (CSA, 2022a). For sorghum, the yield for the main season 2020/2021 was reported to be 1,945 kilogram per hectare for Fafan zone (CSA, 2021b) and no yield was reported for 2021/2022 due to too high coefficients of variation (CSA, 2022a). Onion was not reported in both years due to the same reason (CSA, 2021b, 2022a). For the short rainy season 2021, the maize yield was at 483 kilogram per hectare according to CSA, while no values were reported for onion and sorghum (CSA, 2021a). In the 2022 short rainy season, an average maize yield of 557 kilogram per hectare was reported for Somali region, while for sorghum and onion no yield estimation was reported (CSA, 2022b).

classifying those amounts as particularly low (HEDBEZ BUSINESS & CONSULTANCY PLC, 2018)[55].

Taking into consideration that Somali region was affected by drought in 2016, recovering from that in the years after (LAMESO ET AL., 2022), low yields in 2016/2017 are no surprise. Most yield estimates calculated for rehabilitated DVs in Afar region are as well higher than the ones obtained in the present research[56]. Most of those data, however, do not include much information about the exact calculation method, so that from there, differences might result as well[57]. Summarizing, despite comparably low average yields for all crops, in the present research, onion has been identified as an, in comparison, high-yielding crop which is cultivated in the examined DVs in the majority of cases due the additional income opportunities it provides. This finding is backed by SORPARI (2023) which reported vegetables to be in general higher yielding than grains in Fafan zone. The same has been found by a study conducted before for the area, while also pointing to the labour intensity of those crops (FSIABD CONSULT, 2021).

With respect to cost components, the present research found that onion is also the crop with highest variable expenses per hectare, 52 per cent of which are allocated to the sowing phase, although per unit seed cost is lower for onion than for maize and sorghum. For the main produced cereals, maize and sorghum, the highest cost driver was the harvest, pointing to most of labour allocated in this production step. Estimations of production costs have been made within other studies for Somali region, but those are not easily comparable to the present

[55] The study conducted by MOHAMMED RESHID CONSULTANCY (2018) mainly assessed value chains in Somali region while the study conducted by EAST AFRICA ENGINEERING AND GENERAL CONSULTANT (2018) assessed the fodder market in Somali region. The study conducted by HEDBEZ BUSINESS & CONSULTANCY PLC (2018) represents a baseline report to evaluate the status quo before implementation of measures undertaken by the Sustainable Drought Resilience Project in Somali region. All of them were conducted for GIZ Ethiopia.

[56] A study conducted in sites rehabilitated through WSW in Afar documented a mean yield of 627 kilogram per hectare and an average of 547 kilogram per hectare for maize and sorghum in 2022 (APARI, 2023b) while earlier studies found a considerably higher yield (AMEDE ET AL., 2022) even during low season (AMEDE, 2017; GETNET ET AL., 2022). The maize yield found in Chifra, Afar, amounted to 2,100 kilogram per hectare in the low season 2017 experiencing a failure of rains although the plots were experimental and management practices were applied with the support of ICRISAT (AMEDE, 2017). Maize and sorghum yields in the main season 2017 were 5,990 and 6,200 kilogram per hectare, although also due to, among others, intense crop management and various planted crop varieties (ibid.). Maize yields in 2018/2019 in Chifra, Afar and 2019 in Yallo, Afar amounted to 3,540 and 5,800 kilogram per hectare (AMEDE ET AL., 2022). Sorghum yields in those locations were 620 and 1,430 kilogram per hectare (ibid.). GETNET ET AL. (2022) reported maize yields between 2,100 and 5,390 kilogram per hectare for different seasons between 2016 and 2017 in Chifra while yields varied significantly depending on location within the catchment area of the DV.

[57] In the present research, (agro-) pastoralists who lost the harvest are included in the calculation and at least the figure for sorghum changes considerably from 113 to 533 kilogram per hectare when excluding the lost harvest, demonstrating the importance of the exact calculation method.

research as estimations are subject to the fluctuating inflation prevalent in Ethiopia as measured by the WORLD BANK (2024)[58].

Regarding the GMs obtained, the amount of data collected allows a meaningful inference only for onion, maize and sorghum as data collected for the other crops were less than five observations, most of them only represented by one observation. Nevertheless, the exceptionally high margins of most of vegetables should be investigated in subsequent studies as they may imply considerable opportunities to earn additional income as mentioned above. From the analysis, it is clearly visible that onion features a considerably higher mean GM of 31,832 birr per hectare than the cereals maize and sorghum with 1,190 and -8,765 birr per hectare.

To investigate the high variability in the onion GM with values ranging from -36,500 to 184,760 birr per hectare as well as high variability in GMs of sorghum and maize, an attempt was made within this research, the results of which are demonstrated in chapter 5.5 and will be referred to again in chapter 6.5. Despite this high variability and although onion is more perishable than cereals (MOHAMMED RESHID CONSULTANCY, 2018), implying more risk than maize or sorghum, the present research provides evidence for higher productivity and potential profitability of onion, opening up additional income opportunities as mentioned above. This may be backed further by more research, for instance through experimental provision of seeds as the sowing phase is found to be the step implying most of variable expenses.

However, the GM calculation scheme itself has some limitations which have to be mentioned as well. The produce was valued not distinguishing between home consumption and sold crops which bends reality slightly as for example transaction costs usually are not included in the value of crops produced and consumed at home while sold crops are subject to those, in addition to demand and supply forces. Farmgate prices reported in Harre and Amadle were used to

58 An estimation of total production cost mounting to 8,320 birr per hectare has been made before for maize produced in Godey (MOHAMMED RESHID CONSULTANCY, 2018) without provision of the exact calculation scheme, although it can be assumed from the context of the paper that total variable cost was meant. The figure is close to the estimation of 9,109 birr per hectare made in the present research. The same study provided a cost-benefit-analysis for onion, reaching a total cost of production of 68,800 birr per hectare although the main cost driver is the fuel used for irrigation pumps (ibid.). Deducting that, 40,800 birr per hectare remain, being almost double of the estimation of 22600 birr per hectare made in this research. However, it is difficult to compare the calculated amounts as, like mentioned before, the exact calculation method is not provided and it is unclear which elements are based on data and which assumptions have been made. Further, the study has been conducted in 2018 and, thus, is subject to inflation.

determine an average in order to value the production. This average was obtained through very few reported values[59], restricting the meaningfulness of this figure.

As the corresponding question in the questionnaire was conditional and only posed in case the respective participant actually sold a part of their production, a better approach may have been to ask all participants for price estimations for their respective crops, although this implies potential further biases for instance related to incorrectly memorized prices or currency fluctuations for cases when people consequentially report past farmgate prices. In case the prices could not be reported by participants they were obtained from the market deducting an average margin sellers reported they keep for themselves. This reduces the degree of realism as prices obtained in different locations vary due to (non-) incorporated transaction costs. Further, according to SORPARI (2023), the limited infrastructure forces (agro-) pastoralists to sell their produce for low prices in the closest markets indicating that prices obtained could be higher depending on the access an individual has.

Transport cost and frequency have been included in the questionnaire with the intention to incorporate also those expenses into the GM calculation. It turned out though, that those questions should have had to be formulated with a far larger degree of detail as there was no distinction between the exact purposes of the market visits. A person mainly producing for subsistence for example might go to the market to buy inputs, or, in case seeds were saved, for a completely different purpose, but would report this in the same way like a person who went to buy inputs. Further, also participants selling produce have to go to the market, but in case of this research, this transport cost would not have been adequate to be included in the calculation as farmgate values were compared.

Due to this, transport cost was excluded from the calculation. Apart from that, after data collection was discovered that at least one participant included the transport cost he incurred directly into prices of seeds and inputs reported so there, a clarification would have been necessary that only prices without additional costs were asked for. In addition to that, the questionnaire for the present research did not take into account further inputs necessary for crop production mainly through labour such as plant care as well as transplanting seedlings. Including those would have extended the questionnaire too much while it now has to be taken into account that GMs would be lower if those would have been considered.

[59] Table A.10 in appendix II provides more information on this.

Further, Khat had to be treated separately as the calculation could not be applied in the exact same way due to the perennial character of the plant. The production steps had to be separated into elements for which an allocation to fixed costs is more appropriate and variable elements to be considered in the GM calculation. An even more detailed and extensive degree of detail within the questionnaire as well as more explanation and training provided to the enumerator could have led to more exact collected data. As Khat was not covered in the pilot phase during questionnaire testing, this obstacle was not discovered in time. A general limitation of GM analysis is that the GM calculated is larger than the net return remaining after fixed costs have been subtracted as also noticed by BALOYI & MAUTJANA (2018). Apart from that, it is, similar to yield, a value calculated solely for one point in time which would need more studies in subsequent years to provide a meaningful base for interpretation while controlling for inflation. Finally, it represents a fast variable according to the descriptions in chapter 2.5 and is dependent on lots of external factors[60] which may be investigated in future studies.

6.4 Differences in gross margins

Regarding hypothesis 2 stating that the profitability of the crops differs, the employed statistical test confirmed this only in part. A significant difference could only be confirmed for sorghum and onion as well as sorghum and maize. Maize and onion are not significantly different in their GMs. In contrast to that, the used statistical analyses allowed to confirm hypothesis 2.1 claiming that profitability is higher for vegetables than for cereals. Although this analysis was limited to only three crops, it implies again that onion may represent a quite profitable option, also with regard to objectives of the DVRPU Approach mentioned above.

6.5 Drivers influencing gross margins

Regarding the drivers influencing GMs of crops produced, that is, hypothesis 3, which stipulates that profitability increases with agricultural experience, the use of fertilizer, the use of pest control mechanisms and the availability of water, the results were limited. For all three crops the chosen factors did not explain the variation in the GMs very well. The strong significant negative effects of fertilizer for maize and pest control for sorghum were not based on sufficient observations. However, SUMAKA (2017) also found a negative significant effect of quantity of pesticides when investigating drivers of output. In the present research, a significant result regarding drivers of profitability is the coefficient of fertilizer application for onion, although the coefficient was not significant in all models and all equations featured a bad model fit.

[60] Tables A.2 to A.6 in appendix II show a compilation of various potential influencing factors.

Fertilizer application was also found to have a significant positive effect on bean profitability in Malawi (KASONGA, 2018) and quantity of fertilizer was significant and positively affecting output in further studies (SUMAKA, 2017; XABA & MASUKU, 2013). As other studies conducted in Afar region, although only examining grains and legumes and no vegetables, suggest that actually fewer inputs in the catchment area of WSW are necessary (AMEDE ET AL., 2022; GETNET ET AL., 2022) which may decrease production cost (TESFAI & STERK, 2002), further research is highly recommended to examine the status of soil fertility in rehabilitated DVs as well as exact amounts of potentially beneficial fertilizer in vegetable production.

Perceived water availability was associated with a negative coefficient although the intuitive assumption was that it rather increases the GM of crops. For the case of maize, this might indicate that the scale has not been explained or not been understood in the way it was necessary during the interview to facilitate a correct and meaningful answer to the question. This is possible as maize was usually the first crop for which participants had to go through the questions. For onion, however, too much water might in fact reduce production as has been indicated by one participant. Finally, the indicator was not optimal as the perceived water available may be quite high, while for successful crop production it may still be insufficient. Education had marginally significant effects on the GMs of maize and onion while the number of males in the family of the participant was marginally significant for maize only.

Regarding education, a significant positive effect on vegetable profitability was found also in other studies investigating drivers of GMs (MERSHA ET AL., 2017; XABA & MASUKU, 2013). Further, the factor was reported to be significant in thematically similar studies (GEBRIE, 2018; SHUMET, 2011; WOLLIE ET AL., 2018; YASIN, 2020). Education is assumed to enforce talent and enterprising ability of vegetable farmers (XABA & MASUKU, 2013). In the setting of the present research, it is assumed that education also leads to an improved capacity to interpret and calculate figures, therefore also an understanding of prices of inputs and outputs as well as an improved capacity to take informed decisions about investments and associated risks, thus, to financial literacy. This assumption is backed by a high magnitude marginally significant effect of education in the regression table of the GM of onion. The marginal positive significance of number of males in the family for the GM of maize seems intuitively logical as it represents an increase in the workforce available for the completion of tasks related to the production process.

The limited results regarding hypothesis 3 imply that the covariates included, with the exception of fertilizer in case of onion, do not explain the high variability in the GMs of maize, sorghum and onion. While this may be due to inherent problems in the model such as multicollinearity, that is, correlated independent variables, there are also lots of factors not considered in the present research which could offer an explanation. Those may, among others, be related to soil fertility and water availability in the distinct plots (GETNET ET AL., 2022), environmental, institutional and financial circumstances or factors related to agricultural practices[61]. More studies are necessary to determine which specific factors influence GMs in rehabilitated DVs.

Further research could also explore different regression models implying for instance the creation of a binary variable for profitability being equal one for a positive GM and zero for a negative one as done by KASONGA (2018) or different forms of regressions such as exponential, double log or semi log types as employed by SUMAKA (2017). Apart from that, the phrasing of the hypothesis was not exactly suited to the type of data planned to be collected as only the perceived water availability was reported while it was beyond the scope of the study to quantify real availability of water in the various plots. This represents a very interesting field for investigation, particularly over the course of the year and covering various years. Finally, regression results employed like this may in general only be able to demonstrate a correlation and cannot verify a causation as implied by the phrasing of the hypothesis. Apart from drivers influencing the GM of crops produced, further regression studies may also examine determinants of the sold share of crops produced[62].

6.6 Drivers of cereal cultivation

A linear mixed model was used to investigate hypothesis 4 which claimed that more cereals are cultivated compared to vegetables due to risk aversion of the family heads, easier storage possibility, drought resilience, subsistence agriculture and the dual-use benefit for livestock production. The model allowed to verify most parts of the hypothesis with the exception of drought resilience of crops which was expected to be one of the main reasons for crop choice, but none of the participants mentioned it, leading to a drop from the equation. However, SORPARI (2024) found drought tolerance to be one of the most important factors for crop choice as mentioned above.

The model with the best fit was the one including the remaining four variables of the hypothesis. The high significance and magnitude of the coefficients of subsistence agriculture and dual use of crop present a logical result as vegetables represented by onion in the present research were

[61] Regarding factors potentially influencing GMs, tables A.2 to A.6 in appendix II provide a comprehensive compilation.

[62] Table A.7 shows potential factors influencing the sold share of crops produced.

cultivated due to additional income opportunities while cereals were not. Further, cereal cultivation was justified in most of cases with the dual use benefit those crops offer. Also, a decrease in the probability of cereal cultivation related to an increase in the willingness to take risk represents a consistent result as a less risk averse person might decide to invest in riskier crops such as onion in order to gain a higher revenue in the end. The correlation between an improved possibility to store the crop and the increase of cereal cultivation probability was not expected as described in chapter 4.3, although better storage facilities may not only facilitate vegetable production; also, the cultivation of other crops may be simplified.

Apart from that, an increase in the likelihood that a cereal is produced associated with loan usage may be counterintuitive first, as loans may be related stronger to risky investments like vegetable production. Nevertheless, also for cereal production, improved financial means represent a support as this may facilitate, among others, the access to inputs such as seeds, mechanization such as tractor rental, transportation and markets as well as provide opportunities to improve storage facilities. Further investigations with regard to frequency of loan usage among (agro-) pastoralists and examinations of the supply side looking at financial products potentially accessible for them are recommended to get an understanding of opportunities and potentials in this field. Finally, the decrease in cereal cultivation probability related to a perceived better access to inputs constitute a plausible result as the access to inputs opens up opportunities to produce crops in need of more inputs in general, such as vegetables (SCHREINEMACHERS ET AL., 2018). However, also here, the latter is represented with a rather low magnitude. Research would be necessary to investigate how production of vegetables and also legume crops can be supported through improved access.

With respect to the model created, it is worth mentioning that multicollinearity was not assessed which could be present among some of the variables and would influence the results obtained. Further, subsistence agriculture was created out of the variable indicating whether participants sold their produce or not, reducing the observations which could be used for this model considerably as lots of interviewees lost the harvest as demonstrated in table 4. A question directly asking whether cultivation was intended for subsistence or the market may have led to more usable observations, producing a more representative result. A different approach is possible also by using the question asking for crop choice to which participants answered frequently additional income to create the variable subsistence agriculture, which would take the value one when additional income was not given as reason and the value zero when the opposite is the case.

Regarding the exact phrasing of the hypothesis, in the present research was not investigated whether more cereals were produced due to the listed factors. The type of statistical assessment employed only verified the significance of the associated possibility increases and decreases and did not establish a link to the produced grain and vegetable quantities. Finally, as described in chapter 6.5, also the model used for hypothesis 4 does not allow to infer causation as it only models the relation between the included variables.

Nevertheless, the assessment of hypothesis 4 shows that cereals might be selected for production with a higher probability when (agro-) pastoralists mainly cultivate for own consumption and use the crop not only for food but also for forage, combined with risk aversion and better available storage options. Although this does not allow the direct inference that the opposite has to be true to lead to vegetable cultivation, it provides an entry point for further analyses in this direction which might be of interest particularly regarding DVRPU objectives such as income diversification through the cultivation of vegetable crops[63]. In case the analysis is backed by further investigation of drivers of vegetable cultivation, measures such as capacity building may equip (agro-) pastoralists with information about the potentials of vegetable production as well as improved ability to take better decisions also regarding riskier crops.

7 SUMMARY & CONCLUSION

The analysis of the data collected from 44 (agro-) pastoralists in the frame of the present research contributed to the understanding of the productive use of the rehabilitated DVs in Somali region, particularly related to the profitability of crop production as well as crop choices. Conceptualized within a DSES lens, those variables allow to get insights into living conditions of (agro-) pastoralists but do not allow much inference on the further development of the DVs regarding rehabilitation as explained in chapter 2.5. The research found that most participants only cultivated in Gu'u season corresponding to March to September, while SORPARI's (2024) study indicates that also cultivation in Jilal corresponding to September to March is possible, which could mean a step towards the envisaged DVRPU effect of multiple harvests. More research regarding the implementation of double cropping practices is therefore recommended.

The two investigated DVs are similar regarding geographical and agrophysical conditions, as well as in terms of most socio-economic parameters, although levels of education were considerably lower in Harre, possibly related to the non-existence of a school, pointing to the

[63] For exploratory purposes, the probability of vegetable cultivation was modelled in addition while using the same predictors as specified in chapter 5.6. Table A.13 in appendix III shows the results.

need to promote the establishment of a school within the village. The investigation of degrees of income diversification in conjunction with education levels is interesting as it also relates to desired DVRPU impacts. Land size was surprisingly not at all consistent with results obtained in other studies, while reasons for those findings are not clear and deserve investigation. Also, the exact use of land owned by participants which is not cultivated should be examined. Further interesting fields for research are related to prevailing religious cultural and social values potentially impacting productivity and/or food security.

Crops found to be produced were maize, sorghum, onion, wheat, khat, chickpea, barley, tomato, carrot, beetroot and Sudan grass, while SORPARI (2024) reported also pepper. Research is recommended to establish whether the range of crops found is a trend or an exception. During the Gu'u season 2023 (March to September) investigated in the present research, maize and sorghum were produced for subsistence providing food and forage while onion was planted to generate income. Those three crops were produced most frequently, most often in combination with each other. The present research found that after the construction of WSW significantly more vegetables were produced, while research from SORPARI (2023) reported very low and non-continuous production of tomato and onion in the years before the intervention started. This indicates a start of vegetable production potentially correlated with the installation of WSW and their effects. Further research is recommended to examine this thoroughly.

Although frequencies of crops other than maize, sorghum and onion were very low, the variety found indicates an adaption to different seasons as well as a diversification of production and, thus, nutrition and income streams, representing a targeted effect of DVRPU as this contributes to food and nutrition security and diversifies livelihoods. Further research is strongly recommended to investigate the continuity of this development. A production system encompassing various crops also improves soil quality, which is why the diversification should be promoted further, also regarding soil improving legume crops as recommended by SORPARI (2024). Apart from that, current cropping patterns should be investigated and optimized, if possible, to make more use of the above-described benefits of crop diversity.

Widespread harvest losses of sorghum and simultaneously reported bird attacks point to a particular vulnerability of this crop regarding those animals. Further research is recommended to explore which sorghum varieties are used in the rehabilitated DVs and whether better suited varieties can be introduced. In addition to machinery, seeds in general were mentioned as most needed inputs for current crops while physical access to inputs such as seeds is a challenge for (agro-) pastoralists who want to produce different crops, a finding backed by SORPARI's

(2024) study. This leads to the recommendation to explore which crops would be desired most by (agro-) pastoralists as well as options for improving access to inputs in conjunction with controlled crop experiments as a means to further efficiently diversify the production aligned with DVRPU goals.

Despite low cultivation frequencies, the research indicates higher productivity levels of vegetables in comparison to grains while more research is necessary to verify the potential of those crops in contributing to food security as well as income diversification and, thus, to DVRPU objectives. Yields of maize, onion and sorghum calculated in the present research were low compared to the majority of other reviewed studies while this may be due to sample, exact plot location, season, year, agricultural practices, weather patterns, measurement and calculation method, response bias of participants and intentions of the organisation conducting the study. Further research is recommended to create more data-based information about exact productivity potentials of the different crops.

GMs of vegetables in general were remarkable, indicating huge income generating potentials, but need more investigation due to few observations. Based on a representative number of observations, the present research identifies onion as particularly high yielding crop with an average GM significantly higher than the one of sorghum. However, not only potential profitability of onion is high, also the variability of the GM is. Nevertheless, the crop is used purposefully to earn income, perceived to face strong demand and market prices and therefore indicates a step towards the envisioned DVRPU impact to generate additional income opportunities through cash crop production. As onion is a more perishable crop than cereals and as storage was mentioned as a challenge it is recommended to explore cost-efficient solutions to this. Production costs for onion were found to be high as well, particularly relating to the sowing phase, so further research could examine whether costs can be reduced as well, for instance through provision of seeds or more efficient production methods. The GM of maize is significantly higher than the one of sorghum while further investigation could explore seed varieties used and production improvement potentials for both crops.

The calculation of GMs implies several limitations related to the degree of detail for instance in terms of cost components which were not covered in this analysis such as transport and proxies used to be able to value production like the farmgate prices employed. The collected data were also very limited apart from maize, sorghum and onion, making the results a lot less representative. Finally, a GM study should be complemented by further similar studies conducted in subsequent years to be able to interpret the development of crop production, while adjusting for inflation.

The investigation of drivers of GMs did not yield many results. The effect of primary or higher education on GMs deserves more investigation as it was marginally significant in some of the models. Fertilizer was found to have a significant effect on the GM of onion in one of the models. While it may have an increasing effect on the GM, more investigation here is recommended as the model fit was insufficient and because fertilizer was found to be obsolete in other studies investigating rehabilitated DVs. Further research regarding drivers of GMs is recommended, in conjunction with further studies determining soil quality and water availability and their development over time across the rehabilitated DVs. Apart from that, determinants of productive output as well as factors influencing the sold share of crops produced may offer interesting research fields.

Regarding the investigated drivers of cereal cultivation, it was found that subsistence agriculture and dual use are associated with a significant and large increase of the predicted probability that cereals are produced. Better storage facilities were associated with an increase of this probability as well while the coefficient of willingness to take risk has a significant decreasing effect. The coefficient of perceived better access to inputs was reported with a significant negative effect as well, while loan usage was reported with a significant positive effect, a result which deserves more research as well. As cereals such as maize and sorghum are the most important products for (agro-) pastoralists in that area, this analysis provides an entry point to an understanding of the circumstances leading to those crop choices. While an exploratory regression was modelled already to predict the possibility of vegetable cultivation, further studies may explore the drivers of vegetable and legume cultivation thoroughly to gain insights into which preconditions have to be met to successfully diversify production in direction of those crops.

REFERENCES

ABERA, W., TAMENE, L., TIBEBE, D., ADIMASSU, Z., KASSA, H., HAILU, H., MEKONNEN, K., DESTA, G., SOMMER, R., & VERCHOT, L. (2020). Characterizing and Evaluating the Impacts of National Land Restoration Initiatives on Ecosystem Services in Ethiopia. *Land Degradation & Development*, *30*, 37–52.

ABU, G. A., ABAH, D., & OKPACHU, S. A. (2011). Analysis of cost and return for sesame production in Nasarawa state: Implication for sustainable development in Nigeria. *Journal of Sustainable Development in Africa*, *13*(3), 238–249.

ACAPS. (2017). *Ethiopia. Food insecurity and malnutrition in Somali region* (Briefing Note). https://www.acaps.org/fileadmin/Data_Product/Main_media/20170804_acaps_briefing_note_ethiopia_food_security_and_nutrition_0.pdf (accessed 22/05/2024)

ACTION AGAINST HUNGER. (2023). *Deadly Climate-Induced Flooding Displaces Nearly 1.6 Million People across the Horn of Africa*. Action Against Hunger. https://www.actionagainsthunger.org/press-releases/deadly-climate-induced-flooding-displaces-nearly-1-6-million-people-across-the-horn-of-africa/ (accessed 09/05/2024)

ADEWUYI, S. A., PHILLIP, B. B., AYINDE, I. A., & AKERELE, D. (2010). Analysis of Profitability of Fish Farming in Ogun State, Nigeria. *Journal of Human Ecology*, *31*(3), 179–184.

AGROMISA FOUNDATION. (2006). *Agrosource 3. The Farm as a Commercial Enterprise. To be used with AgroSource 4 (Farm Accounting)*. https://www.rfilc.org/wp-content/uploads/2020/08/1163527622352_Farm_commercial_enterprise_0.pdf (accessed 12/08/2023)

AHMED, Y. E., GIRMA, A. B., & AREDO, M. K. (2016). Determinants of Smallholder Farmers Participation Decision in Potato Market in Kofele District, Oromia Region, Ethiopia. *International Journal of Agricultural Economics*, *1*(2), 40–44.

ALIYI, I., FARIS, A., AYELE, A., OLJIRRA, A., & BAYESSA, M. (2021). Profitability and market performance of smallholder vegetable production: Evidence from Ethiopia. *Heliyon*, *7*(9), e08008. https://doi.org/10.1016/j.heliyon.2021.e08008

AMEDE, T. (2017). *Project Report on 'Rebuilding Livelihoods of (Agro) Pastoral Communities in Afar Region Through Diversifying and Integrating Drought Resistant Food and Feed Crops'*. International Crops Research Institute for the Semi-Arid Tropics (ICRISAT).

AMEDE, T., VAN DEN AKKER, E., BERDEL, W., KELLER, C., TILAHUN, G., DEJEN, A., LEGESSE, G., & ABEBE, H. (2022). Facilitating livelihoods diversification through flood-based land restoration in pastoral systems of Afar, Ethiopia. *Renewable Agriculture and Food Systems. Published Online by Cambridge University Press*, *37*, 43–54.

AMEDE, T., VAN DEN AKKER, E., BERDEL, W., KETTER, C., TILAHUN, G., DEJEN, A., LEGESSE, G., ABEBE, H., & GETNET, M. (2018). *Flooding Events Turned into Farming Opportunities. Innovation transforms livelihoods of pastoralists in Ethiopia* (Policy Brief 13). International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). https://www.researchgate.net/publication/363255233_Flooding_events_turned_into_farming_opportunities_Innovation_transforms_livelihoods_of_pastoralists_in_Ethiopia (accessed 08/09/2023)

AMIN. (2018). *Strengthening Drought Resilience (SDR). Afar and Somali Region Mission Request / Week Planning Format*. Gesellschaft für Internationale Zusammenarbeit GmbH.

APARI. (2023a). *Data on biomass, Yield and SOC. Excel-sheet*. Afar Pastoral and Agro-Pastoral Research Institute.

APARI. (2023b). *Yield/Biomass Measurements, Soil Sampling/Testing and Cropping Pattern Research on Target Weredas of GIZ-ASRP in Afar Regional State, Ethiopia. A Progressive Report Implemented in Wet & Dry Season (September-March, 2022-23). Submitted to GIZ-SDR-GIZ (Afar Soil Rehabilitation Project)*. Afar Pastoral and Agro-Pastoral Research Institute.

BALK, B. M. (2003). The Residual: On Monitoring and Benchmarking Firms, Industries, and Economies with Respect to Productivity. *Journal of Productivity Analysis*, *20*(1), 5–47. https://doi.org/10.1023/A:1024817024364

BALOYI, I. Y., & MAUTJANA, H. (2018). The Impact and Financial Viability of Rural Women's Food Security Projects in South Africa. *Journal of Public Administration*, *53*(1), 74–90.

BENU, F., RACHAPUTI, R., & DOUGLAS, C. (2010). *The Economic Performance and Management Practices of Mungbean Production Systems in Belu, West Timor. Proceedings of the 1st Australian*

Summer Grains Conference, Gold Coast, Australia, 2010 June 21–24. https://www.academia.edu/63292338/The_Economic_Performance_and_Management_Practices_of_Mungbean_Production_Systems_in_Belu_West_Timor?uc-sb-sw=81964168 (accessed 05/04/2024)

BMZ. (2023). *Äthiopien. Land mit großen Herausforderungen*. Bundesministerium Für Wirtschaftliche Zusammenarbeit Und Entwicklung. https://www.bmz.de/de/laender/aethiopien (accessed 19/03/2024)

BOWMAN, M. S., & ZILBERMAN, D. (2013). Economic Factors Affecting Diversified Farming Systems. *Ecology and Society*, *18*(1). https://www.jstor.org/stable/26269286

CALOW, R., LUDI, E., & PICHON, F. (2018). *Evaluating the Impact of Natural Resource Management Interventions on Land, Water and Pastoral Livelihoods in the Afar Region of Ethiopia. Draft Research Report.*

CATLEY, A. (2017). *Pathways to Resilience in Pastoralist Areas: A Synthesis of Research in the Horn of Africa*. Feinstein International Center, Tufts University. https://fic.tufts.edu/wp-content/uploads/FIC-Publication-Q1_web_2.26s.pdf (accessed 21/05/2024)

CHANYALEW, D. (2015). Ethiopia Indigenous Policy and Growth: Agriculture, Pastoral and Rural Development.

CHAPIN, F. S., CARPENTER, S. R., KOFINAS, G. P., FOLKE, C., ABEL, N., CLARK, W. C., OLSSON, P., SMITH, D. M. S., WALKER, B., YOUNG, O. R., BERKES, F., BIGGS, R., GROVE, J. M., NAYLOR, R. L., PINKERTON, E., STEFFEN, W., & SWANSON, F. J. (2010). Ecosystem stewardship: Sustainability strategies for a rapidly changing planet. *Trends in Ecology & Evolution*, *25*(4), 241–249. https://doi.org/10.1016/j.tree.2009.10.008

CHAPIN, III, F. S., FOLKE, C., & KOFINAS, G. (2009). A Framework for Understanding Change. In *CHAPIN III, F. S.; KOFINAS, G. P.; FOLKE, C. (eds): Principles of Ecosystem Stewardship: Resilience-Based Natural Resource Management in a Changing World, New York: Springer Science+Business Media, LLC, pp. 3-28*. https://doi.org/10.1007/978-0-387-73033-2_1

CNFA EUROPE. (2018). *CNFA Final Report. Market Systems Analysis on the Availability and Quality of Inputs for Livestock and Agricultural Production in Selected Woredas in Afar and Somali Region*. Cultivating New Frontiers in Agriculture.

CSA. (2021a). *Agricultural Sample Survey 2020/2021 (2013 E.C). Volume V. Report on Area, Production and Farm Management Practice of Belg Season Crops for Private Peasants Holdings*. Central Statistical Agency. http://www.statsethiopia.gov.et/wp-content/uploads/2022/02/Area-Production-and-Farm-Management-Practices-Private-Peasant-Holdings-Belg-Season-2020-21-2013-E.C.pdf (accessed 14/05/2024)

CSA. (2021b). *Agricultural Sample Survey 2020/2021. Volume I. Report on Area and Production of Major Crops (Private Peasant Holdings, Meher Season)*. Central Statistical Agency. https://www.statsethiopia.gov.et/wp-content/uploads/2021/05/2013-MEHER-REPORT.FINAL_.pdf (accessed 16/06/2023)

CSA. (2022a). *Agricultural Sample Survey 2021/2022. Volume I. Report on Area and Production of Major Crops (Private Peasant Holdings, Meher Season)*. Central Statistical Agency. http://www.statsethiopia.gov.et/wp-content/uploads/2023/05/The-2014-EC-Meher-Season-Report-on-Area-and-Production-of-Major-Crops_Final-1.pdf (accessed 26/04/2024)

CSA. (2022b). *Agricultural Sample Survey 2021/2022. Volume V. Report on Area, Production and Farm Management Practice of Belg Season Crops for Private Peasants Holdings*. Central Statistical Agency. http://www.statsethiopia.gov.et/wp-content/uploads/2023/07/3.2014EC.Belge_.pdf (accessed 26/04/2024)

CULLIS, A. (2022). *Strengthening Drought Resilience of Pastoral and Agro-Pastoral Populations in Arid and Semi-Arid Lowlands (SDR-ASAL) Visit to Somali Regional State*. Gesellschaft für Internationale Zusammenarbeit GmbH.

DEMIR, O., & GÖZÜBÜYÜK, Z. (2020). A comparison of different tillage systems in irrigated conditions by risk and gross margin analysis in Erzurum region of Turkey. *Environment, Development and Sustainability*, *22*, 2529–2544.

DERESE, S. A., SHIMELIS, H., LAING, M., & MENGISTU, F. (2018). The impact of drought on sorghum production, and farmer's varietal and trait preferences, in the north eastern Ethiopia: Implications for breeding. *Acta Agriculturae Scandinavica, Section B — Soil & Plant Science*, *68*(5), 424–436. https://doi.org/10.1080/09064710.2017.1418018

DESTRIJCKER, L., YISHAK, M., THOMSON, M., TRAORE, A., XU, Y. A., & KURNOTH, H. (2023). *Weathering Risk. Climate, Peace and Security Study: Somali Region, Ethiopia*. adelphi research gemeinnützige GmbH. https://adelphi.de/system/files/document/climate_peace_security_study_somali_region_ethiopia.pdf (accessed 12/08/2023)

DEVKOTA, M., & ATNAFE YIGEZU, Y. (2020). Explaining yield and gross margin gaps for sustainable intensification of the wheat-based systems in a Mediterranean climate. *Agricultural Systems, 185*, 1–16.

DJOKOTO, J. G., & ZIGAH, D. E. (2021). Gross margin of smallholder palm fruit processors with non-allocable inputs in Assin north and south districts in Ghana. *Journal of Agriculture and Food Research*, *5*, 1–7. https://doi.org/10.1016/j.jafr.2021.100177

DJOMO CHOUMBOU, R. F., ODOEMENEM, I. U., & OBEN, N. E. (2015). Gross Margin Analysis and Constraints Faced by Small Scale Rice Producers in the West Region of Cameroon. *Journal of Biology, Agriculture and Healthcare*, *5*(21), 108–112.

DOUTHWAITE, B., & GETNET, K. (2019). *Outcome Evaluation of the work of the CGIAR Research Program on Land, Water and Ecosystems (WLE) on soil and water management in Ethiopia.* International Water Management Institute (IWMI). CGIAR Research Program on Water, Land and Ecosystems (WLE). https://cgspace.cgiar.org/items/0887b9b2-8393-4d0e-b59d-ab5cea126026 (accessed 12/08/2023)

DUGUMA, L. A., MINANG, P. A., MPANDA, M., KIMARO, A., & ALEMAGI, D. (2015). Landscape restoration from a social- ecological system perspective? In *MINANG, P. A., VAN NOORDWIJK, M., FREEMAN, O. E., MBOW, C., DE LEEUW, J., & CATACUTAN, D. (Eds.): Climate-Smart Landscapes: Multifunctionality in Practice, Nairobi: World Agroforestry Centre (ICRAF), pp. 63-73*.

EAST AFRICA ENGINEERING AND GENERAL CONSULTANT. (2018). *Germen-Swiss Support Programme to the Government of Ethiopia. Strengthening Drought Resilience of the Pastoral and Agro-pastoral Populations in Arid and Semi-Arid Lowlands in Ethiopia (SDR-ASAL). Fodder Market*

Assessment (GIZ) Report of Harorays, Shabeleay, Shinile, Erer and Gode Districts of Ethiopian Somali Regional State.

EBUKIBA, E. (2010). Economic analysis of cassava production (farming) in Akwa Ibom State. *Agriculture and Biology Journal of North America*, *1*(4), 612–614.

EID, A. (2014). Jostling for Trade: The Politics of Livestock Marketing on the Ethiopia – Somaliland Border. *Future Agricultures - Working Paper*, *075*. https://www.future-agricultures.org/publications/working-papers-document/jostling-for-trade-the-politics-of-livestock-marketing-on-the-ethiopia-somaliland-border/ (accessed 12/08/2023)

EILON, S. (1985). A Framework for Profitability and Productivity Measures. *Interfaces*, *15*(3), 31–40.

EKYALIGONZA, M., TIBASIIMA, T., DIETRICH, P., AKORAEBIRUNGI, B., KAGORORA, J., FRIEDEL, J., MELCHER, A., & FREYER, B. (2022). Biomass contribution and nutrient recycling of organic matter management practices in tropical smallholder annual farming systems. *Acta Agriculturae Scandinavica, Section B - Soil & Plant Science*, *72,* 945–956. https://doi.org/10.1080/09064710.2022.2134819

ERCS. (2022). *2014 EFY. Physical & Financial Report*. Ethiopian Red Cross Society. https://www.google.com/url?sa=t&source=web&rct=j&opi=89978449&url=https://data-api.ifrc.org/documents/ET/AR_FS_unaudited_Ethiopia_2021.pdf&ved=2ahUKEwjmuLvc86aGAxW7gf0HHfZ6A5oQFnoECCYQAQ&usg=AOvVaw3Z3OIiYnq_VpXvkdmO4d3x (accessed 24/05/2024)

ESS. (2022). *Agricultural Sample Survey 2021/22. [2014 E.C.]. Volume II. Report on Livestock and Livestock Characteristics (Private Peasant Holdings, Meher Season)* (Statistical Bulletin). Ethiopian Statistics Service. http://www.statsethiopia.gov.et/wp-content/uploads/2023/07/6.The_6_2014_AGSS_2014.LIVESTOCK-REPORT_Final-3.pdf (accessed 11/05/2024)

ESS, & WORLD BANK. (2023). *Ethiopia Socioeconomic Panel Survey (ESPS) Report—Wave 5, 2021/22*. Ethiopian Statistical Service/ World Bank. http://www.statsethiopia.gov.et/wp-content/uploads/2024/01/2021-22-Survey-Report.pdf (accessed 26/04/2024)

FAO. (2017). *Ethiopia Revised Drought Plan and Priorities in 2017*. Food and Agriculture Organization. https://openknowledge.fao.org/handle/20.500.14283/i7693en (accessed 21/05/2024)

FAO GIEWS. (2023). *Country Brief on Ethiopia*. Food and Agriculture Organisation Global Information and Early Warning System. https://www.fao.org/giews/countrybrief/country.jsp?code=ETH (accessed 26/05/2024)

FAO, & ITPS. (2015). *Status of the World's Soil Resources (SWSR)—Main report*. Food and Agriculture Organization of the United Nations and Intergovernmental Technical Panel on Soils. https://openknowledge.fao.org/server/api/core/bitstreams/6ec24d75-19bd-4f1f-b1c5-5becf50d0871/content (accessed 22/05/2024)

FEWS NET. (2024). *Lasting, severe impacts of conflict and drought leave millions struggling to cope*. https://fews.net/east-africa/ethiopia/food-security-outlook/june-2023 (accessed 22/05/2024)

FIELD TRIP. (2023). *Field Trip in July to get to know the context of the study sites.*

FIRTH, C. (2002). The use of gross and net margins in the economic analysis of organic farms. In *UK Organic Research 2002: Proceedings of the COR Conference, 26-28th March 2002*. https://orgprints.org/id/eprint/8290/1/firth_margins_economic_analysis.pdf (accessed 24/01/2024)

FISCHER, J., GARDNER, T. A., BENNETT, E. M., BALVANERA, P., BIGGS, R., CARPENTER, S., DAW, T., FOLKE, C., HILL, R., HUGHES, T. P., LUTHE, T., MAASS, M., MEACHAM, M., NORSTRÖM, A. V., PETERSON, G., QUEIROZ, C., SEPPELT, R., SPIERENBURG, M., & TENHUNEN, J. (2015). Advancing sustainability through mainstreaming a social–ecological systems perspective. *Current Opinion in Environmental Sustainability*, *14*, 144–149. https://doi.org/10.1016/j.cosust.2015.06.002

FLOWER, K. C., WARD, P. R., CORDINGLEY, N., MICIN, S. F., & CRAIG, N. (2017). Rainfall, rotations and residue level affect no-tillage wheat yield and gross margin in a Mediterranean-type environment. *Field Crops Research*, *208*, 2–10.

FSIABD CONSULT. (2021). *Baseline Study & Analyzing the Context of Implementation of the DVR Project in the Intervention Zones of Somali Region, Ethiopia (Final Report)*.

FU, B., STAFFORD-SMITH, M., FU, C., LIU, Y., WANG, Y., WU, B., YU, X., LU, N., & OJIMA, D. S. (2024). Chapter 1. The Global-DEP: A Research Programme to Promote Sustainability of Dryland

Social-Ecological Systems. In *FU, B, & STAFFORD-SMITH, M. (eds): Dryland Social-Ecological Systems in Changing Environments, Singapore: Springer Nature Singapore Pte Ltd, pp. 1-20*.

GEBREMEDHIN, B., WOLDEHANNA, M., FLINTAN, F., WIELAND, B., & POOLE, J. (2017). *Baseline Survey Report for the Regional Pastoral Livelihoods Resilience Project in Ethiopia.* International Livestock Research Institute (ILRI).

GEBREMESKEL, E. N., DESTA, S., & KASSA, G. K. (2019). *Pastoral Development in Ethiopia. Trends and the Way Forward*. World Bank & International Fund for Agricultural Development. https://pdfs.semanticscholar.org/2351/789d1b1a641f19a5e53cd27e9b6006554e54.pdf (accessed 31/03/2024)

GEBRIE, A. (2018). *Technical Efficiency of Smallholder Wheat Producers in Simada Distric of Amhara Region, Ethiopia. M.Sc. Thesis*. https://www.google.com/url?sa=t&source=web&rct=j&opi=89978449&url=https://scholar.archive.org/work/22q2opvntvblvcupmqqyzh4d6m/access/wayback/https://nadre.ethernet.edu.et/record/3034/files/aderagewgebriefinalthesisedit21Copy.pdf&ved=2ahUKEwjZ45mj166GAxU9i_0HHZp0DgEQFnoECA4QAQ&usg=AOvVaw3FsiUc0iKLRBOYIKhpb0s5 (accessed 13/10/2023)

GELAN, A. U. (2007). Does food aid have disincentive effects on local production? A general equilibrium perspective on food aid in Ethiopia. *Food Policy*, *32*(4), 436–458. https://doi.org/10.1016/j.foodpol.2006.09.001

GEORGIS, K. (2010). *Agricultural based Livelihood Systems in Drylands in the Context of Climate Change Inventory of Adaptation Practices and Technologies of Ethiopia*. Food and Agriculture Organization. https://openknowledge.fao.org/items/90c209bb-3f66-47b0-941e-08a7aa115ac9 (accessed 31/03/2024)

GEORGIS, K. (2015). Session on climate change adaptation and resilience building in the drylands. 2. Agricultural and pastoral technologies and practices for climate change adaptation in dryland areas of Ethiopia. In *UNDP (eds.): Integrated Drylands Management in Ethiopia: Proceedings of the High Level Policy Forum 6—7 March 2014, Semera, Afar National Regional State, Addis Ababa: United Nations Development Programme, pp. 2-21*.

GEORGIS, K. (2021). Dryland development through resource base restoration in Ethiopia and beyond. In *HAILE, M.; LIVINGSTONE, J.; SHIBESHI, A. & PASIECZNIK, N. (eds): Dryland restoration and dry forest management in Ethiopia: Sharing knowledge to meet local needs and national commitments. A review, Addis Ababa: PENHA & Ede: Tropenbos International, pp. 53-60.*

GETNET, M., AMEDE, T., TILAHUN, G., LEGESSE, G., KRISHNA GUMMA, M., ABEBE, H., GASHAW, T., KETTER, C., & V. AKKER, E. (2022). Water spreading Weirs Altering Flood, Nutrient Distribution and Crop Productivity in Upstream–downstream settings in dry lowlands of Afar, Ethiopia. *Renewable Agriculture and Food Systems*, *37*, 17–27.

GIZ. (2021). *Rehabilitating and Restoring Degraded Areas in Ethiopia's Arid and Semi-Arid Lowlands: Teaching and Learning Guide Water-Spreading Weirs. First Edition*. Gesellschaft für Internationale Zusammenarbeit GmbH.

GIZ. (2022a). *Lowland Soil Rehabilitation Project (LSRP). Enhancing resilience to environmental change and degradation of natural resources*. Gesellschaft für Internationale Zusammenarbeit GmbH.

GIZ. (2022b). *Projektänderungsvorschlag. Globalvorhaben Bodenschutz und Bodenrehabilitierung für Ernährungssicherung—Länderpaket Äthiopien/Tiefland Projektnummer 2014.0156.1*. Gesellschaft für Internationale Zusammenarbeit GmbH.

GIZ. (2023a). *Amadle Dry Valley. Dry Valley Rehabilitation and Productive Use, Jigjiga-South Woreda, Somali Region*. Gesellschaft für Internationale Zusammenarbeit GmbH.

GIZ. (2023b). *Dry Valley Rehabilitation and Productive Use. An integrated approach to rehabilitate degraded dry valleys for sustainable livelihoods. DVRPU standard presentation.*

GIZ. (2023c). *Dry Valley Rehabilitation and Productive Use. DVRPU Guideline. An Integrated Approach to Rehabilitate Dry Valleys for Sustainable Livelihoods*. Gesellschaft für Internationale Zusammenarbeit GmbH.

GIZ. (2024a). *DVRPU Info Base*. Gesellschaft für Internationale Zusammenarbeit GmbH.

GIZ. (2024b). *Various meetings and emails communication in the context of the Master's thesis research process*. Gesellschaft für Internationale Zusammenarbeit GmbH.

GÓMEZ-LIMÓN, J. A., SÁNCHEZ-CAÑIZARES, S., HIDALGO-FERNÁNDEZ, A., & CASTILLO-CANALEJO, A. M. (2023). Profit and viability persistence: Evidence from the Spanish agricultural sector. *Agribusiness*, *39*(4), 1300–1332. https://doi.org/10.1002/agr.21822

GROßE-RÜSCHKAMP, A. (2015). *Productivity and Income Contribution of Family Farm Enterprises: A Gross Margin Study on the Sustainable Land Management Program (SLMP)—Summary Report*. Gesellschaft für Internationale Zusammenarbeit GmbH.

GUMMADI, S., RAO, K. P. C., SEID, J., LEGESSE, G., KADIYALA, M. D. M., TAKELE, R., AMEDE, T., & WHITBREAD, A. (2018). Spatio-temporal variability and trends of precipitation and extreme rainfall events in Ethiopia in 1980–2010. *Theoretical and Applied Climatology*, *134*(3), 1315–1328. https://doi.org/10.1007/s00704-017-2340-1

HA, N., FEIKE, T., BACK, H., XIAO, H., & BAHRS, E. (2015). The effect of simple nitrogen fertilizer recommendation strategies on product carbon footprint and gross margin of wheat and maize production in the North China Plain. *Journal of Environmental Management*, *163*, 146–154.

HAMLE. (2011). *Assessing Development Gaps in Somali Regional State. Gross and Transformational Plan II (GTP II) (2008 – 2010 EC)*. Somali Regional State. Bureau of Finance and Economic Development. https://www.google.com/url?sa=t&source=web&rct=j&opi=89978449&url=https://srbofed.gov.et/wp-content/uploads/2019/11/GTP-II-performance-and-Gap-analysis.docx&ved=2ahUKEwiKrJSh-K6GAxUY9AIHHbRWBxYQFnoECA8QAQ&usg=AOvVaw2TiVvlefjsUwr6CYlRSkdl (accessed 12/10/2023)

HEDBEZ BUSINESS & CONSULTANCY PLC. (2018). *Baseline Study of Sustainable Drought Resilience (SDR) Project in Somali Region, Ethiopia (Final Report)*.

HUBER-SANNWALD, E., MARTÍNEZ-TAGÜEÑA, N., ESPEJEL, I., LUCATELLO, S., COPPOCK, D. L., & REYES GÓMEZ, V. M. (2020). Chapter 1. Introduction: International Network for the Sustainability of Drylands. Transdisciplinary and Participatory Research for Dryland Stewardship and Sustainable Development. In *LUCATELLO, S.; HUBER-SANNWALD, E.; ESPEJEL, I. & MARTÍNEZ-TAGÜEÑA, N. (EDS): Stewardship of Future Drylands and Climate Change in the Global South.*

Challenges and Opportunities for the Agenda 2030, Cham: Springer Nature Switzerland AG, pp. 1-24.

HUBER-SANNWALD, E., RIBEIRO PALACIOS, M., ARREDONDO MORENO, J. T., BRAASCH, M., MARTÍNEZ PEÑA, R. M., DE ALBA VERDUZCO, J. G., & MONZALVO SANTOS, K. (2012). Navigating challenges and opportunities of land degradation and sustainable livelihood development in dryland social-ecological systems: A case study from Mexico. *Philosophical Transactions of the Royal Society*, *B*, 3158–3177.

HURNI, K., ZELEKE, G., KASSIE, M., TEGEGNE, B., KASSAWMAR, T., TEFERI, E., MOGES, A., TADESSE, D., AHMED, M., DEGU, Y., KEBEBEW, Z., HODEL, E., AMDIHUN, A., MEKURIAW, A., DEBELE, B., DEICHERT, G., & HURNI, H. (2015). *Economics of Land Degradation (ELD) Ethiopia Case Study. Soil Degradation and Sustainable Land Management in the Rainfed Agricultural Areas of Ethiopia: An Assessment of the Economic Implications. Report for the Economics of Land Degradation Initiative*. https://www.eld-initiative.org/fileadmin/pdf/ELD-ethiopia_i_06_72dpi-D.pdf (accessed 10/09/2023)

IDMC. (2024). *Country Profile Ethiopia*. IDMC - Internal Displacement Monitorning Centre. https://www.internal-displacement.orgundefined (accessed 22/05/2024)

IFRC. (2022). *Emergency Appeal. Operational Strategy. Ethiopia, Africa. Hunger Crisis*. International Federation of Red Cross and Red Crescent Societies. https://adore.ifrc.org/Download.aspx?FileId=528464 (accessed 12/08/2023)

IOM. (2022). *IOM East and Horn of Africa Drought Response. Situation Report. 1-30 November 2022*. United Nations International Organization for Migration. https://www.iom.int/sites/g/files/tmzbdl486/files/situation_reports/file/HoA_drought_Sit-Rep_Nov22_Web.pdf (accessed 21/05/2024)

IOM. (2023). *Ethiopia. Crisis Response Overview. June 2023*. UN International Organization for Migration. https://ethiopia.iom.int/sites/g/files/tmzbdl996/files/documents/2023-07/iom-ethiopia-humanitarian-and-drought-response-overview-june-2023.pdf (accessed 12/08/2023)

IOM. (2024). *Ethiopia National Displacement. Site assessment round 35 and village assessment survey round 18. 23 November-31 December 2023*. International Organisation for Migration.

https://dtm.iom.int/sites/g/files/tmzbdl1461/files/reports/DTM%20Ethiopia_National%20Displacement%20Report%2018%20%28Nov-Dec%2023%29.pdf?iframe=true (accessed 23/05/2024)

IPBES. (2024). Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. https://www.ipbes.net/node/41907 (accessed 03/04/2024)

IPCC. (2010). *Guidance Note for Lead Authors of the IPCC Fifth Assessment Report on Consistent Treatment of Uncertainties. IPCC Cross-Working Group Meeting on Consistent Treatment of Uncertainties. Jasper Ridge, CA, USA 6-7 July 2010*. Intergovernmental Panel on Climate Change. https://www.ipcc.ch/site/assets/uploads/2017/08/AR5_Uncertainty_Guidance_Note.pdf (accessed 10/05/2024)

IPCC. (2023). *Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]*. Intergovernmental Panel on Climate Change. https://www.ipcc.ch/report/ar6/syr/downloads/report/IPCC_AR6_SYR_FullVolume.pdf (accessed 18/03/2024)

KAHAN, D. (2008). *Managing risk in farming* (Reprint). FAO. https://www.fao.org/4/i3229e/i3229e.pdf (accessed 20/05/2024)

KASONGA, F. C. (2018). Gross Margin Analysis of Irrigated Beans: A Case of Khosolo Extension Planning Area. *Advances in Crop Science and Technology*, *6*(6), 1–5.

KASSA, H. (2021). Improving natural resource management in Ethiopian drylands: Drivers of change, livelihood dynamics and challenges. In *Haile, M.; Livingstone, J.; Shibeshi, A. & Pasiecznik, N. (eds): Dryland restoration and dry forest management in Ethiopia: Sharing knowledge to meet local needs and national commitments. A review, Addis Ababa: PENHA & Ede: Tropenbos International, pp. 27-37.*

KEBA, A., & MILKIAS, D. (2020). Review on Factors Affecting Technical Efficiency of Sorghum Production by Smallholder Farmers in Ethiopia. *Journal of Economics and Sustainable Development*, *11*(9), 46–49.

KETTER, C., & AMEDE, T. (2017). *Tropentag, September 20—22, 2017 in Bonn. Enhancing resilience of communities in pastoral and agro-pastoral systems by using water-spreading weirs as a* *rainwater management strategy (example Ethiopia)*. Future Agriculture: Social-ecological transitions and bio-cultural shifts., Bonn. https://www.tropentag.de/2017/abstracts/abstract.php?code=SmufYclQ (accessed 06/09/2023)

KOHLING, M., & HOLTER, P. (2022). *Final Report: Methodology to Quantify Areas Under Rehabilitation Based on Earth Observation Data. A feasibility study as part of the GIZ SDR program in the Afar region, Ethiopia Project 14.0156.1-006.00*. unique forestry and landuse GmbH.

KRAUSE, DR. H.-U., & ARORA, DR. D. (2008). *Controlling—Kennzahlen—Key Performance Indicators. Zweisprachiges Handbuch. Deutsch/Englisch. Bi-lingual Compendium. German/English*. Oldenbourg Verlag. https://www.degruyter.com/document/doi/10.1524/9783486592474/html (accessed 09/04/2024)

LAMESO, L., SHENKUT, B., & ABDILAHI, A. (2022). Drought characteristics and pastoralists' response strategies in Korahey zone, Somali regional state, Eastern Ethiopia. *Scientific African*, *16*, e01254. https://doi.org/10.1016/j.sciaf.2022.e01254

LATRUFFE, L., DIAZABAKANA, A., BOCKSTALLER, C., DESJEUX, Y., FINN, J., KELLY, E., RYAN, M., & UTHES, S. (2016). Measurement of sustainability in agriculture: A review of indicators. *Studies in Agricultural Economics*, *118*(3), 123–130. https://doi.org/10.7896/j.1624

LE, Q. B., NKONYA, E., & MIRZABAEV, A. (2014). *Biomass Productivity-Based Mapping of Global Land Degradation Hotspots (July 2014). ZEF-Discussion Papers on Development Policy No. 193*. https://deliverypdf.ssrn.com/delivery.php?ID=699064116031076102084112121104102025123011062088031092022073114100022101028123125089013000007026033049005011002122089085013106102026033060067065108026115067017088074002003007013029072079098101099075017102066089070118098005124073116066112118023126065027&EXT=pdf&INDEX=TRUE (accessed 25/05/2024)

LE, Q. B., NKONYA, E., & MIRZABAEV, A. (2016). Chapter 4. Biomass Productivity-Based Mapping of Global Land Degradation Hotspots. In *NKONYA, E.; MIRZABAEV, A. & VON BRAUN, J. (eds.): Economics of Land Degradation and Improvement – A Global Assessment for Sustainable*

Development, Cham—Heidelberg—New York—Dordrecht—London: Springer International Publishing AG Switzerland, pp. 55-84.

LESLIE, H. M., BASURTO, X., NENADOVIC, M., SIEVANEN, L., CAVANAUGH, K. C., COTA-NIETO, J. J., ERISMAN, B. E., FINKBEINER, E., HINOJOSA-ARANGO, G., MORENO-BÁEZ, M., NAGAVARAPU, S., REDDY, S. M. W., SÁNCHEZ-RODRÍGUEZ, A., SIEGEL, K., ULIBARRIA-VALENZUELA, J. J., WEAVER, A. H., & ABURTO-OROPEZA, O. (2015). Operationalizing the social-ecological systems framework to assess sustainability. *Proceedings of the National Academy of Sciences*, *112*(19), 5979–5984. https://doi.org/10.1073/pnas.1414640112

MAFF. (1980). An Introduction to farm business management. Ministry of Agriculture, Fisheries and Food and ADAS.

MANGIAFICO, S. S. (2016). *Summary and Analysis of Extension Program Evaluation in R, version 1.20.04, revised 2023*. https://rcompanion.org/documents/RHandbookProgramEvaluation.pdf (accessed 16/05/2024)

MASIH, I., MASKEY, S., MUSSÁ, F. E. F., & TRAMBAUER, P. (2014). A review of droughts on the African continent: A geospatial and long-term perspective. *Hydrology and Earth System Sciences*, *18*(9), 3635–3649. https://doi.org/10.5194/hess-18-3635-2014

MEAZA, H., ABERA, W., & NYSSEN, J. (2020). Impacts of Catchment Restoration on Water Availability and Drought Resilience in Ethiopia: A Meta-Analysis. *Land Degradation & Development*, *33*(4), 547–564.

MELESSE, K. A. (2016). Commercial Behaviour of Smallholder Potato Producers: The Case of Kombolcha Woreda, Eastern Part of Ethiopia. *Economics of Agriculture, 1*, 159–173.

MERCY CORPS. (2020). *Assessment and Recommendations: Economic Impact of COVID-19 in the Somali Region*. https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&cad=rja&uact=8&ved=2ahUKEwjtxtbH1vT-AhVQ2KQKHdC5AesQFnoECA0QAQ&url=https%3A%2F%2Fdata.unhcr.org%2Fen%2Fdocuments%2Fdownload%2F77372&usg=AOvVaw09Sp4atZ4FW3Pkmp6KZXn5 (accessed 14/05/2023)

MERSHA, M., DEMEKE, L., & BIRHANU, A. (2017). *Analysis of Factors Affecting Potato Farmers' Gross Margin in Central Ethiopia: The Case of Holeta District* (MPRA Paper). https://mpra.ub.uni-muenchen.de/92828/1/MPRA_paper_92366.pdf (accessed 12/08/2023)

MESBAH, S. H., MOHAMMADNIA, M., & AHANG KOWSAR, S. (2016). Long-term improvement of agricultural vegetation by floodwater spreading in the Gareh Bygone Plain, Iran. In the pursuit of human security, is artificial recharge of groundwater more lucrative than selling oil? *Hydrogeology Journal*.

MEZGEBE, A. G., TEREFE, Z. K., BOSHA, T., MUCHIE, T. D., & TEKLEGIORGIS, Y. (2016). Post-harvest losses and handling practices of durable and perishable crops produced in relation with food security of households in Ethiopia: Secondary data analysis. *Journal of Stored Products and Postharvest Research*, *7*(5), 45–52.

MILLENNIUM ECOSYSTEM ASSESSMENT. (2005a). *Ecosystem and human well-being. Desertification Synthesis*. Island Press. https://www.millenniumassessment.org/documents/document.355.aspx.pdf (accessed 21/03/2024)

MILLENNIUM ECOSYSTEM ASSESSMENT. (2005b). *Ecosystems and human well-being: Synthesis*. Island Press. https://www.millenniumassessment.org/documents/document.356.aspx.pdf (accessed 09/05/2024)

MIR, M. S., SAXENA, A., KANTH, R., RAJA, W., DAR, K., MAHDI, S., BHAT, A., NAIKOO, N., NAZIR, A., AMIN, Z., MANSOOR, T., MYINT, M., KHAN, M. R., MOHAMMAD, I., & MIR, S. (2022). Role of Intercropping in Sustainable Insect-Pest Management: A Review. *International Journal of Environment and Climate Change*, *12*(11), 3390–3404. https://doi.org/10.9734/IJECC/2022/v12i111390

MOA, & PENHA. (2022). *Ethiopian National Drylands Restoration Strategy*. Ministry of Agriculture, Federal Democratic Republic of Ethiopia, and the Pastoral and Environmental Network in the Horn of Africa. https://www.tropenbos.org/resources/publications/ethiopian+national+drylands+restoration+strategy (accessed 23/01/2024)

MOGES, Y. (2021). Drylands and dry forests: The global and East African context. In *HAILE, M.; LIVINGSTONE, J.; SHIBESHI, A. & PASIECZNIK, N. (eds): Dryland restoration and dry forest management in Ethiopia: Sharing knowledge to meet local needs and national commitments. A review, Addis Ababa: PENHA & Ede: Tropenbos International, pp. 17-24*.

MOHAMMED, E. A., NAUGLER, C., & FAR, B. H. (2015). Chapter 32—Emerging Business Intelligence Framework for a Clinical Laboratory Through Big Data Analytics. In *TRAN, Q. N.; ARABNIA, H. (eds.): Emerging Trends in Computational Biology, Bioinformatics, and Systems Biology, Boston: Morgan Kaufmann, pp. 577-602*. https://doi.org/10.1016/B978-0-12-802508-6.00032-6

MOHAMMED, M., & KENADID, B. (2020). Dryland restoration: Challenges and ways forward for Somali Regional State. In *HAILE, M.; LIVINGSTONE, J.; SHIBESHI, A. & PASIECZNIK, N. (eds): Dryland restoration and dry forest management in Ethiopia: Sharing knowledge to meet local needs and national commitments. A review, Addis Ababa: PENHA & Ede: Tropenbos International, pp. 138-143*.

MOHAMMED RESHID CONSULTANCY. (2018). *Scoping Study and Value Chain Analysis for Identification of Potential Value Chain Clusters in Selected Woredas of Ethiopian Somali Regional State (Final Revised Report)*.

MOTUMA ASSEN, M., & ASHEBO, T. (2018). Agro-pastorals' Adoption of Soil and Water Conservation (SWC) Technologies: The Case of Aba'ala district in Afar Region, Ethiopia. *International Journal of Biodiversity and Conservation*, *10*(7), 303–317.

MUSSA, E. C., OBARE, G. A., BOGALE, A., & SIMTOWE, F. P. P. (2012). Analysis of Resource Use Efficiency in Smallholder Mixed Crop-Livestock Agricultural Systems: Empirical Evidence from the Central Highlands of Ethiopia. *Developing Country Studies*, *2*(9), 30–40.

NIELSEN, T. D., KUDAHL, A. B., ØSTERGAARD, S., & NIELSEN, L. R. (2013). Gross margin losses due to Salmonella Dublin infection in Danish dairy cattle herds estimated by simulation modelling. *Preventive Veterinary Medicine*, *111*, 51–62.

NILL, D., ACKERMANN, K., VAN DEN AKKER, E., SCHÖNING, A., WEGNER, M., VAN DER SCHAAF, C., & PIETERSE, J. (2012). *Water-spreading Weirs for the Development of Degraded Dry River*

Valleys. Experience from the Sahel. Gesellschaft für Internationale Zusammenarbeit GmbH. https://catalogue.unccd.int/1327_GIZ_water_spreading_weirs.pdf (accessed 12/08/2023)

NKADIMENG, M. V., MAKOMBE, G., MAPIYE, O., MAPIYE, C., OLUWATAYO, I., DZAMA, K., MOJAPELO, C., MOLLEL, N., NGAMBI, J., & MAUTJANA, M. H. (2021). A Gross Margin Analysis for Nguni Cattle Farmers in Limpopo Province, South Africa. *PLoS ONE*, *16*(6), 1–13.

NLRC, & ERCS. (2018). *A Step towards resilience. Joint Initiatives Addressing Protracted Crisis in Somali Region-Ethiopia*. Netherlands Red Cross & Ethiopian Red Cross Society. https://www.climatecentre.org/wp-content/uploads/A-Step-Towards-Resilience-Joint-Initiatives-Addressing-Protracted-Crisis-in-Somali-Region-Ethiopia.pdf (accessed 24/05/2024)

OCHA. (2023a). *Ethiopia. Situation Report. Last updated: 27 Juli 2023*. United Nations Office for the Coordination of Humanitarian Affairs. https://reports.unocha.org/en/country/ethiopia/ (accessed 12/08/2023)

OCHA. (2023b). *Horn of Africa Drought: Regional Humanitarian Overview & Call to Action (Revised 26 May 2023)*. United Nations Office for the Coordination of Humanitarian Affairs. https://reliefweb.int/report/ethiopia/horn-africa-drought-regional-humanitarian-overview-call-action-revised-28-november-2022 (accessed 21/05/2024)

OCHA. (2024). *Ethiopia Humanitarian Needs Overview 2024 (February 2024)—Ethiopia*. United Nations Office for the Coordination of Humanitarian Affairs. https://reliefweb.int/report/ethiopia/ethiopia-humanitarian-needs-overview-2024-february-2024 (accessed 22/05/2024)

ODOEMENEM, I. U., & INAKWU, J. A. (2011). Economic Analysis of Rice Production in Cross River State, Nigeria. *Journal of Development and Agricultural Economic*, *3*(9), 469–474.

OGBANJE, E. C. (2023). Financial Performance of Soybean Farmers in Vandeikya Local Government Area of Benue State, Nigeria. *Journal of Agriculture and Food Sciences*, *21*(1), 128–146.

OKPARA, U. T., STRINGER, L. C., AKHTAR-SCHUSTER, M., METTERNICHT, G. I., DALLIMER, M., & REQUIER-DESJARDINS, M. (2018). A social-ecological systems approach is necessary to achieve land degradation neutrality. *Environmental Science and Policy*, *89*, 59–66.

OSTROM, E. (2009). A General Framework for Analyzing Sustainability of Social-Ecological Systems. *Science*, *325*, 419–422.

PANDEY, A., & GAUTAM, K. R. (2021). Gross margin analysis of major vegetables of Phedikhola Rural Municipality, Syangja. *Nepalese Journal of Agricultural Sciences*, *21*, 210–217.

PEDERSEN, S. M., BIZIK, J., DALLA, L., COUTINHO, J., DOLEZAL, F., & GLUSKA, A. (2005). *Potato production in Europe—A gross margin analysis.* (FOI Working Paper). Fødevareøkonomisk Institut, Københavns Universitet. https://ifro.ku.dk/english/staff/staffproduction/?pure=en%2Fpublications%2Fpotato-production-in-europe--a-gross-margin-analysis(d70298c0-a1bf-11dd-b6ae-000ea68e967b).html (accessed 05/04/2024)

PENOT, E., CHAMBON, B., & MYINT, T. (2021). *Economic Calculations for Assessing Agricultural Systems Cost Benefit Analysis and Farm Level Real Budget Analysis*. Cirad Agricultural Research for Development. https://agritrop.cirad.fr/598716/1/doc%20travail%20Manual%20economic%20calculation%20%20GRO%20english%20_2021%20last%204.pdf (accessed 13/08/2023)

PLANING, P. (2022). *Statistik Grundlagen*. Planing Publishing. https://statistikgrundlagen.de/ebook/ (accessed 16/08/2023)

RASCH, B., FRIESE, M., HOFMANN, W., & NAUMANN, E. (2014). *Quantitative Methoden. Band 1.: Einführung in die Statistik für Psychologen und Sozialwissenschaftler. 4th edition*. Springer. https://doi.org/10.1007/978-3-662-43524-3

REACH INITIATIVE. (2023a). *Ethiopia. Joint Marketing Monitoring Initiative (JMMI). February 2023*. Impact Initiatives.

REACH INITIATIVE. (2023b). *Joint Rapid Assessment of Markets (JRAM) in drought affected areas of Somali Region, Ethiopia*. Impact Initiatives. https://repository.impact-initiatives.org/document/reach/78885b4c/ETH2303_REACH_Joint-Rapid-Assessment-of-Market_Jun_2023.pdf (accessed 22/05/2024)

REACH INITIATIVE. (2024). *The Impact of Drought and Climate-Related Shocks on Livelihood Practices in Somali*. Impact Initiatives. https://repository.impact-initiatives.org/document/reach/0579137a/REACH_ETH_Factsheet_SomaliLivelihoods_1504.pdf (accessed 22/05/2024)

RETTBERG, S., BECKMANN, G., MINAH, M., & SCHLECHEN, A. (2017). *Ethiopias arid and semi-arid lowlands: Towards inclusive and sustainable rural transformation: country study*. Seminar für ländliche Entwicklung (SLE). https://edoc.hu-berlin.de/bitstream/handle/18452/18671/03.pdf (accessed 23/05/2024)

REYNOLDS, J. F., STAFFORD SMITH, D. M., LAMBIN, E. F., TURNER II, B. L., MORTIMORE, M., BATTERBURY, S. P. J., DOWNING, T. E., DOWLATABADI, H., FERNÁNDEZ, R. J., HERRICK, J. E., HUBER-SANNWALD, E., JIANG, H., LEEMANS, R., LYNAM, T., MAESTRE, F. T., AYARZA, M., & WALKER, B. (2007). Global Desertification: Building a Science for Dryland Development. *Science, 316*, 847–851.

SAMUEL, P., & IDRIS, M. (2021). Economic Analysis of Soybean Production in Taraba State, Nigeria. *International Journal of Applied Research and Technology*, *10*(11), 24–44.

SAVE THE CHILDREN. (2023, November 30). *ETHIOPIA: At least 23 killed as a new cholera outbreak poses deadly threat to thousands of displaced children*. Save the Children International. https://www.savethechildren.net/news/ethiopia-least-23-killed-new-cholera-outbreak-poses-deadly-threat-thousands-displaced-children (accessed 23/05/2024)

SCHIMEL, D. (2010). Drylands in the Earth System. Science, 327, 418–419. https://doi.org/10.1126/science.1184946

SCHÖNING, A., VAN DEN AKKER, E., WEGNER, M., & ACKERMANN, K. (2012). *Water-Spreading Weirs: Improving Resilience in Dry Areas. Tropentag 2012*. Gesellschaft für Internationale Zusammenarbeit GmbH. https://www.tropentag.de/2012/abstracts/posters/714.pdf (accessed 09/09/2023)

SCHREINEMACHERS, P., SIMMONS, E., & WOPEREIS, M. C. (2018). Tapping the economic and nutritional power of vegetables. *Global Food Security*, *16*, 36–45. https://doi.org/10.1016/j.gfs.2017.09.005

SCOONES, I. (2021). Pastoralists and peasants: Perspectives on agrarian change. *The Journal of Peasant Studies*, *48*(1), 1–47. https://doi.org/10.1080/03066150.2020.1802249

SHUMET, A. (2011). *Analysis of Technical Efficiency of Crop Producing Smallholder Farmers in Tigray, Ethiopia.* (MPRA Paper). https://mpra.ub.uni-muenchen.de/40461/1/shumet_manuscript.pdf (accessed 13/10/2023)

SINGH, S. K., & SINGH, V. (2023). Does Productivity Really Matter for Profitability? Evidence from a Publicly Owned Transport Corporation. *International Journal of Mathematical, Engineering and Management Sciences*, *8*(4), 581–594. https://doi.org/10.33889/IJMEMS.2023.8.4.033

SMITH, W. K., DANNENBERG, M. P., YAN, D., HERRMANN, S., BARNES, M. L., BARRON-GAFFORD, G. A., BIEDERMAN, J. A., FERRENBERG, S., FOX, A. M., HUDSON, A., KNOWLES, J. F., MACBEAN, N., MOORE, D. J. P., NAGLER, P. L., REED, S. C., RUTHERFORD, W. A., SCOTT, R. L., WANG, X., & YANG, J. (2019). Remote sensing of dryland ecosystem structure and function: Progress, challenges, and opportunities. *Remote Sensing of Environment*, *233*, 111401. https://doi.org/10.1016/j.rse.2019.111401

SORPARI. (2022). *Proceedings of 2021/22, SoRPARI research report*. Somali Region Pastoral and Agro-Pastoral Research Institute.

SORPARI. (2023). *Farming Systems Characterization and Analysis in a Mixed Agro- ecology, Somali Region*. Somali Region Pastoral and Agro- pastoral Research Institute.

SORPARI. (2024). *Yield/Biomass Measurements, Soil Sampling and Cropping Pattern Research Somali Region. Interim Report submitted by: Somali Region Pastoral and Agro-pastoral Research Institute*. Somali Region Pastoral and Agro-Pastoral Research Institute.

SPRINGER-HEINZE, A. (2018). *ValueLinks 2.0. Manual on Sustainable Value Chain Development. Volume 2. Value Chain Solutions*. Gesellschaft für Internationale Zusammenarbeit GmbH & ValueLinks. https://valuelinks.org/material/manual/ValueLinks-Manual-2.0-Vol-2-January-2018.pdf (accessed 12/08/2023)

STAVI, I., & LAL, R. (2015). Achieving Zero Net Land Degradation: Challenges and opportunities. *Journal of Arid Environments*, *112*, 44–51. https://doi.org/10.1016/j.jaridenv.2014.01.016

STRINGER, L. C., REED, M. S., FLESKENS, L., THOMAS, R. J., BAO LE, Q., & LALA-PRITCHARD, T. (2017). A new dryland development paradigm grounded in empirical analysis of dryland systems science. Accepted Article. *Land Degradation and Development*, *28*(7). https://doi.org/10.1002/ldr.2716

SUMAKA, E. C. (2017). Comparative Analysis of Income of Smallholder Cereals and Legumes Crop Enterprises in Nasarawa State—Nigeria. *International Journal of Agriculture*, *2*(1), 18–40.

TADESSE, M., TSEGA, W., KIDANIE, D., & MOHAMED, A. (2022). Market Chain Analysis of Live Goats: The Case of Korahe Zone, Somali Regional State, Ethiopia. *Journal of Agricultural Science and Food Research*, *13*(3), 1–8.

TESFAI, M. (2001). *Soil and Water Management in Spate Irrigation Systems in Eritrea. PhD Thesis.* https://edepot.wur.nl/199032 (accessed 09/09/2023)

TESFAI, M., & STERK, G. (2002). Sedimentation rate on spate irrigated fields in Sheeb area, eastern Eritrea. *Journal of Arid Environments*, *50*, 191–203.

TESFAI, M., & STROOSNIJDER, L. (2001). The Eritrean spate irrigation system. *Agricultural Water Management*, *48*, 51–60.

TÓTH, G., HERMANN, T., RAVINA DA SILVA, M., & MONTANARELLA, L. (2018). Monitoring Soil for Sustainable Development and Land Degradation Neutrality. *Environmental Monitoring and Assessment*, *190*(57).

TUFA, F. A. (2024). *Conflict, climate change and displacement in the Somali Region of Ethiopia*. Humanitarian Practice Network. https://odihpn.org/publication/conflict-climate-change-and-displacement-in-the-somali-region-of-ethiopia/ (accessed 22/05/2024)

TUINHOF, A., VAN STEENBERGEN, F., VOS, P., & TOLK, L. (2012). *Profit from Storage The Costs and Benefits of Water Buffering*. 3R Water Secretariat. https://www.samsamwater.com/suswa/3R_Profit_from_Storage_2012.pdf (accessed 06/09/2023)

UCLA. (2021a). *Annotated Stata Output Multiple Regression Analysis*. University of California, Los Angeles Advanced Research Computing. Statistical Methods and Data Analysis. https://stats.oarc.ucla.edu/stata/webbooks/reg/chapter1/multiple-regression-analysis/ (accessed 17/05/2024)

UCLA. (2021b). *Choosing the Correct Statistical Test in SAS, Stata, SPSS and R*. University of California, Los Angeles Advanced Research Computing. Statistical Methods and Data Analysis. https://stats.oarc.ucla.edu/other/mult-pkg/whatstat/ (accessed 10/10/2023)

UCLA. (2021c). *FAQ: How are the likelihood ratio, Wald, and Lagrange multiplier (score) tests different and/or similar?* University of California, Los Angeles Advanced Research Computing. Statistical Methods and Data Analysis. https://stats.oarc.ucla.edu/other/mult-pkg/faq/general/faqhow-are-the-likelihood-ratio-wald-and-lagrange-multiplier-score-tests-different-andor-similar/ (accessed 04/06/2024)

UCLA. (2021d). *Introduction to generalized mixed effects models*. University of California, Los Angeles Advanced Research Computing. Statistical Methods and Data Analysis. https://stats.oarc.ucla.edu/other/mult-pkg/introduction-to-generalized-linear-mixed-models/ (accessed 24/04/2024)

UCLA. (2021e). *Introduction to Linear Mixed Models*. University of California, Los Angeles Advanced Research Computing. Statistical Methods and Data Analysis. https://stats.oarc.ucla.edu/other/mult-pkg/introduction-to-linear-mixed-models/ (accessed 14/05/2024)

UN. (1994). *United Nations Convention to Combat Desertification. In those Countries Experiencing Serious Drought and/or Desertification, Particularly in Africa*. United Nations. https://www.unccd.int/sites/default/files/2022-02/UNCCD_Convention_ENG_0.pdf (accessed 04/09/2023)

UN. (2013). *United Nations Convention to Combat Desertification*. United Nations. https://legal.un.org/avl/pdf/ha/unccd/unccd_ph_e.pdf (04.09/2023)

UN. (2015). *Resolution adopted by the General Assembly on 25 September 2015. Transforming our world: The 2030 Agenda for Sustainable Development*. United Nations. https://documents.un.org/doc/undoc/gen/n15/291/89/pdf/n1529189.pdf?token=o827pI23smc4wVs2Z0&fe=true (accessed 04/09/2023)

UN. (2024). *Climate Change 'Biggest Threat Modern Humans Have Ever Faced', World*-*Renowned Naturalist Tells Security Council, Calls for Greater Global Cooperation. Press Release Security*

Council. United Nations Meetings Coverage and Press Releases. https://press.un.org/en/2021/sc14445.doc.htm (accessed 18/03/2024)

UNDP ETHIOPIA. (2014). *Dealing with Complexity in Dryland Management in Ethiopia: An Integrated Approach*. United Nations Development Programme Ethiopia. https://land.igad.int/index.php/documents-1/countries/ethiopia/rural-development-1/291-dealing-with-complexity-in-dryland-management-in-ethiopia/file (accessed 20/03/2024)

UNEP. (1992). *World Atlas of Desertification. United Nations Environment Programme*. Edward Arnold. https://wedocs.unep.org/handle/20.500.11822/42137 (21/03/2024)

UNEP. (2022). *Case Study. Upscaling community resilience through Ecosystem-based Disaster Risk Reduction in Ethiopia*. United Nations Environment Programme. https://wedocs.unep.org/bitstream/handle/20.500.11822/40824/UCREBDR.pdf?sequence=3 (accessed 19/04/2024)

UNFCCC. (2023). *The Rio Conventions*. United Nations Framwork Convention on Climate Change. https://unfccc.int/process-and-meetings/the-rio-conventions (accessed 04/09/2023)

VAN DEN AKKER, E., BERDEL, W., & NUR MURELE, J. (2015). *Reversing natural degradation into resilience: The Afar case. Conference on International Research on Food Security, Natural Resource Management and Rural Development. Tropentag 2015, Berlin, Germany*. https://www.tropentag.de/2015/abstracts/full/602.pdf (accessed 08/09/2023)

VAN DEN BERG, M., VAN MARREWIJK, C., & TAMMINEN, S. (2018). Trade, productivity and profitability: On profit levels and profit margins. *The World Economy*, *41*(8), 2149–2174. https://doi.org/10.1111/twec.12630

WALDSCHMIDT, F., ROJAS, A., DAOU, D., BEHRE, E., ARCE MOJICA, T., KOIRALA, P., SEBESVARI, Z., KREFT, S., & SOUVIGNET, M. (2020). *Economics of Climate Adaptation. Report 02. Base Data Report Ethiopia Drought Risk*.

WANG, G., LI, X., XI, X., & CONG, W.-F. (2022). Crop diversification reinforces soil microbiome functions and soil health. *Plant and Soil*, *476*(1), 375–383. https://doi.org/10.1007/s11104-022-05436-y

WETLANDS INTERNATIONAL. (2016). *Atlas of the Upper Fafan Catchment An assessment towards building resilience through ecosystem restoration in Somali Regional State, Ethiopia*. https://www.wetlands.org/publication/atlas-ethiopias-upper-fafan-catchment/ (accessed 20/04/2024)

WFP. (2020). *WFP Ethiopia. Situation Report #3 (28 May 2020)*. World Food Programme. https://reliefweb.int/report/ethiopia/wfp-ethiopia-situation-report-3-28-may-2020 (accessed 12/08/2023)

WFP. (2023a). *Research Assessment and Monitoring (RAM). More Than a Decade of Drought—Impacts and lessons learned across the Eastern Horn of Africa 2011-2022*. World Food Programme. https://reliefweb.int/report/ethiopia/more-decade-drought-impacts-and-lessons-learned-across-eastern-horn-africa-2011-2022-february-2023 (accessed 21/05/2024)

WFP. (2023b). *The worst is yet to come: Severe floods ravage eastern Africa, threatening more hunger*. World Food Programme. https://www.wfp.org/news/worst-yet-come-severe-floods-ravage-eastern-africa-threatening-more-hunger (accessed 21/05/2024)

WMO. (2023). *Provisional State of the Global Climate 2023*. World Meteorological Organization. https://reliefweb.int/report/world/provisional-state-global-climate-2023-enarruzh (accessed 21/05/2024)

WOCAT SLM DATABASE. (2012). *Water-spreading weirs for the development of degraded dry river valleys [Chad]. Reviewed by Fabian Ottiger and Joana Eichinger. Updated 07/13/2022*. World Overview of Conservation Approaches and Technologies (WOCAT) Sustainable Land Management (SLM) Database. https://qcat.wocat.net/en/wocat/technologies/view/technologies_1536/ (accessed 07/09/23)

WOLLIE, G., ZEMEDU, L., & TEGEGN, B. (2018). Economic efficiency of smallholder farmers in barley production in Meket district, Ethiopia. *Journal of Development and Agricultural Economics, 10*(10), 328–338.

WORLD BANK. (2019a). *Lowland Livelihood Resilience Project (P164336). Combined Project Information Documents / Integrated Safeguards Datasheet (PID/ISDS). Appraisal Stage | Date Prepared/Updated: 21-Mar-2019 | Report No: PIDISDSA26162*.

https://documents1.worldbank.org/curated/en/849011553174003078/pdf/Project-Information-Document-Integrated-Safeguards-Data-Sheet-Lowlands-Livelihood-Resilience-Project-P164336.pdf (accessed 22/04/2024)

WORLD BANK. (2019b). *Project appraisal document on a proposed credit in the amount of SDR 125.2 million (US$175.0 million equivalent) and a proposed grant in the amount of SDR 125.2 million (US$175.0 million equivalent) to the federal democratic Republic of Ethiopia for the Lowlands Livelihood Resilience Project. Report No: PAD3228*. The World Bank Group. https://documents1.worldbank.org/curated/pt/631541558922443947/pdf/Ethiopia-Lowlands-Livelihood-Resilience-Project.pdf (accessed 19/03/2024)

WORLD BANK. (2023). *Ethiopia. Country Climate and Development Report*. The World Bank Group. https://openknowledge.worldbank.org/server/api/core/bitstreams/715c3822-4a9d-437f-8b3c-89585f7fe3b0/content (accessed 10/05/2024)

WORLD BANK. (2024). *Inflation, consumer prices (annual %)—Ethiopia*. World Bank Open Data. https://data.worldbank.org/indicator/FP.CPI.TOTL.ZG?locations=ET (accessed 03/05/2024)

WORLD BANK & UNITED KINGDOM'S DEPARTMENT FOR INTERNATIONAL DEVELOPMENT. (2019). *Poverty and Vulnerability in the Ethiopian Lowlands: Building a More Resilient Future*. https://elibrary.worldbank.org/doi/pdf/10.1596/33422 (accessed 13/06/2023)

WU, B., SMITH, W. K., & ZENG, H. (2024). Chapter 2. Dryland Dynamics and Driving Forces. In *FU, B, & STAFFORD-SMITH, M. (eds): Dryland Social-Ecological Systems in Changing Environments, Singapore: Springer Nature Singapore Pte Ltd, pp. 23-69.* https://link.springer.com/chapter/10.1007/978-981-99-9375-8_2 (accessed 09/05/2024)

XABA, B. G., & MASUKU, M. B. (2013). Factors Affecting the Productivity and Profitability of Vegetables Production in Swaziland. *Journal of Agricultural Studies, 1*(2), 37–52.

YASIN, J. (2020). Economic Efficiency of Onion Producers: The Case of Small Scale Farmers in Kelafo District, Somali Regional State, Ethiopia. *International Researchers, 9*(1).

YING, L., & SCOTT, M. (2023). *Generalized Linear Mixture Model*. New York University. https://bookdown.org/ks6017/GLM_bookdown3/ (accessed 20.04.2024)

ZERFU, F., MOHAMMED, S., & LED, A. (Eds.). (2010). Community Based Rangeland Management: A Manual. Somali Region Livestock, Crop and Rural Development Bureau.

Appendix I: Figures

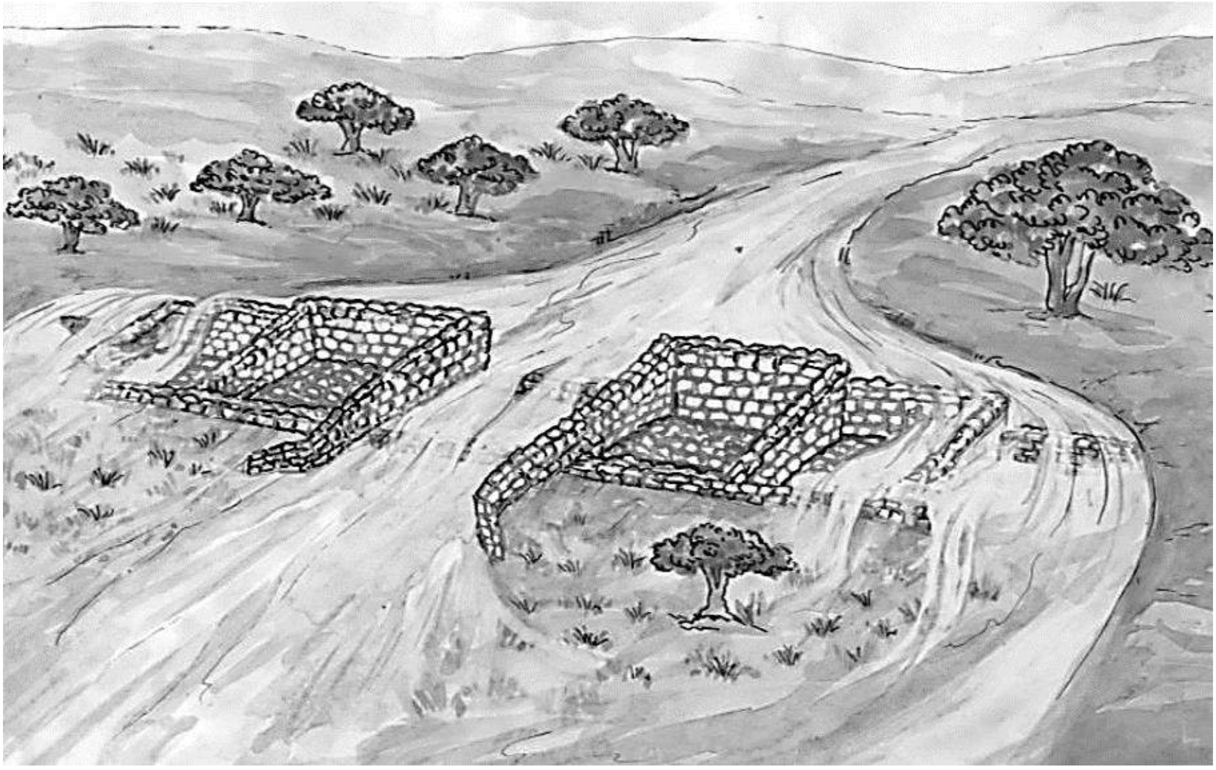

Figure 1: Illustration of a water-spreading weir

Remark: Figure 1 shows an illustration of a WSW. The flood originating in the highlands is flowing into lower laying areas where it meets the first WSW of the cascade. The velocity of the floodwater is decreased, while the majority of the excess water is channelled through the central spillway in direction of the next WSW. Abutments flanking the spillway and wing walls stretching over the whole riverbed spread the water into the surroundings of the structure.

Source: Adapted from GIZ (2021).

Appendix II: Tables

Table A.1: Criteria used to evaluate potential for Dry Valley rehabilitation

Category	Criteria
Environmental & landscape	Dry valley rivers receiving annually seasonal floods from the highlands
	Dry valley degraded by erosion
	Dry valley has a valley base of at least 250m with the potential to spread water
	Riverbed maximum 4 meters below valley floor
	Soil in the dry valley suitable for crop production
Community	A community living in proximity of the selected dry valley (within 3 km)
	Dry valley does not cross administrative boundaries
	Area not affected by conflict
Access	Dry Valley reachable by car
	Stone present within 3 km
	Sand present within 3 km
	Proximity to a market town within 5-10 km
Stakeholder	Woreda has an active PSNP team or willingness to create a DVRPU team
	Woreda has sufficient capacity to create a budget and administrate funds
	Woreda is committed to support the community technically and financially for more than 5 years
	No existing or planned NRM Projects decreasing the potential of DVRPU upstream

Remark: The table shows a listing of the requirement criteria used by GIZ to evaluate whether a particular DV features the necessary preconditions to be able to realize the full potential the DVRPU Approach offers. PSNP refers to the Ethiopian governmental initiative Productive Safety Net Programme providing food and cash to households facing food-insecurity (ACAPS, 2017). The listed criteria have to be met before implementation starts. Further selection criteria in the frame of step (1) and (2) such as slope, soil, hydrology and land tenure (GIZ, 2023c) are assessed as well. Those criteria are relevant with regard to the selection of covariates for regression models investigating for instance yield or GMs. Potential covariates for various regression models are displayed in tables A.2 to A.7. Covariates such as water availability, slope, soil quality, infrastructure, proximity to town and market as well as distance to farmland are influencing the allocation of the treatment, that is, the implementation of the DVRPU Approach, and may be selected for regression models only with caution.

Source: GIZ, 2023c

Table A.2: Potential socio-economic covariates for regression models

Covariate	Mentioned as influencing factor / included due to logical conclusions drawn	Significant in regression	Not significant in regression	Reflected in survey	Included in regression models	Expected sign of coefficient
Sex/gender household head	(ODOEMENEM & INAKWU, 2011)	(MUSSA ET AL., 2012; XABA & MASUKU, 2013; YASIN, 2020)	(KASONGA, 2018; MERSHA ET AL., 2017; MUSSA ET AL., 2012; SHUMET, 2011; WOLLIE ET AL., 2018;	x	x	No particular direction expected

			Xaba & Masuku, 2013; Yasin, 2020)			
Age	(Keba & Milkias, 2020)	(Mussa et al., 2012; Shumet, 2011; Sumaka, 2017; Yasin, 2020)	(Kasonga, 2018; Mussa et al., 2012; Xaba & Masuku, 2013)	-	-	-
Marital status	-	-	(Kasonga, 2018)	-	-	-
Education household head	(Keba & Milkias, 2020)	(Gebrie, 2018; Mersha et al., 2017; Shumet, 2011; Wollie et al., 2018; Xaba & Masuku, 2013; Yasin, 2020)	(Kasonga, 2018; Nkadimeng et al., 2021; Sumaka, 2017; Yasin, 2020)	x	x	positive
Literacy family members	-	(Shumet, 2011)	-	x	x	positive
Dependency (economically inactive family members)	-	(Shumet, 2011)	(Xaba & Masuku, 2013)	-	-	-
Family size/ household size	(Odoemenem & Inakwu, 2011)	(Mersha et al., 2017; Mussa et al., 2012; Shumet, 2011; Yasin, 2020)	(Mussa et al., 2012; Sumaka, 2017)	x	x	Could be positive or negative
Expenditure	-	(Wollie et al., 2018)	(Wollie et al., 2018)	-	-	-
Gross income	-	(Kasonga, 2018)	-	-	-	-
Experience	-	(Wollie et al., 2018; Yasin, 2020)	(Kasonga, 2018; Nkadimeng et al., 2021; Samuel & Idris, 2021; Wollie et al., 2018; Xaba & Masuku, 2013; Yasin, 2020)	x	x	positive
Distance to farmland/	-	(Samuel & Idris, 2021;	(Wollie et al., 2018)	-	-	-

distance to home		WOLLIE ET AL., 2018)				
Distance to all weather roads	(KEBA & MILKIAS, 2020)	-	-	GPS coordinates of households and of main road were collected	-	-
Infrastructure/ proximity to town	(DJOMO CHOUMBOU ET AL., 2015)	-	-	See above	-	-
Distance to market	-	(NKADIMENG ET AL., 2021; WOLLIE ET AL., 2018; XABA & MASUKU, 2013)	(XABA & MASUKU, 2013)	x	-	-
Access to market	(DJOMO CHOUMBOU ET AL., 2015; ODOEMENEM & INAKWU, 2011)	-	(MUSSA ET AL., 2012)	Included as perceived market access	x	positive
Seasonal migration	-	-	(GEBRIE, 2018)	-	-	-

Remark: The table shows socio-economic factors potentially influencing GMs or yields which were compiled in the frame of a brief literature search before finalizing questionnaire and hypotheses. The factors were either mentioned in literature, added due to conclusions drawn or directly used in regression models created for various studies. The factors and sources provided here are non-exhaustive. As the literature only covering drivers of GMs is scarce, also models investigating other key indicators such as output, economic, technical or allocative efficiency were included in the table. The table shows whether factors were mentioned only as influencing factor or whether they were significant or not significant when included a regression equation, whether they were included in the survey created for the present research, whether they were included in the final regression model investigating GMs and the expected sign before running the model. In case the same source appears both columns regarding (non-) significance, studies comprised more than one regression model.

Source: Literature reviewed before creation of the survey questionnaire.

Table A.3: Potential environmental covariates for regression models

Covariate	Mentioned as influencing factor / included due to logical conclusions drawn	Significant in regression	Not significant in regression	Reflected in survey	Included in regression models	Expected sign of coefficient
Invasive species	(GIZ, 2023C)	-	-	-	-	-
Rainfall	(GROßE-RÜSCHKAMP, 2015)	-	-	-	-	-
Water availability	(EAST AFRICA ENGINEERING AND	-	-	Included as perceived water availability	Included as perceived water availability	positive

	GENERAL CONSULTANT, 2018; GIZ, 2023B; WOLLIE ET AL., 2018)					
Pest/disease	(ALIYI ET AL., 2021; DJOMO CHOUMBOU ET AL., 2015; GROßE-RÜSCHKAMP, 2015; ODOEMENEM & INAKWU, 2011; WOLLIE ET AL., 2018)	-	-	x	-	-
Land fertility	(KEBA & MILKIAS, 2020; WOLLIE ET AL., 2018)	(SHUMET, 2011; WOLLIE ET AL., 2018)	(WOLLIE ET AL., 2018)	-	-	-
Slope	(GIZ, 2023C)	-	-	-	-	-
Temperature	Included due to logic	-	-	-	-	-
Natural disasters	Included due to logic	-	-	-	-	-
Soil type	(GIZ, 2023C)	-	-	-	-	-

Remark: The table shows environmental factors. The remark added to table A.2 provides further information.
Source: Literature reviewed before creation of the survey questionnaire.

Table A.4: Potential institutional and financial covariates for regression models

Covariate	**Mentioned as influencing factor / included due to logical conclusions drawn**	**Significant in regression**	**Not significant in regression**	**Reflected in survey**	**Included in regression models**	**Expected sign of coefficient**
Knowledge about land policy	(KEBA & MILKIAS, 2020)	-	-	-	-	-
Land tenure	(DJOMO CHOUMBOU ET AL., 2015; ODOEMENEM & INAKWU, 2011)	-	(GEBRIE, 2018)	-	-	-
Access to credit service	(DJOMO CHOUMBOU ET AL., 2015; KEBA & MILKIAS, 2020;	(GEBRIE, 2018; SHUMET, 2011; XABA & MASUKU, 2013;	(MERSHA ET AL., 2017; MUSSA ET AL., 2012; WOLLIE ET	Included as loan usage	x	positive

	ODOEMENEM & INAKWU, 2011)	YASIN, 2020)	AL., 2018; YASIN, 2020)			
Amount of credit	-	(SAMUEL & IDRIS, 2021)	-	-	-	-
Amount of savings	-	(SAMUEL & IDRIS, 2021)	-	-	-	-
Amount of investment	-	(SAMUEL & IDRIS, 2021)	-	-	-	-
Access to market information	(ALIYI ET AL., 2021)	(MERSHA ET AL., 2017)	(XABA & MASUKU, 2013)	-	-	-
Access to extension service/ agricultural training/ frequency of extension service contact	(DJOMO CHOUMBOU ET AL., 2015; GROßE-RÜSCHKAMP, 2015; KEBA & MILKIAS, 2020)	(GEBRIE, 2018; WOLLIE ET AL., 2018; YASIN, 2020)	(KASONGA, 2018; MERSHA ET AL., 2017; NKADIMENG ET AL., 2021; XABA & MASUKU, 2013)	Included as question about agricultural advice	-	-
Member to association	-	(MUSSA ET AL., 2012)	(SHUMET, 2011)	-	-	-
Marketing agency member	-	(XABA & MASUKU, 2013)	(NKADIMENG ET AL., 2021)	-	-	-
Member to cooperative	-	-	(KASONGA, 2018)	x	-	-
Transport	(ALIYI ET AL., 2021; ODOEMENEM & INAKWU, 2011)	-	-	x	-	-

Remark: The table shows institutional and financial factors. The remark added to table A.2 provides further information.

Source: Literature reviewed before creation of the survey questionnaire.

Table A.5: Potential covariates related to agricultural practices for regression models

Covariate	Mentioned as influencing factor / included due to logical conclusions drawn	Significant in regression	Not significant in regression	Reflected in survey	Included in regression models	Expected sign of coefficient
Fulltime/parttime	-	(SUMAKA, 2017)	(SUMAKA, 2017)	-	-	-
Off-farm activities	(KEBA & MILKIAS, 2020)	(MUSSA ET AL., 2012; SHUMET, 2011; WOLLIE ET AL., 2018)	-	x	Agriculture as the most important income source	positive
Participation soil and water conservation	(KEBA & MILKIAS, 2020)	-	-	-	-	-
Record keeping	-	-	(GEBRIE, 2018)	-	-	-
Poor storage	(ALIYI ET AL., 2021; DJOMO CHOUMBOU ET AL., 2015; ODOEMENEM & INAKWU, 2011)	-	-	Included as perceived storage	-	-
Number of plots	-	(WOLLIE ET AL., 2018)	-	-	-	-
Livestock owned	(KEBA & MILKIAS, 2020)	(MERSHA ET AL., 2017; WOLLIE ET AL., 2018)	(GEBRIE, 2018)	x	-	-
Crop diversification	(KEBA & MILKIAS, 2020)	(SHUMET, 2011)	-	-	-	-
Crop rotation	-	-	(WOLLIE ET AL., 2018)	-	-	-
Share cropping	(KEBA & MILKIAS, 2020)	(SHUMET, 2011)	-	-	-	-
Access to irrigation	-	-	(MERSHA ET AL., 2017; SHUMET, 2011)	-	-	-
Improved variety	(WOLLIE ET AL., 2018)	(ODOEMENEM & INAKWU, 2011)	(KASONGA, 2018)	-	-	-
Row sowing	-	(GEBRIE, 2018)	-	-	-	-
Frequency of plowing	-	(GEBRIE, 2018)	-	-	-	-
Machinery used	(MERSHA ET AL., 2017)	-	-	x	-	-

Rented or family labour	(DJOMO CHOUMBOU ET AL., 2015; ODOEMENEM & INAKWU, 2011)	-	(KASONGA, 2018)	-	-	-
Fertilizer use (as dummy)	(DJOMO CHOUMBOU ET AL., 2015)	(KASONGA, 2018)	(ODOEMENEM & INAKWU, 2011)	x	x	positive
Pesticide application (as dummy)	(DJOMO CHOUMBOU ET AL., 2015; ODOEMENEM & INAKWU, 2011)	-	-	x	x	positive

Remark: The table shows factors related to agricultural practice. The remark added to table A.2 provides further information.

Source: Literature reviewed before creation of the survey questionnaire.

Table A.6: Variables directly related to calculation and used in regression models

Covariate	Significant in regression	Not significant in regression	Reflected in survey
Livestock size	(Mussa et al., 2012; Nkadimeng et al., 2021; Shumet, 2011)	-	-
Produced quantity	(Mersha et al., 2017; Sumaka, 2017)	(Kasonga, 2018)	x
Damaged part of yield	(Djomo Choumbou et al., 2015)	-	-
Sales	-	(Samuel & Idris, 2021)	x
Prices	(Xaba & Masuku, 2013)	-	x
Total input cost	(Kasonga, 2018; Mersha et al., 2017)	-	x
Cost of agrochemicals	(Samuel & Idris, 2021)	-	x
Cost of hiring machinery	(Samuel & Idris, 2021)	-	x
Cost of hired labour	(Samuel & Idris, 2021)	-	x
Pesticide cost	-	(Odoemenem & Inakwu, 2011)	x
Fertilizer quantity	(Sumaka, 2017; Xaba & Masuku, 2013)	-	x
Pesticide quantity	(Sumaka, 2017)		
Land size per crop	(Mersha et al., 2017; Xaba & Masuku, 2013)	-	x
Farm size	(Kasonga, 2018; Nkadimeng et al., 2021; Samuel & Idris, 2021; Sumaka, 2017; Yasin, 2020)	(Odoemenem & Inakwu, 2011; Shumet, 2011)	x
Farm size square	(Shumet, 2011)	-	-

Remark: The table shows factors related to GMs having been directly used in regression models created to investigate GMs or output. The table shows whether factors were significant or not significant and whether they were included in the survey for the present research. Those factors were not included in the regression models investigating GMs having been formulated in this research as they are expected to influence the GM anyways because they are used for its calculation. The remark added to table A.2 provides further information.

Source: Literature reviewed before creation of the survey questionnaire.

Table A.7: Covariates potentially influencing sold share

Covariate	Significant in regression	Not significant in regression	Reflected in survey
Sex/gender	-	(MELESSE, 2016)	x
Age	-	(MELESSE, 2016)	-
Education	(AHMED ET AL., 2016)	-	x
Family size	-	(AHMED ET AL., 2016; MELESSE, 2016)	x
Farming experience	-	(AHMED ET AL., 2016)	x
Distance to market	-	(AHMED ET AL., 2016; MELESSE, 2016)	x
Access to market information	(AHMED ET AL., 2016; MELESSE, 2016)	-	-
Extension contact	-	(AHMED ET AL., 2016; MELESSE, 2016)	x
Non/off farm income	(AHMED ET AL., 2016; MELESSE, 2016)	-	x
Number of plots	(MELESSE, 2016)	-	-
Access to irrigation	(MELESSE, 2016)	-	-
Access to improved seed	(MELESSE, 2016)	-	-
Fertilizer application	-	(AHMED ET AL., 2016)	x
Livestock owned	(AHMED ET AL., 2016)	-	x
Livestock size	-	(MELESSE, 2016)	-
Total value of produce	(AHMED ET AL., 2016)	(MELESSE, 2016)	x
Landholding (ha)	-	(MELESSE, 2016)	x
Land size per crop	-	(AHMED ET AL., 2016)	x
Market price	(AHMED ET AL., 2016)	-	Limited data collected in the frame of additional data collected in the market

Remark: The table shows covariates having been used in regression models investigating the share of the produce participants sold. The table shows whether the factors were significant or not and whether related data were collected in the present research. This may be used for future investigations. The remark added to table A.2 provides further information.

Source: Literature reviewed before creation of the survey questionnaire.

Table A.8: Base for selection of crops included in the survey

Group	Crop	Literature
Cereals	Maize	(CSA, 2021B; CULLIS, 2022; EAST AFRICA ENGINEERING AND GENERAL CONSULTANT, 2018; FIELD TRIP, 2023; FSIABD CONSULT, 2021; GEBREMEDHIN ET AL., 2017; HAMLE, 2011; HEDBEZ BUSINESS & CONSULTANCY PLC, 2018; MOHAMMED RESHID CONSULTANCY, 2018; SORPARI, 2023; WALDSCHMIDT ET AL., 2020; WORLD BANK & UNITED KINGDOM'S DEPARTMENT FOR INTERNATIONAL DEVELOPMENT, 2019)
	Sorghum	(CSA, 2021B; CULLIS, 2022; EAST AFRICA ENGINEERING AND GENERAL CONSULTANT, 2018; FIELD TRIP, 2023; FSIABD CONSULT, 2021; GEBREMEDHIN ET AL., 2017; HAMLE, 2011; HEDBEZ BUSINESS & CONSULTANCY PLC, 2018; MOHAMMED RESHID CONSULTANCY, 2018; SORPARI, 2023; WALDSCHMIDT ET AL., 2020; WORLD BANK & UNITED KINGDOM'S DEPARTMENT FOR INTERNATIONAL DEVELOPMENT, 2019)
	Wheat	(CSA, 2021B; EAST AFRICA ENGINEERING AND GENERAL CONSULTANT, 2018; HAMLE, 2011; HEDBEZ BUSINESS & CONSULTANCY PLC, 2018; SORPARI, 2023; WALDSCHMIDT ET AL., 2020; WORLD BANK & UNITED KINGDOM'S DEPARTMENT FOR INTERNATIONAL DEVELOPMENT, 2019)

	Barley	(CSA, 2021B; HAMLE, 2011; HEDBEZ BUSINESS & CONSULTANCY PLC, 2018; SORPARI, 2023; WALDSCHMIDT ET AL., 2020)
	Teff	(CSA, 2021B)
	Rice	(HAMLE, 2011)
	Oats	(SORPARI, 2023)
	Millet	(SORPARI, 2023)
Vegetables	Onion	(CSA, 2021B; CULLIS, 2022; EAST AFRICA ENGINEERING AND GENERAL CONSULTANT, 2018; FIELD TRIP, 2023; FSIABD CONSULT, 2021; HEDBEZ BUSINESS & CONSULTANCY PLC, 2018; MOHAMMED RESHID CONSULTANCY, 2018; SORPARI, 2023; YASIN, 2020)
	Tomato	(CSA, 2021B; CULLIS, 2022; EAST AFRICA ENGINEERING AND GENERAL CONSULTANT, 2018; FIELD TRIP, 2023; HEDBEZ BUSINESS & CONSULTANCY PLC, 2018; SORPARI, 2023)
	Garlic	(FIELD TRIP, 2023; GIZ, 2024B)
	Carrot	(CULLIS, 2022; HEDBEZ BUSINESS & CONSULTANCY PLC, 2018)
	Potato	(HEDBEZ BUSINESS & CONSULTANCY PLC, 2018)
	Beetroot	(FIELD TRIP, 2023; HEDBEZ BUSINESS & CONSULTANCY PLC, 2018)
	Cabbage	(HEDBEZ BUSINESS & CONSULTANCY PLC, 2018; SORPARI, 2023)
	Watermelon	(HEDBEZ BUSINESS & CONSULTANCY PLC, 2018; SORPARI, 2023)
	Pepper	(HEDBEZ BUSINESS & CONSULTANCY PLC, 2018; SORPARI, 2023)
	Pumpkin	(FIELD TRIP, 2023)
Fruits	Orange	(CNFA EUROPE, 2018)
	Banana	(CNFA EUROPE, 2018)
	Avocado	(CNFA EUROPE, 2018)
Pulses	Chickpea	(CSA, 2021B; FIELD TRIP, 2023; HAMLE, 2011; SORPARI, 2023)
	Beans (different types)	(CSA, 2021B; EAST AFRICA ENGINEERING AND GENERAL CONSULTANT, 2018; FSIABD CONSULT, 2021; HAMLE, 2011; SORPARI, 2023)
	Peas (different types)	(CSA, 2021B; SORPARI, 2023)
Oilseeds	Sesame	(EAST AFRICA ENGINEERING AND GENERAL CONSULTANT, 2018; HAMLE, 2011; HEDBEZ BUSINESS & CONSULTANCY PLC, 2018; MOHAMMED RESHID CONSULTANCY, 2018)
	Groundnuts	(CSA, 2021B; HAMLE, 2011; SORPARI, 2023)
	Wild sunflower	(FIELD TRIP, 2023)
Forage	Sudan grass	(CULLIS, 2022; EAST AFRICA ENGINEERING AND GENERAL CONSULTANT, 2018; FIELD TRIP, 2023)
	Elephant grass	(AMIN, 2018)
Other	Greenleaves	(FIELD TRIP, 2023)
	Khat	(FIELD TRIP, 2023; GEBREMEDHIN ET AL., 2017; HEDBEZ BUSINESS & CONSULTANCY PLC, 2018)
	Apiculture	(EAST AFRICA ENGINEERING AND GENERAL CONSULTANT, 2018; ESS, 2022; FIELD TRIP, 2023; FSIABD CONSULT, 2021; GIZ, 2023A)

Remark: The table shows which crops are produced in general in Somali region according to the field trip to Somali region in July 2023 and according to the research investigated within a brief literature review before compiling questionnaire and hypotheses.

Source: Literature reviewed before creation of the survey questionnaire.

Table A.9: Simplified overview over survey questions (shortened)

	Question or request (titles of different sections in bold)
1.	Please enter participant code.
2.	Consent form signed?

3.	Enter the name of the Dry Valley:
4.	Please enter the participant’s gender.
5.	Any frenchie present?
6.	Save participant's household location.
7.	How many people live in your family including yourself?
8.	How many households are those?
9.	How many of your family members are male?
10.	How many of your family members are older than 18?
11.	Of these adults, how many are able to read and write?
12.	Of these literate adults, what is the highest grade a household member achieved in school?
13.	**Questions on Income Sources and Land-use**
14.	What are your family's sources of livelihood?
15.	Please specify your family's other source of livelihood.
16.	Please rate the chosen options according to their importance for your family's livelihood.
17.	Importance of agriculture
18.	Importance of livestock
19.	Importance of non-farm income
20.	Importance of bee-keeping
21.	Importance of other source of income
22.	Which type of non-farm income does your family have?
23.	Please specify the non-farm income your family generates.
24.	How many years have you been practicing agriculture?
25.	Did you engage in agricultural activities before the construction of water-spreading weirs?
26.	Which crops did you produce BEFORE the construction of water-spreading weirs?
27.	Please specify which crop you produced before.
28.	For how many Qodi of land are you and your family directly responsible?
29.	Of this, how many Qodi do you use for agriculture?
30.	**Now, please think about the last Gu'u season.**
31.	Which crops did you produce in the last Gu'u season?
32.	Please specify the other crop you produced in Gu'u.
33.	**Questions regarding obtained gross margins of crops produced in Gu'u**
34.	Enter crop type selected by participant.
35.	On how many Qodi did you cultivate this crop?
36.	How many bags of this crop did you produce in the last Gu'u season?
37.	Of the bags produced, how many bags did you give to charity?
38.	Of the bags produced, how many did you save to have seeds for the following season?
39.	How many bags did you sell?
40.	To whom or where did you sell it?
41.	Please specify to whom you sold it.
42.	For how much birr per bag did you sell it?
43.	How many bundles of straw did you produce in the last Gu'u season?
44.	How many bundles of the straw did you sell?
45.	To whom did you sell it?
46.	Please specify to whom you sold it.
47.	For how much birr per bundle did you sell it?
48.	How was the land of this plot prepared in the in the last Gu'u season?
49.	Is the oxen your own?
50.	What is the rental cost per hour in birr?
51.	Is the tractor your own?
52.	What is the rental cost per hour in birr?
53.	How many labour hours did the land preparation take for this crop?
54.	How many people were involved?
55.	Where did you obtain the seeds for this crop for the in the last Gu'u season?
56.	Please specify where you obtained your seeds.
57.	What was the cost per bag you bought in birr?
58.	How many bought bags did you use for this crop?
59.	What was the cost per bag supplied by the NGO in birr?
60.	How many bags supplied by the NGO did you use for this crop?

61.	What was the cost per bag supplied by the government in birr?
62.	How many bags supplied by the government did you use for this crop?
63.	How many labour hours did sowing take for this crop?
64.	How many people were involved?
65.	Did you use fertilizer for this crop in the in the last Gu'u season?
66.	What type of fertilizer did you use?
67.	Please specify the kind of fertilizer you used.
68.	Did you spray the fertilizer on your own?
69.	How many hours did you hire the person for spraying fertilizer?
70.	What did you pay that person per hour in birr?
71.	How many units of fertilizer did you use for this crop?
72.	Fertilizer unit:
73.	Please specify the unit.
74.	Number of units:
75.	What was the cost per unit in birr?
76.	How many labour hours did it take to apply the fertilizer for this crop?
77.	How many people were involved?
78.	Was there any pest or disease in the in the last Gu'u season?
79.	Which?
80.	Please specify which pest or disease occurred.
81.	What did you do against pests and diseases for this crop?
82.	Please specify what you used against pests and diseases.
83.	Did you spray the chemicals on your own?
84.	How many hours did you hire the person spraying?
85.	What did you pay that person in birr per hour?
86.	How many labour hours did it take in total to apply the measures against pests and diseases for this crop?
87.	How many people were involved?
88.	How many units did you use?
89.	What was the cost per unit in birr?
90.	Did you use a tractor for harvesting?
91.	How much did you pay for the tractor per bag of harvested crop?
92.	How many more people apart from the tractor driver were involved?
93.	How many labour hours did the harvest of this crop take in the in the last Gu'u season?
94.	How many people were involved?
95.	**Further general questions**
96.	Please think about the market.
97.	How often did you or a family member go to the market in the last Gu'u season and the previous Jilal season to sell crops or buy inputs?
98.	How many hours does it take you to go there each time?
99.	Which means of transportation do you use?
100.	Please specify which transport means you use.
101.	How high is the cost for fuel in birr each time?
102.	How high is the cost for rent each time?
103.	What did you pay for the bajaj each time?
104.	Which challenges do you face to reach the next market?
105.	Please specify the challenge you face in reaching the market.
106.	How accessible is the next market for you?
107.	Now, please think about the demand for your crops.
108.	Maize: Please describe the demand for it.
109.	Please think about the prices you (could) obtain for your crop in the market
110.	Are prices fluctuating or stable?
111.	Maize: Are prices fluctuating or stable?
112.	Are prices low or high?
113.	Maize: Are prices low or high?
114.	Please think about the storage of your crop.
115.	Maize: Is the storage of your harvested crop difficult or easy?
116.	Please think about the financial access you have to your inputs.

117.	How financially accessible are the inputs you need for your crops for you?
118.	Maize: Financial accessibility of inputs:
119.	Please think about the physical access you have to your inputs.
120.	How physically accessible are the inputs you need for your crops for you?
121.	Maize: Physical accessibility of inputs:
122.	Please think whether you would like to use more inputs for your crops?
123.	Maize: Would you like to use more inputs?
124.	Which ones would you like to use?
125.	Please specify the inputs you would like to you use.
126.	Please think about the reasons for your crop choice.
127.	Maize: Why did you choose to cultivate this crop?
128.	Please specify the reasons for which you choose the crop.
129.	Would you like to try other crops?
130.	What do you need to be able to do that?
131.	Please specify what you need to try out other crops.
132.	How long is water available on your land?
133.	Did you take out loans to finance crop production?
134.	How did you access them?
135.	Please specify how you accessed your loans.
136.	Do you receive advice on agriculture/crop production?
137.	Who advises you on agriculture?
138.	Please specify who advises you.
139.	Is your family a member in a cooperative/association?
140.	Questions about economic preferences
141.	I now ask for your willingness to act in a certain way. Please indicate your answer on a scale from 0 to 10, where 0 means you are ‘completely unwilling to do so’ and a 10 means you are ‘very willing to do so’. You can also use any numbers between 0 and 10 to indicate where you fall on the scale, like 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10.
142.	How willing are you to take risks, in general?
143.	How willing are you to give up something that is beneficial for you today in order to benefit more from that in the future?
144.	How well does the following statement describe you as a person? Please indicate your answer again on a scale from 0 to 10. A 0 means ‘does not describe me at all’ and a 10 means ‘describes me perfectly’. You can also use any numbers between 0 and 10 to indicate where you fall on the scale, like 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10.
145.	I assume that people have only the best intentions
146.	Did you already save the participant's household location?
147.	Save participant's household location.
148.	Additional comments regarding the interview.

Remark: The table shows a simplified, shortened version of the questionnaire used for data collection. Part 34. to 94. was repeated for each season and as well for each crop selected as having been grown by the participant in the respective season. Part 108. to 128. was repeated only per crop, not per season. Lots of questions are conditional and were only posed depending on an answer given before.

Source: Created based on literature reviewed, information obtained during the field trip in July 2023 and the pilot phase before data collection in November 2023.

Table A.10: Bag sizes & obtained mean bag prices

Crop	Bag size in kilogram	Mean bag price in birr
Maize	50	1233
Sorghum	50	2167
Onion	50	1878
Wheat	50	2500
Khat	0.25	3000
Chickpea	50	2814
Barley	50	2714
Tomato	12	300
Carrot	50	2000
Beetroot	50	-
Sudan grass	-	-

Remark: Bag sizes were obtained through occasionally posted questions to survey participants as well as additional data collected in the market of Jigjiga. Khat is sold in the local unit Michin which corresponds to 0.25 kilogram. Tomatoes are sold in various bag sizes; the tomato grower participating in the present research sold the indicated bag size of 12 kilogram. Bag prices were obtained using the average of prices indicated by survey participants who actually sold their crops. If survey participants sold parts of their produce for differing prices, the mean was taken. The values for maize and sorghum are based on three observations each. The onion bag price was calculated using 21 observations while the values for wheat, tomato and carrot originate from one observation each. The Khat price is based on two observations. Chickpea and barley were not sold. For those two, market prices were used instead to proxy farmgate prices. For chickpea, only one price equalling 3000 birr was obtained in the market. Subsequently, the average margin (excluding one outlier of 1100 birr) reported to be kept by vendors of grains such as maize, sorghum and wheat corresponding to 186 birr was calculated and deducted from the chickpea price to proxy a farmgate price. The same procedure was done for barley for which a market price of 2900 was collected.

Source: Own calculations based on collected data.

Table A.11: Social parameters of participants

Variable		Amadle			Harre		
		Frequency	Percentage	Mean	Frequency	Percentage	Mean
Gender	Male	19	90.48	-	21	91.3	-
	Female	2	9.52	-	2	8.7	-
Family size	0-5	3	14.29	-	5	21.74	-
	6-10	13	61.90	-	12	52.17	-
	11-15	4	19.05	-	5	21.74	-
	15+	1	4.76	-	1	4.35	-
	Total	21	100	8.62	23	100	8.52
Male members	-	-	-	4.26	-	-	4.1
Adult members	-	-	-	5.33	-	-	3.65
Literate adult members	-	-	-	2.48	-	-	0.82
Family's highest grade	Illiterate/no grade completed	3	14.29	-	15	65.22	-
	1-4	8	38.10	-	1	4.35	-
	5-8	5	23.81	-	4	17.39	-
	9-12	3	14.29	-	1	4.35	-
	College+	2	9.52	-	1	4.35	-
	Refuse to answer	-	-	-	1	4.35	-

Remark: The table shows frequencies and percentages and means where applicable related to social parameters of participants, displayed for Harre and Amadle separately.
Source: Own calculations based on collected data.

Table A.12: Prevalence of cultivated crops

Crop	Number cultivating	Percentage	Mean cultivated land in Qodi (hectares)
Maize	39	88.64	13.63 (3.41)
Sorghum	33	75	7.44 (1.86)
Onion	27	61.36	5.74 (1.44)
Wheat	4	0.09	10 (2.5)
Khat	3	0.07	6.33 (1.58)
Chickpea	2	0.05	4 (1)
Barley	1	0.02	5 (1.25)
Tomato	1	0.02	1 (0.25)
Carrot	1	0.02	1 (0.25)
Beetroot	1	0.02	3 (0.75)
Sudan grass	1	0.02	1 (0.25)

Remark: The table shows the number cultivating the various crops, the percentage and the average crop land size.
Source: Own calculations based on collected data.

Table A.13: Farmgate price information for onion in birr

Crop	Mean market	Mean intermediary	Mean wholesaler	Mean total	St.dev.	Minimum	Maximum	Median
Onion	2159	1952	1917	1878	1216	500	5000	1700

Remark: The table shows additional information regarding the onion prices obtained by survey participants. The mean price obtained in the market is calculated with nine observations, the intermediary price is based on 14 observations and the wholesaler price is the average of three observations. The mean total considers all 21 participants selling onion. Standard deviation, minimum, maximum and median take into account all 21 observations as well.

Source: Own calculations based on collected data.

Table A.14: Desired inputs for crops produced in absolute numbers & percentages

Crop	Machinery	Seeds	Water	Fertilizer	Labour	Chemicals	Other
Maize	29 (74.36)	22 (56.41)	14 (35.90)	9 (23.08)	2 (5.13)	2 (5.13)	3 (7.69)
Sorghum	25 (75.76)	18 (54.55)	10 (30.30)	4 (12.12)	2 (6.06)	-	1 (3.03)
Onion	17 (62.96)	17 (62.96)	11 (40.74)	3 (11.11)	1 (3.70)	-	-
Wheat	3 (75)	1 (25)	2 (50)	-	-	-	-
Khat	2 (66.67)	1 (33.33)	1 (33.33)	1 (33.33)	1 (33.33)	-	-
Chickpea	2 (100)	-	1 (50)	-	1 (50)	-	-
Tomato	1 (100)	-	-	-	-	-	-
Carrot	-	1 (100)	1 (100)	-	-	-	-
Barley	1 (100)	-	-	-	-	-	-
Sudan grass	-	-	-	-	-	-	-
Beetroot	-	1 (100)	1 (100)	-	-	-	-

Remark: The table shows the number of participants mentioning a desire for inputs such as machinery, seeds, water, fertilizer, labour, chemicals or other in absolute numbers and percentage shares relative to the total number of participants producing the respective crop in parentheses. Chemicals summarize pesticides, fungicides, insecticides and herbicides. For maize, other included once (2.56 per cent) a motorbike to buy inputs and twice (5.13 per cent) an increase in the number of WSW. For sorghum, other referred to financial support.

Source: Own calculations based on collected data.

Table A.15: Seed origin in absolute numbers & percentages & seed price in birr

Crop	Saved	Family	NGO	Government	Bought	Mean price
Sorghum	11 (33.33)	-	-	-	22 (66.67)	3,020
Carrot	-	-	-	-	1 (100)	3,000
Beetroot	-	-	-	-	1 (100)	3,000
Maize	11 (29.21)	1 (2.56)	-	2 (5.13)	27 (69.23)	2,976
Onion	-	-	-	-	27 (100)	2,372
Wheat	-	-	-	2 (50)	2 (50)	1,750
Tomato	-	-	-	-	1 (100)	800
Chickpea	-	-	-	-	2 (100)	100
Sudan grass	-	-	-	-	1 (100)	50
Khat	1 (33.33)	2 (66.67)	-	-	-	-
Barley	1 (100)	-	-	-	-	-

Remark: The table shows the number of participants obtaining their seeds from the last season (saved), their family, an NGO, the government or from the market (bought). The percentage share relative to the total number of participants producing the respective crop are shown in parentheses. Percentages do not necessarily add up as for the corresponding question multiple selections were possible. In addition, the mean price per unit in birr is shown for those cases when seeds were bought. Although the unit size of the seed bags was not obtained, it is visible from the data that maize and sorghum seeds were sold in two different sizes, one being very small bags of which a high number is used for sowing and a larger size of which not many are used (e.g. a seed unit price may be 50 birr and 30 of them are used or it may be 2500 birr and only one bag is used). Due to this, for the calculation of the maize and sorghum seed bag prices, six, respectively seven cases were excluded, leaving 21 and 15 observations for maize and sorghum. If included, mean prices change to 2,327 birr for maize and 2,078 birr for sorghum seed bags. For wheat, the same was observed, thus, one observation was excluded. When included, the mean price changes to 925 birr.

Source: Own calculations based on collected data.

APPENDIX III: REGRESSION MODEL FOR EXPLORATORY PURPOSES

Table A.16: Model results – drivers of vegetable cultivation

	Dependent variable:						
	Vegetable cultivation as predicted by formula (A.1) to (A.7)						
	(A.1)	(A.2)	(A.3)	(A.4)	(A.5)	(A.6)	(A.7)
Subsistence agriculture	-0.62*** (0.09)				-0.47*** (0.09)	-0.57*** (0.10)	-0.36*** (0.10)
Dual use of crop		-0.62*** (0.07)			-0.32*** (0.10)	-0.20* (0.11)	-0.22** (0.11)
Willingness to take risk			-0.01 (0.02)		0.03 (0.02)	0.06** (0.02)	0.04 (0.03)
Ease of storage				-0.04** (0.02)	-0.02 (0.02)	-0.04** (0.02)	-0.03 (0.02)
Female						0.17 (0.16)	0.18 (0.16)
Primary education or higher						0.11 (0.11)	0.04 (0.11)
Agriculture=most important						0.13 (0.13)	-0.01 (0.14)
Nr of literate family members						0.03 (0.02)	0.03 (0.02)
Family size						-0.0003 (0.03)	-0.01 (0.03)
Nr of male family members						-0.02 (0.04)	-0.002 (0.04)
Perceived market access						-0.03* (0.02)	-0.02 (0.02)
Loan usage						-0.22** (0.09)	-0.25*** (0.09)
Perceived demand for crop							0.01 (0.02)
Perceived stability of market prices							-0.01 (0.01)
Perceived level of prices							0.05** (0.02)
Perceived financial access to inputs							-0.003 (0.02)
Perceived physical access to inputs							0.05 (0.03)
Perceived water availability							-0.001 (0.02)
Additional income possibility							0.16 (0.10)
Constant	0.70*** (0.07)	0.70*** (0.06)	0.37** (0.18)	0.43*** (0.07)	0.62*** (0.18)	0.56** (0.24)	-0.15 (0.33)
Observations	71	114	114	114	71	71	71
Log Likelihood	-33.90	-43.42	-75.61	-72.84	-32.53	-43.44	-53.76
Akaike Inf. Crit.	75.80	94.84	159.21	153.69	79.07	116.88	151.52
Bayesian Inf. Crit.	84.85	105.78	170.16	164.63	94.90	150.83	201.30

Note: This table shows mixed model estimates using the collected data in Somali region. The dependent variable vegetable cultivation is binary and takes the value of 1 if a cereal is cultivated and 0 if not. Subsistence agriculture, dual use of crop, female, primary education or higher, agriculture=most important, loans usage and additional income possibility are binary variables. Additional income possibility takes the value 1 when additional income was mentioned as reason for crop choice and it takes the value 0 if this is not the case. Nr of literate family members, family size, nr of male family members are discrete variables. The remaining variables were assessed using an 11-point Likert scale ranging from 0 to 10. For willingness to take risk the scale ranges from unwillingness to very willing. For ease of storage, perceived market access, perceived financial access to inputs and perceived physical access to inputs it extends from very difficult to very easy. For perceived water availability it ranges from very short to very long. For perceived demand for crop and perceived level of price it extends from very low to very high. For perceived stability of market prices, it ranges from very fluctuating to very stable. Standard errors are shown in parentheses. Significance indications: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Source: Own calculations based on collected data.

Appendix IV: Acknowledgements

I am particularly grateful to GIZ Ethiopia for facilitating my research and enabling me to come to Somali region twice in the frame of my thesis. The project staff of the office in Addis Ababa and the regional office in Jigjiga at all times provided steady input and guidance as well as expertise and exchange of information. All of this is sincerely valued.

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APPENDIX V: PERSONAL DECLARATION

I hereby affirm that I have prepared the present thesis self-dependently, and without the use of any other tools, than the ones indicated. All parts of the text, having been taken over verbatim or analogously from published or not published scripts, are indicated as such. The thesis hasn't yet been submitted in the same or similar form, or in extracts within the context of another examination.

Bonn, 05.06.2024

Student's signature