8 Supplementary material

8.1 Characteristics of the case study areas and the measures

Table 2 Characteristic of the case study areas, the sample and the covered measures

country	region	district	characteristics of the sampling area	sampled villages [n]	sampled households [n]	measures
(1) Ethiopia	(i) Oromia Region	(a) Ada'a (b) Boset	Altitude: 1500-3100m.a.s.l. Rainfall (bimodal): 700-860mma^{-1} Mean temperature range: 8-30°C Agro-Ecological Zones (AEZ): tepid, sub-moist mid highlands (weynadega) / warm, sub-moist lowlands (kolla)	10	275	irrigation systems early mature varieties weather forecast reduced tillage improved harvesting technologies
(2) Ghana	(ii) Ashanti	(c) Offinso South (d) Ejisu-Juaben	Altitude: 180-300m.a.s.l. Rainfall (bimodal): 1200-1400mma^{-1} Mean annual temperature: 26.4-27°C AEZ: transitional zone / deciduous forest	4	152	irrigation systems shade trees fire belts bookkeeping mulching
	(iii) Western Region	(e) Sefwi Wiawso (f) Ellembelle	Altitude: 0-510m.a.s.l. Rainfall (bimodal): 1400-2400mma^{-1} Mean annual temperature: 26.4°C AEZ: deciduous forest / rain forest	4	155	

Source: (Antwi-Agyei et al. 2012; Government of Ghana [GoG] 2015; Government of Ghana [GoG] 2017a; Government of Ghana [GoG] 2017b; Government of Ghana [GoG] 2017c; Government of Ghana [GoG] 2017d; IPMS 2007; Issaka et al. 2012; Muhie 2001; World Vision Ethiopia 2000)

Table 3 Description of the measures

Ghana: measures	description
irrigation	Irrigation technologies are implemented only by few Ghanaian cocoa farmers and hence, drought often results in soil water deficit, which leads to damages in form of a high seedling mortality (Anim-Kwapong & Frimpong, 2006; Carr & Lockwood, 2011). There is little literature though assessing and quantifying the effects of irrigation on cocoa yields and other possible benefits. Therefore, recommendations on specific irrigation technologies for cocoa and their practical application are hard to find (Carr & Lockwood, 2011). Several reports on adaptation to climate change in Ghana mention irrigation technologies among other action measures as possible adaptation strategy (Anim-Kwapong & Frimpong, 2006; Stanturf et al., 2011). In the 'Manual for Cocoa Extension in Ghana' drip irrigation is recommended during the establishment phase of cocoa to prevent mortality and promote growth (CCAFS, 2018). The Ghana Cocoa Board (COCOBOD) has started an irrigation project to increase yields. The recommended irrigation technology depends on the planting pattern and on the available water resources.
shade trees	Anim-Kwapong and Frimpong (2006) emphasize the importance of promoting shade trees. Manu and Tetteh (1987) recommend to keep 16 to 18 evenly distributed and mature shade trees per hectare on a cocoa farm with cocoa trees planted on a 3x3 m spacing (Ofori-Frimpong et al., 2010). Shade trees have several benefits on cocoa farms, such as reducing extremes in soil and air temperature, reducing evapotranspiration of cocoa, increasing humidity, higher water use efficiency, improving nutrient recycling, suppressing weed growth, protecting the cocoa from heavy rainfall and harsh winds, prolonging the economic life of cocoa trees, provision of mulch, reduced need for agrochemicals (compared to full sun cocoa), income and product diversification (fruit and timber trees) and carbon storage (Beer, 1987; Carr & Lockwood, 2011; Dohmen, Noponen, Enomoto, Mensah, & Muilerman, 2018; Ofori-Frimpong et al., 2010). Blaser et al. (2018) show that a shade tree cover up to 30% does not compromise with yields while at the same time reducing the pressure from pests and diseases, decreasing diurnal temperatures, increasing aboveground carbon storage and promoting biodiversity, even though not at as much as in systems with higher shade tree cover.
fire belts	Bushfires are often occurring on an annual basis and it is expected that their occurrence will increase as a consequence of the drier and hotter climate (Appiah, Damnyag, Blay, & Pappinen, 2010; Stanturf et al., 2011). The spread of bushfires can be controlled by constructing fire belts around cocoa farms before the dry season, before burning and clearing lands or when informed of nearby fire outbreaks (Amissah, Kyereh, & Agyeman, 2010; Appiah et al., 2010). Fire belts in Ghana are typically showing a width from 2 to 3 m, but there is a lack of research about the effectiveness of these fire belts.
bookkeeping	For any kind of business, record keeping is crucial for a successful management (Muchira, 2012). Deficient economic management is often the main cause of failure in small and medium enterprises in developing countries (ibid.; Mutua, 2015). Cocoa is a cash crop and should be seen as a small-scale enterprise (Matthess, 2015). Record keeping supplies valuable information about the performance of the farm which are important for any economic decisions (Muchira, 2012). It is a useful tool for the organization and planning of the farm and the identification of possible problems (CCAFS, 2018). Farm planning is crucial to know the situation on the farm and prepare for the future, regardless of the effects of climate change (Dohmen et al., 2018). Calculating the costs and benefits give an overview of the financial situation (profitability of the farm) and is a prerequisite to get access to loans (CCAFS, 2018). Besides financial records in cocoa farming, it is also important to keep production and labor records.

mulching	Mulching is a farming practice where by definition "at least 30% of the soil surface is covered by organic material" (Erenstein, 2003, p.18). This threshold level is arbitrary, and a higher share of soil cover should be aspired. Mulch functions as both soil protection and soil amelioration (Dohmen et al., 2018; ibid.). The protective function includes preventing soil erosion, where the prevention increases with increasing soil cover. Furthermore, it enhances the aggregate stability of the soil surface, protects the soil from heavy rainfall, slows down run-off, improves infiltration and conserves water by reducing evaporative water losses. The ameliorating function includes improving soil fertility, promoting the activity of soil organisms, and reducing soil temperature extremes. Another benefit of mulching is suppression of weeds through cutting off the source of sunlight (CCAFS, 2018; Erenstein, 2003). Mulching is particularly important and beneficial during the establishment of cocoa farms, after planting the cocoa seedlings. The mulch, consisting of dry plant material or plantain pseudostems should be spread around the cocoa seedlings especially before the dry season to keep soil moisture (Carr & Lockwood, 2011; CCAFS, 2018).
Ethiopia: measures	description
irrigation	Tef is one of the most reliable crops under unpredictable climatic conditions and therefore irrigation technologies are not widely distributed and applied (Hilemicael & Alamirew, 2017). Nevertheless, moisture stress, especially during the grain filling stage, is critical and leads to significant yield losses (Tsegay et al., 2012; Yihun et al. 2013). Since water deficit in the late season stage has no significant impact on yield, a proper scheduling of irrigation could contribute to an efficient irrigation, maximizing yield in grain and biomass under insufficient water supply (Hilemicael & Alamirew, 2017). Yihun et al. (2013) observe that grain yield of tef is tree fold, the yield farmers harvest from rainfed agriculture if irrigation technologies are used. Irrigation technologies are therefore an interesting measure to enhance the resilience to drought (Joerin et al., 2018). In the case study area East Shewa Zone, irrigation technologies have been introduced for vegetables, flower, and sugarcane, but so far, the technology is not used for tef (Legesse & Suryabhagavan, 2014).
early mature varieties	Most of the smallholder farmers use traditional landraces (Ketema, 1997). Despite abundant occurrence of drought and moisture stress, tef breeding programs focus mostly on higher-yielding tef cultivars, a trait farmer are showing a high demand. In contrast, breeding activities for drought tolerance in tef are limited (Abraha, Hussein, Laing, & Assefa, 2015). Of the 33 new varieties that have been released by the National Agricultural Research System of Ethiopia (Minten et al., 2018) only a few of them have early maturing properties, namely: Tsedey (DZCr- 37) (Abraha et al., 2015), Simada (DZ-Cr-285 RIL295), and Boset (DZ-Cr-409 RIL50d). They are recommended for terminal low moisture stress areas (Minten et al., 2018). The share of formal seed supply in Ethiopia is estimated between 10 and 20% (Balemie & Singh, 2012) and poorly targeted crop breeding policies as reasons for low adoption of modern crop varieties in Ethiopia (Ahmed, Sanders, & Nell, 2000; Byerlee, Spielman, Alemu, & Gautam, 2007). For this work, the definition of Ketema (1997) applies that is classifying varieties as early maturing when they mature in less than 85 days and tolerating even less than 300mm of seasonal rainfall without distinguish early mature varieties and drought tolerant varieties.
weather forecast	Weather forecast has been disseminated for decades and in most parts of Ethiopia, but they have not been often integrated into the farmers decision-making processes yet (Kassie et al., 2013). It is the National Meteorological Agency (NMA) that produces the official weather forecast for Ethiopia. Its service is covering various different time resolutions, among them a one-to-three-day forecast, a monthly outlook, a seasonal outlook, and an agro-meteorological analysis, providing the agriculture sector with information. The dissemination of the weather forecasts is done through national television and radio on a daily basis. Moreover, they operate a website with current information (Duguma et al., 2017). Wood, Jina, Jain, Kristjanson, and DeFries (2014) report that households having access to immediate or short-run weather forecasts are more likely to have adopted farming practices, such as the use of improved varieties or fertilizer.
reduced tillage	Soils are traditionally ploughed between three and six times before sawing tef (Tulema et al., 2008). The frequency of plowing depends on soil type and climate. Most smallholder farmers use the high frequency of tillage for weed control, preparation of the fine seedbed that is required for sawing tef grains, and to improve infiltration ratios especially on heavy soils (Habtegebrial et al., 2007; Tulema et al., 2008). Habtegebrial et al. (2007) further mention that the frequency of tillage for seedbed preparation is one of the reasons for yield differences between poor and rich farmers because cost-, and labor-intensive plowing reduces weed infestation affecting yields. As a consequence of high frequency in tillage, erosion by water and wind occurs which is seen as the main factor of degradation for many parts of Ethiopia (Tulema et al., 2008). Tulema et al. (2008) and Habtegebrial et al. (2007) observe that the good results obtained with reduced tillage can be explained by a higher soil moisture content in the plough layer, an interesting fact for minimizing the adverse effects of drought.
improved harvesting	Harvesting of tef is difficult because of lodging and often it is cut manually with sickles before threshing it by trampling either with oxen or in some rare cases by using machines. The little existing mechanization for tef harvesting is mainly done by using small threshers or combine harvesters (Ketema, 1997). But seed loss is incurred because the grain is small and light and gets blown away with the chaff. Other cereal crops (e.g. wheat and barley) are more frequently harvested and threshed with machinery than tef. The machines are either imported or manufacture in Ethiopia. Woldemariam (2017) explains that the small grain of tef hinders an adaption of the existing threshers for tef harvesting. But in accordance with EIAR experts, tef could be harvested with improved technologies such as small threshers or combine harvester designed particularly for tef.

Table 4 Summary statistic for socioeconomic and -demographic variables in Ghana and Ethiopia

Ethiopia (N=275)		
variable	*M*	*SD*
age of the farmer [a]	44.6	11.9
household size [n people]	5.7	2.2
farm size [ha]	2.9	2.5
size of tef field [ha]	1.7	1.8
	frequency [n]	valid percent [%]
gender		
female	20	7.3

male	255	92.7
education		
none	95	34.5
primary school	151	54.9
secondary school	27	9.8
higher education	2	.7
land ownership		
owning	108	39.3
leasing	43	15.6
leasing out	2	.7
owning and leasing	120	43.6
owning and leasing out	2	.7
total household income [ETB $hh^{-1}a^{-1}$]		
<5000	10	3.6
5000-13333	29	10.5
13334-21666	43	15.6
21667-30000	56	20.4
>30000	137	49.8
income share of tef [%]		
0-20	6	2.2
21-40	36	13.1
41-60	109	39.6
61-80	81	29.5
81-100	43	15.6

Ghana (N=302)

variable		*M*	*SD*
age [a]		50.5	13.2
household size [n people]		8.8	6.4
total farm size [ha]		5.2	4.3
area cocoa [ha]		4.3	3.7
number farms [n]		2.1	1.5
mean age farms [a]		14.2	10.8
	categories	frequency [n]	valid percent [%]
sex	female	116	38.4
	male	186	61.6
education	none	75	25.1
	basic education	201	67.2
	secondary	17	5.7
	tertiary	6	2.0
entitlements	owning	201	66.6
	renting	53	17.5
	other	41	13.9
land allocated to cocoa	21-40	1	.3
	41-60	23	7.6
	61-80	41	13.6
	81-100	237	78.5
share of income from cocoa	0-20	4	1.3
	21-40	3	1.0
	41-60	33	11.0
	61-80	52	17.4
	81-100	207	69.2
household income	<6,500	202	70.9
	6,500-12,600	64	22.5
	12,601-18,700	6	2.1
	18,701-25,000	6	2.1
	no answer	7	2.5

Fig. 8 Visual Five-point Likert scale used for facilitating farmers to answer the surveys and avoiding translation bias by pointing to the corresponding field themselves

8.2 Supplementary results

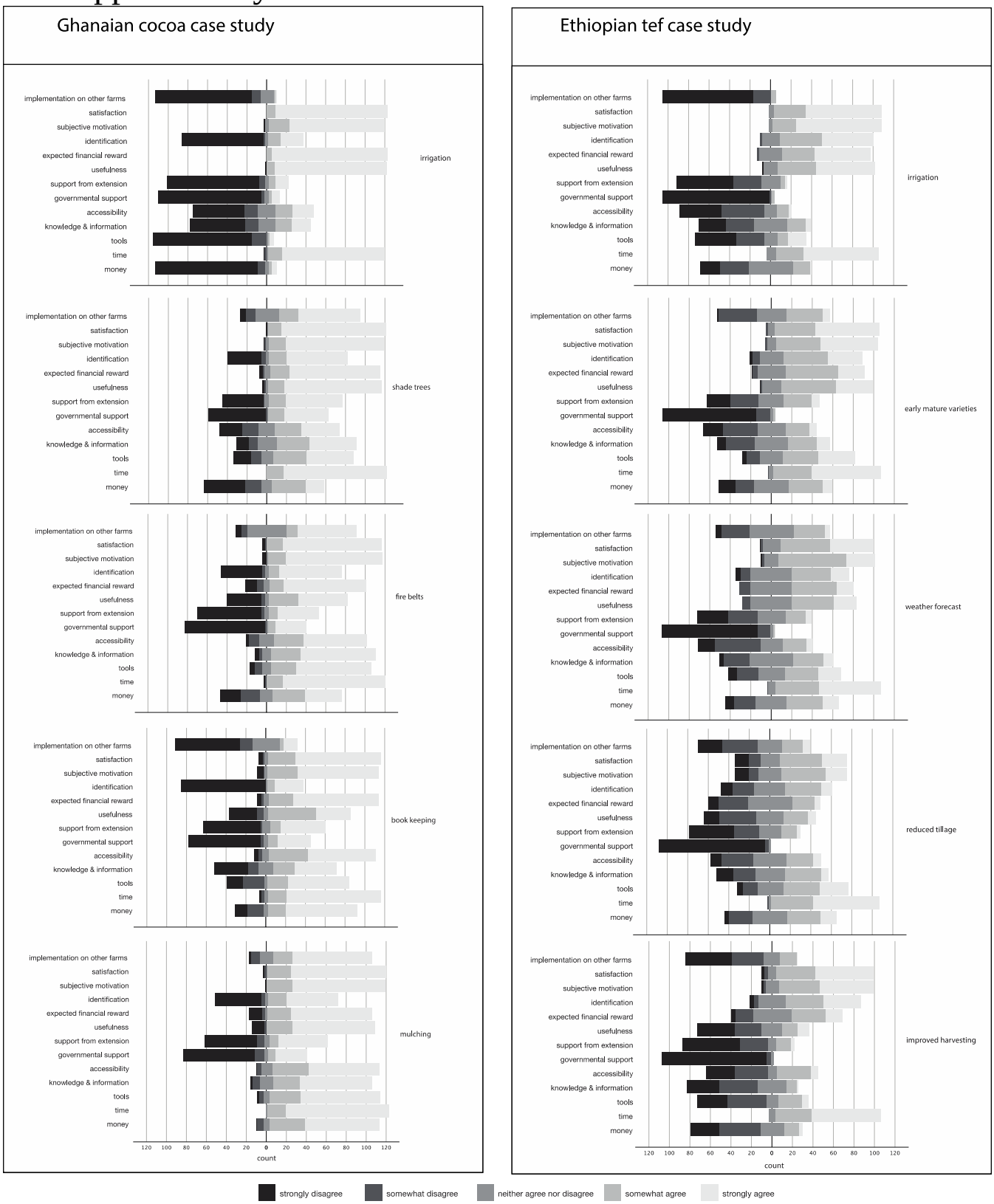

Fig. 9 Number of respondents for each indicator statement on the a five-point Likert scale from strongly disagree to strongly agree for each of the ten measures from both case studies separately

8.3 Questionnaire

Farmer_ID: Version (S_{mno}) : Date:

Assessing the perception of the viability of action measures to enhance the resilience of crop x production

I'm a Swiss agronomy student working with [...]. We would like to talk with you about your farm and learn about your experiences with droughts. We would be very grateful if you would answer us some questions and tell us your valuable opinion.
All your answers and your personality will be treated confidntially, and the results will not contain any information that can be used to identify you. However, if you agree we will write down your contact information in case some responses are unclear and also to invite you for a workshop. If you have any hesitations with regard to the interview you can contact me via email or phone [...].
Thank you very much, in advance, for your kind cooperation and patience.

Socioeconomic and Sociodemographic Questions

Age _____ [years] [age]

Household size _____ [#people] [hh_size]

Gender ☐ f ☐ m [sex]

Main form of land tenure [choose all options] [entit]
☐ Owning
☐ Renting
☐ Renting out

What level of schooling did you complete? [edu]
☐ None
☐ Primary (1.-8.)
☐ Secondary (9.-12.)
☐ Higher education
☐ no answer

Total farm size [crop x and other crops] _____ [ha] [f_size]

	0-20%	21-40%	41-60%	61-80%	81-100%	
Land allocated to crop x	☐	☐	☐	☐	☐	[crop]
Share of household income from crop x	☐	☐	☐	☐	☐	[off_inc]

Level of household income [currency/year/household]	<w	w-x	x-y	y-z	>z	no answer	
	☐	☐	☐	☐	☐	☐	[hh_inc]

Farmer_ID:

Overall questions drought/moisture stress and motivation

How was the yield compared to average years in...	very bad	somewhat bad	neither good nor bad	somewhat good	very good		
2017	☐	☐	☐	☐	☐	_____[kg]	[y_17] [kg_17]
2016	☐	☐	☐	☐	☐	_____[kg]	[y_16] [kg_16]
2015	☐	☐	☐	☐	☐	_____[kg]	[y_15] [kg_15]

Did you already experience droughts in your life?	yes ☐	no ☐		[d_exp]
If no — Did you already experience moisture stress in your life?	yes ☐	no ☐		[m_exp]

If drought or moisture stress experienced...

	strongly disagree	somewhat disagree	neither agree nor disagree	somewhat agree	strongly agree	
The damage of droughts/ moisture stress on my farm was severe in...						
2017	☐	☐	☐	☐	☐	[dd_17]
2016	☐	☐	☐	☐	☐	[dd_16]
2015	☐	☐	☐	☐	☐	[dd_15]
I manage droughts/ moisture stress in the same way as my ancestors did.	☐	☐	☐	☐	☐	[anc]
Droughts/ moisture stress make me feel helpless.	☐	☐	☐	☐	☐	[help]
I want to receive information from extension services about measures that help to minimize the adverse effects of droughts/ moisture stress.	☐	☐	☐	☐	☐	[ext]

Farmer_ID:

	strongly disagree	somewhat disagree	neither agree nor disagree	somewhat agree	strongly agree	
I'm proud of being a tef farmer.	☐	☐	☐	☐	☐	[pr]
I'm satisfied with the performance of my farm	☐	☐	☐	☐	☐	[per]
I'm regularly trying out new things (farming practices) on my farm.	☐	☐	☐	☐	☐	[adop]
The damages of droughts/ moisture stress on my farm will increase in the next 10 years.	☐	☐	☐	☐	☐	[dd_f]
If damages of droughts/ moisture stress increase, I will switch from tef to other crops or give up farming.	☐	☐	☐	☐	☐	[give]
I think droughts/ moisture stress are the most devastating shock events happening on my farm.	☐	☐	☐	☐	☐	[d_se]

The following attributes influnce drought events/ moisture stress...

	strongly disagree	somewhat disagree	neither agree nor disagree	somewhat agree	strongly agree	
government failure	☐	☐	☐	☐	☐	[gov]
climate change	☐	☐	☐	☐	☐	[cc]
will of God	☐	☐	☐	☐	☐	[god]
coincidence	☐	☐	☐	☐	☐	[coin]

[The farm measures that we will present you now, have been recommended from farmers in a workshop. The result were many different measures and now we randomly picked two of them and would like to find out what you think about them. The measures apply only for your crop x production and not for the other farming systems or the whole farm.]

Farmer_ID:

Mi

[Present and explain the Measure Mi to the farmer]

Do you use Mi on your crop x field?	yes ☐ no ☐	[imp1]
If yes	Why and since when do you implement Mi on your farm?	[why1]
	How does the implementation of Mi looks like on your farm? **Category l**: ☐ ... ☐ ... ☐ ... ☐ ... ☐ Other_____ **Category m**: ☐ ... ☐ ... ☐ ... ☐ Other _____ **Category n**: ☐ ... ☐ ... ☐ ... ☐ Other _____	[how1]
	If you have the option, how would an optimal Mi look like on your farm? **Category l**: ☐ ... ☐ ... ☐ ... ☐ ... ☐ Other_____ **Category m**: ☐ ... ☐ ... ☐ ... ☐ Other _____ **Category n**: ☐ ... ☐ ... ☐ ... ☐ Other _____	[opt_i1]
If no	Why don't you implement Mi on your farm?	[whynot1]
	If you have the option, how would an optimal Mi look like on your farm? **Category l**: ☐ ... ☐ ... ☐ ... ☐ ... ☐ Other_____ **Category m**: ☐ ... ☐ ... ☐ ... ☐ Other _____ **Category n**: ☐ ... ☐ ... ☐ ... ☐ Other _____	[opt_ni1]

Farmer_ID:

Motivation

	strongly disagree	somewhat disagree	neither agree nor disagree	somewhat agree	strongly agree	
I think an optimal Mi is useful to minimize the adverse effects of droughts.	☐	☐	☐	☐	☐	[d1_1]
I can earn more money if an optimal Mi is implemented.	☐	☐	☐	☐	☐	[d1_2]
I often recommend to other farmers to implement an optimal Mi.	☐	☐	☐	☐	☐	[d1_3]
I'm motivated to implement an optimal Mi.	☐	☐	☐	☐	☐	[d1_4]
Seeing an optimal Mi implemented gives me satisfaction.	☐	☐	☐	☐	☐	[d1_5]
Most people in my community have an optimal Mi.	☐	☐	☐	☐	☐	[d1_6]

Feasibility

	strongly disagree	somewhat disagree	neither agree nor disagree	somewhat agree	strongly agree	
I possess the money needed to implement an optimal Mi.	☐	☐	☐	☐	☐	[f1_1]
I have the time needed to implement an optimal Mi.	☐	☐	☐	☐	☐	[f1_2]
I possess all tools needed to implement an optimal Mi.	☐	☐	☐	☐	☐	[f1_3]
I have all the knowledge & information required to implement an optimal Mi.	☐	☐	☐	☐	☐	[f1_4]
I have access to all inputs & resources needed for an optimal im - plementation of Mi (e.g. water, land, energy, farming inputs). [Accessability not affordability!]	☐	☐	☐	☐	☐	[f1_5]
I receive support from government to implement an optimal Mi (e.g. seeds,fertilizer,machines,credits,...).	☐	☐	☐	☐	☐	[f1_6]
I receive information from an extension officer about an optimal Mi.	☐	☐	☐	☐	☐	[f1_7]

Farmer_ID:

Are you taking other measures to minimize the adverse effects of droughts that were not mentioned? [am]

What is your priority of these adaptation measures to minimize adverse effects of droughts?

1. Priority _____ [p_1] [high priority]
2. Priority _____ [p_2]
3. Priority _____ [p_3]
4. Priority _____ [p_4]
5. Priority _____ [p_5] [low priority]

GPS Coordinates _____ [latitude, longitude in ° ‘ ‘‘] [gps]

District _____ [reg]

Village _____ [village]

Contact data of farmer _____ [name, surname] [cont]

_____ [phone, e-mail]

Name of the interpreter _____ [name, surname] [inter]

Other notes, observations