Trans-SEC

Innovating pro-poor Strategies to safeguard Food Security using Technology and Knowledge Transfer

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Participatory on-farm/station testing, monitoring and assessing impacts of a) natural resource conservation technologies and b) food production technologies

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Content

1 Summary

This report covers the work implemented under task 5.2 for the period from June to December 2016. It describes the works performed during the named time period and key findings observed so far. Key findings for both Dodoma and Morogoro research sites are included.

The report also summarises the general conclusions, recommendations and key messages that emanated from the preliminary research findings.

2 Introduction

2.1 Background

Trans-SEC project is composed of a group of researchers and practitioners from Tanzanian and German universities and institutions working together to study the food security and agriculture in rural Tanzania. Work Package 5 of the project aims to increase resource efficiency and stabilize crop and livestock production and hence secure food supply using promising and innovative food production upgrading strategies.

Within WP5, Task 5.2 focusses on participatory on-farm/station testing, monitoring and assessing impacts of natural resource conservation technologies, and food production upgrading strategies

2.2 Aims

The general aims of WP 5 are:

- To improve current food production systems in such a manner that the production and nutritional quality of the product is increased
- To participatively test and assess the impact of promising resource- (soil & water) preserving upgrading strategies and/or innovations on-field
- To participatively test and assess promising upgrading strategies on-field that improve and sustain food productivity
- To investigate malnutrition due to low food quality and identify solutions to alleviate malnutrition

Specific aims of Task 5.2:

Specific aim for Task 5.2 was to conduct on-field participatory testing of upgrading strategies for a) soil and water conservation and b) food production, involving farmers' or community land under real life conditions on at two case study sites in the semi-arid Dodoma region, and two case study sites in sub-humid Morogoro region over 3 years

Fig. 1: Installation of the irrigation system

Fig. 3: Water application through emitters

Fig. 2: Trial in dry season 2014

Fig. 4: Nerica trial in dry season 2014

3 Methodological approach

The three selected upgrading strategies, tied-ridging, improved weeding and fertiliser micro-dosing, are implemented at different research and stakeholder involvement levels. At the Agricultural Research Institute (ARI)-Makutupora the effect of tied-ridging in combination with different weeding intensities is investigated under highly controlled conditions. In addition to the effect of the upgrading strategies the experiments aims to determine the actual water needs of the selected crops at both case-study-sites. To mimic precipitation patterns of Morogoro in the rainy season and for both case study sites in the dry season precipitation was reproduced by drip irrigation.

The two mother trials in each case link the on-station trial with the baby plots in the farmers fields. Thus, the on-station trial defines the actual water demand and the potential benefit of tied-riding, the mother trials validate the finding of the on-station trial under local conditions and the baby trials are used to access how much of the actual potential of the upgrading strategies can be achieved by farmers. This output allows determining the efficiency of the technology implementation and/or can serve to identify specific gaps in the technology transfer, adaptation and implementation by smallholder farmers in Tanzania.

3.1 On-station trial Makutupora, Dodoma Urban district, Dodoma region

3.1.1 Location

The field trials were carried out at the Agricultural Research Institute (ARI)-Makutupora (S05°58.543, E035°46.118, 1100 m.a.s.l.) which is part of the Dodoma Urban district, located in the central zone of Tanzania. Both of the field trial areas were fenced to protect the experiments from damage by livestock.

3.1.2 Experimental fields

The main field measures 1.25 hectares and comprises 320 plots (160 plots used in dry season, 160 in the rainy season). The plots measure 5.7 m x 4.0 m, covering a total area of 22.8 m². The small field was solely used in the rainy season, measures 0.355 ha and contains 48 plots of 22.8 m² each. The slope of the main field was 0.78% and of the small field 2.13%. The plots and planting rows of both fields were oriented downhill in East-West direction. Within the randomized complete block design the experimental units were arranged according to the intensity of the slope and the water pressure.

In the rainy season actual tied-ridges were set up. The furrows were 40 cm wide, measured from the original soil surface 15 cm deep and connected to each other with earthen ties in a distance of 70 cm. This way micro-catchments were formed with the aim to reduce run-off and increase infiltration. During storm events excessive water unable to infiltrate was drained off via these lower ties and were directed to drainage channels which were installed at the lower part of each plot. The seeds were sown on top of the ridges.

The soil of the main field has been classified as Rhodic Cambisol. The chemical characteristics are displayed in Table 1. The amount of organic N was analysed in 0 – 30, 30 – 60 and 60 – 90 cm depth as 0.05, 0.04 and 0.03 %, respectively. The amount of organic C in 0 – 30, 30 – 60 and 60 – 90 cm depth is 0.42, 0.29 and 0.24 % respectively.

Table 1: Chemical soil characteristics of the main field

	Na	*Ca*	*Mg*	*P*	*K*	*pH*	*Electrical conductivity*	*KAKpot*
Depth (cm)	*mmol kg^{-1}*	*mmol kg^{-1}*	*mmol kg^{-1}*	*mg kg^{-1}*	*mg kg^{-1}*		*µS*	*$mmolc^{+}$ kg^{-1}*
0-10	0.3	44.5	18.2	16.7	413.7	7.0	58.4	106.5
10-30	1.2	44.6	18.5	5.2	295.2	6.6	61.3	116.3
30-60	3.2	41.4	25.2	2.5	472.3	7.6	55.3	124.1
60-90	2.0	46.8	22.1	5.0	621.8	7.5	59.0	131.4
90-120	5.0	45.2	26.7	1.4	204.2	6.6	101.2	125.8
120-150	6.3	64.3	30.7	1.3	133.3	7.0	87.0	154.8

The field capacity was determined using the ceramic plate method. Saturated soil samples were placed on a ceramic plate and drained by creating a water column of 63 cm (corresponding to a pF-value of 1.8; 1 cm WC = 0.98 mbar roughly 1 mbar = 10^2 Pa = 1 hPa). Surplus water was channeled into a vessel. When there was no more water flowing down into the vessel, the soil reached the FC. The average FC was 28.0 % and 25.3 % for the upper 10 cm, 28.3 % for 20 cm, 28.1 % for 30 cm and 30.5 % for 30-60 cm. This resulted in an average PWP of 15.2 % and 13.7 %, 15.3 %, 15.2 %, 16.5 % for the respective soil depths. The PWP was calculated by dividing the FC by 1.85 for medium texture (Phocaides 2000) according to the bulk density of 1.38 g m^{-3}.

The available water capacity (AWC) was calculated by deducting the PWP from the FC and reached an average of 12.9 %.

3.1.3 Treatments


Fig. 5: Sunflowers under water availability as in Morogoro (left) and under full irrigation (right)

In the dry season rainfall patterns which are typical for Morogoro and Dodoma were simulated and compared to full irrigation. The average daily rainfall amount from 1980-2010 was calculated and used as basis for the irrigation amounts of "Morogoro" and "Dodoma" treatments. For the treatment "Full irrigation" the crop water requirements were met so that no water stress occurred. The water conserving effect of tied-ridging was mimicked by irrigation. The difference in the soil water content between ridging and no ridging was derived from literature (Wiyo et al. 2000).

The net irrigation amounts are displayed in table 2 for the example of sunflower. For the rainy season the precipitation amounts were added to the net irrigation. The surface run-off was calculated using the same formula as in the dry season and subtracted from the rainfall amount for the flat treatments. The same formula as in the dry season was used (Wiyo et al., 2000):

If $Ri > Rw$; $ROi = COEFF/100 * (Ri – Rw)$ and if $Ri < Rw$; $ROi = 0$

where:

COEFF = percentage of rainfall converted to surface runoff
Ri = rain (mm)
Rw = minimum amount of rainfall required to cause surface runoff

The COEFF and Rw were selected according to the prevailing soil type. For the treatments with tied-ridges it was assumed that no surface run-off occurred so the total precipitation amount was regarded as available water.

The field trials were conducted:

- Between July and November 2014 (dry season) with pearl millet (*Pennisetum glaucum* var. *okoa* (L.) R.Br.), sunflower (*Helianthus annuus* var. *record* L.), rice (*Oryza sativa* x *Oryza glaberrima* var. *NERICA 4* L.)
- Between January and May 2015 (rainy season) with pearl millet, sunflower, NERICA rice, sorghum (*Sorghum bicolor* var. *macia* (L.) Moench) and maize (*Zea mays* var. *TMV1* L.)
- and between July and November 2015 (dry season) with pearl millet, sorghum and sunflower.

- Another rainy season trial was set for Jannuary to May 2016 with pearl millet, sorghum, sunflower and maize.

Table 2: Treatments of the main trials and corresponding total water input (mm) received by the sunflower plots at Makutupora station

Dry season 2014	*Rainy season 2015*	*Dry season 2015*	*Rainy season 2016*
FI (919)	FI + CW (627)	FI (767)	FI + CW
FI + drought[a] (841)	FI + FW (627)	FI + early drought[b] (667)	-
Dodoma flat (247)	Rainfed flat + CW (171)	FI + late drought[c] (614)	Rainfed flat + CW
Dodoma flat + drought[a] (235)	Rainfed flat + FW (171)	Dodoma + TR (330)	-
Dodoma + TR (385)	Rainfed + TR + CW (252)	Dodoma + TR + early drought[b] (292)	Rainfed + TR + CW
Dodoma + TR + drought[a] (358)	Rainfed + TR + FW (252)	Dodoma + TR + late drought[c] (286)	-
Morogoro flat (274)	LSI + CW (278)	Morogoro + TR (286)	LSI + CW
Morogoro flat + drought[a] (267)	LSI + FW (278)	Morogoro + TR + early drought[b] (396)	-
Morogoro + TR (424)	LSI + TR + CW (376)	Morogoro + TR + late drought[c] (340)	LSI + TR + CW
Morogoro + TR +drought[a] (403)	LSI + TR + FW (376)	Dodoma 2040-2060 (220)	-

FI = Full irrigation, TR = Tied ridges, CW = Clean weeding, FW = farmer's weeding, LSI = Life saving irrigation, [a]: drought started 50 days after sowing and lasted 10 days, corresponding to typical drought occurrence mid of February, [b]: drought started 40 DAS and lasted until 54 DAS (for most crops during booting stage), [c]: drought started 73 DAS and lasted until 87 DAS (for most crops during flowering stage), Dodoma 2040-2060: ISI-MIP scenario with decreased rainfall amount (climate model rcp4.5 GFDL for period 2040-2060).

In addition, drought events were simulated in order to analyse the physiological responses of the crops to water stress (Tab. 2).

In the rainy season basic water treatments were rainfed, life saving irrigation (when crop is starting to wilt it gets 50 % of full irrigation) and full irrigation which were combined with tied-ridges and different weeding frequencies. Hereby, actual tied ridges have been set up.

The weeding treatments comprised clean weeding (4-5 times weeding) and farmer's weeding (once after emergence and once after canopy closure). Crops were planted on the main field and another field (0.355 hectares with 48 plots each with an area of 22.8 m²). The smaller field was necessary in order to include maize into the study which is not allowed to be planted on the main field because of a neighbouring maize trial.

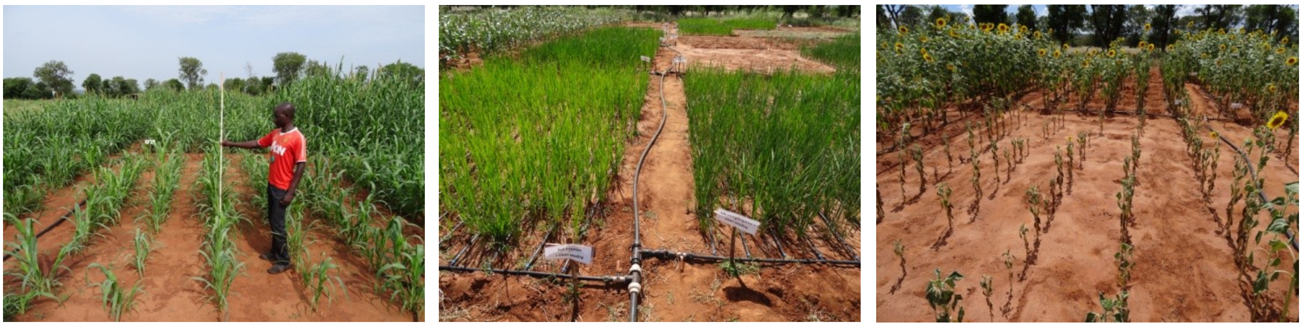

Fig. 6: Trial in the rainy season 2015 on the main field

Fig. 7: Trial in the rainy season 2015 on the small field

3.1.3.1Agronomic practices

The fields were mechanically ploughed by tractor about three weeks before sowing using a disc plough to 15 cm depth. Afterwards, manual hoeing and levelling was carried out. Sowing was done manually. Plants were spaced at 30 cm distance within the row and 80 cm between the rows with respect to sorghum, pearl millet, maize and sunflower. Seedlings were thinned to one plant per hill 2-3 weeks after sowing (3-4 leaves). Rice was sown at 30.0 cm x 12.5 cm distance and its seedlings were thinned to two plants per hill.

All plots received 60 kg N ha^{-1}, 30 kg P_2O_5 ha^{-1}, 30 kg K_2O ha^{-1} via Yara Mila complex fertiliser (23-10-5), potassium nitrate (13-0-46), triple super phosphate (0-44.5-0) and urea (46-0-0) application. Yara Mila, potassium nitrate and TSP were added into each hole at sowing (basal dressing). Urea was broadcast 4 - 6 weeks after emergence (top dressing).

3.1.3.2Irrigation system

A drip irrigation system was installed for conducting the in-depth water intensity study. The water source was a borehole from which the water was pumped every morning into tanks, located next to the experimental field. These tanks were connected to the drip irrigation system.

Drip lines had been set up along each crop row for the irrigated treatments (distance between emitters: 30 cm, flow rate/dripper: 1.0 l hr^{-1}, inlet pressure: 1.6 bar, 16 mm diameter). Consequently, one emitter was placed at each individual plant. Regarding rice, the drip lines were installed between alternate rows so one emitter supplied water to two hills. The irrigation time and hence the water supply for each plot was controlled via ball valves at each plot. A water pump ensured the required pressure for the water distribution within the system. Pressure increase after reducing the number of irrigated plots (by closing their valves) was avoided through a central pressure regulating valve. Between the pump and the regulating valve an obligatory filter was installed (filter disc).

3.1.4 Data collection

3.1.4.1 Weather data

Climate data from the Dodoma airport from 1980 to 2010 was used for the calculation of ETo and served as basis for creating the irrigation schedule. No long-term dataset of climatic data from the ARI-Station was available. In December 2014 a WS-GP1 weather station (DELTA-T) was installed at the centre of the main field which measures rainfall, temperature, solar radiation, wind speed and direction. For the previous trials weather data has been obtained from Dodoma airport, from another ARI-Makutupora weather station and from TinyTag data loggers.

3.1.4.2 Soil data

Three soil moisture access tubes per treatment were installed in order to analyze the soil moisture status in relation to the different water inputs. The soil moisture was measured every 3-4 days. Hereby, a mobile PR2 Profile Probe (tubes and FDR sensor from DELTA-T) was used for readings in 10 cm, 20 cm, 30 cm and 40 cm depth and a SM300 (TDR sensor from DELTA-T) for surface soil moisture (up to 5 cm depth). Furthermore, an additional PR2 Profile Probe sensor was installed for iterative measurements close to the weather station. In order to achieve exact results the PR2 and the SM300 were calibrated according to the prevailing soil type. A set of tubes were inserted at the centre of the main field. At different soil moisture conditions soil samples were taken in the respective depths. Soil moisture content was determined using the gravimetric method and its results plotted against the readings of the PR2 and the SM300 sensors. The obtained functions were used to adjust the readings which were recorded during the data collection.

3.1.4.3Plant data

Non-destructive and destructive methods were applied for analysing the crop responses to the different water inputs. Biomass production was documented via frequent measurements (every 7-10 days) of plant growth parameters (height, diameter, number of leaves, tillers, circumference of the stem). The plant leaf area was measured using the LAI2000 device (Li-Cor). In addition, destructive biomass sampling has been carried out (at panicle initiation and flowering). For this purpose individual plants were harvested and their organs (leaves, stem, reproductive organs) scanned using a flatbed scanner in order to detect the specific areas of the organs. This also served to obtain reference values for the measurements with the LAI2000. Afterwards, the samples were oven dried and weighed for determination of the biomass partitioning. The phenological development of the plants has been documented and recorded based on the scale of the BBCH (Biologische Bundesanstalt, Bundessortenamt and Chemische Industrie) coding. Grain yield, harvest index and thousand grain weight has been determined at the end of each trial.

3.1.5 Preliminary results

The sowing date in the dry season 2014 for the "Dodoma" and "Morogoro" treatments was December 29th. The simulation of the rainfall patterns for Dodoma and Morogoro neglected heavy rainfall events and drought periods. Therefore, nearly every day the plants received water. This resulted in yields in the magnitude of 100 g m^{-2} for NERICA rice in the "Dodoma flat" treatment (Tab. 10).

Table 3: Yields of the main field after trial in the dry season 2014

	Millet (g m^{-2})		*Sunflower (g m^{-2})*		*NERICA 4 rice (g m^{-2})*	
Treatments	*No drought*	*Drought[a]*	*No drought*	*Drought[a]*	*No drought*	*Drought[a]*
Full irrigation	364	355	358	349	373	269
Dodoma flat	152	97	94	94	93	32
Dodoma + TR	166	172	164	155	217	216
Morogoro flat	119	100	123	116	144	156
Morogoro + TR	183	174	191	203	245	250

Flat: run-off is deducted from rainfall, TR = Tied ridges (no run-off), [a]: drought started 50 days after sowing and lasted 10 days, corresponding to typical drought occurrence mid of February. According to recommendations by FAO (2006), the yield data refers to grain moisture contents of 13 % in the case of cereals and 10 % in case of sunflower.

The sowing date in the dry season 2015 for the "Dodoma" and "Morogoro" treatments was January 15th, which led to a reduction of the total amount of applied water compared to the dry season 2014. It is questionable whether this alone can explain the striking yield reduction of pearl millet and sunflower compared to the dry season 2014. For further explanation of the results (Tab. 4) the estimations of the damage caused by birds must be taken into account. Even though precautions have been taken (people were hired to scare the birds with noisy tin cans attached to reflecting tape running through the experimental fields) the bird damage exceeded even that of the previous seasons.

Table 4: Yields of the main field after trial in the dry season 2015

	Millet (g m^{-2})			*Sunflower (g m^{-2})*			*Sorghum (g m^{-2})*		
Treatments	*drought*								
	No	*Early[a]*	*Late[b]*	*No*	*Early[a]*	*Late[b]*	*No*	*Early[a]*	*Late[b]*
Full irrigation	319	195	318	180	168	112	506	429	403
Dodoma + TR	99	138	130	96	95	77	306	234	251
Morogoro + TR	79	60	110	192	120	44	320	287	288

a: drought started 40 DAS and lasted until 54 DAS (for most crops during booting stage), b: drought started 73 DAS and lasted until 87 DAS (for most crops during flowering stage)

During the rainy season 2015 from December 2014 until May 2015 a total precipitation of 375.8 mm was measured in ARI-Makutupora. With reference to the period between sowing and harvest (January 5th until end of April/beginning of May) the rainfall was about 328.8 mm (Tab. 5). Several intermediate drought periods were recorded (e.g. 10 consecutive days in February, 16 days in March and 16 days in April). The rainfall quantity during the growing season 2015 was quite poor compared to the long-term precipitation data.

Table 5: Summary of long term (1980-2010) average rainfall at Dodoma airport and the rainfall pattern for the growing seasons 2015 and 2016 in Makutupora

Month	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Season*
Mean rainfall from 1980-2010 (mm)	136.4	120.2	116.9	51.2	4.7	429.4
Mean rainfall of growing period 2015 (mm)	111.8	201.8	27.0	85.8	1.4	328.8
Mean rainfall of growing period 2016 (mm)	333.6	169.8	42.2	Currently ongoing	Currently ongoing	

The rainfed plots with tied ridges coped better with the low rainfall amount and poor distribution compared to the rainfed treatments on flat plots. The tied-ridges seemed to be advantageous to reduce the surface run-off after erratic rainfall events and to improve the infiltration of large rainfall amounts (precipitation amount ≥ 30 mm day^{-1}: 3 times within growing season; precipitation amount ≥ 20 mm day^{-1}: 4 times within growing season). Soil moisture measurements up to 40 cm depth have been conducted in order to investigate this effect.

For all crops higher yields have been achieved for the treatment “Rainfed+TR+clean weeding” vs. “Rainfed flat + clean weeding”. This is especially striking for Sorghum (52 g m^{-2} vs. 10 g m^{-2} on the main field and 121 g m^{-2} vs. 16 g m^{-2} on the small field) and Maize (69 g m^{-2} vs. 4 g ha^{-2}) (Tab. 6, Tab. 7).

The rainfed treatments of NERICA 4 rice performed poorly during this rainy season in Dodoma. The emergence for the rainfed plots was ≤ 10 % and most plants which were able to emerge died during one of the dry spells (Tab. 6). The yield for fully irrigated plots was lower compared to the dry season 2014 which is due to severe attack of pests especially stalk borer.

The damage by birds was greater than in the dry season 2014. They feed especially on millet and secondly sunflower. The loss due to birds was lower in fully irrigated plots compared to rainfed plots.

Table 6: Yields of the main field after trial in the rainy season 2015

	Millet (g m^{-2})		*Sunflower (g m^{-2})*		*Sorghum (g m^{-2})*		*NERICA 4 rice (g m^{-2})*	
	weeding							
Treatments	*Clean*	*Farmer’s*	*Clean*	*Farmer’s*	*Clean*	*Farmer’s*	*Clean*	*Farmer’s*
Full irrigation	446	342	290	325	324	324	302	181
Rainfed flat	5	4	0	2	10	017	0	0
Rainfed + TR	75	79	12	3	52	51	0	0
LSI	80	129	58	50	129	82	107	59
LSI+TR	226	164	76	100	179	166	63	37

Table 7: Yields of the small field after trial in the rainy season 2015

	Millet (kg m^{-2})		*Sunflower (kg m^{-2})*		*Sorghum (kg m^{-2})*	
Treatments	*weeding*					
	Clean	*Farmer’s*	*Clean*	*Farmer’s*	*Clean*	*Farmer’s*
Rainfed flat	0.003	0.001	0.016	0.007	0.004	0.002
Rainfed + TR	0.047	0.049	0.121	0.185	0.069	0.086

3.1.5.1Delays and difficulties

A major difficulty was to gather all the materials which were required for establishing a drip irrigation system. Therefore, the start of the main trial was delayed by six months (in the dry season 2014 instead as planned in the rainy season 2014).

Another big difficulty throughout all trials has been the occurrence of pests and diseases.

Initially we applied pesticides at the first sight of occurrence but that often proved to be too late so we tried prophylactic spraying based on our experiences from the previous trials. This helped a little, but notorious pests such as the stalk borer still appeared. Further problems were caused by rabbits and rats. A common disease especially for sunflower was leaf blight.

In the rainy season 2015 birds have caused a lot of destruction in millet and sunflower. Scaring the was not enough and the damage remained very high. We assume that the birds got used to the fact that food is available on the main field throughout the year and even in the dry season, so that they became very persistent.

The repeated power cuts have been a big challenge for processing the data especially in the dry season 2015. The lack of electricity caused also a delay in the oven drying of the biomass samples since there is only one oven for the station and this has to serve several researchers.

The emergence of the seedlings was poor in the rainfed treatments in the rainy season, probably due to insufficient and erratic precipitation.

3.1.5.2Work still planned

A rainy season trial is currently ongoing. After harvest, samples need to be oven-dried and weighed and thousand grain weight and yield determined (finished probably July 2016). Data compilation of the previous trials is carried out at the moment so that in depth statistical analysis of the data can be started very shortly.

3.1.6 Preliminary conclusions

Data analysis is currently ongoing. Regarding the yield, certain trends can already be identified though. For the case of upland rice, no grain yield could be achieved for the flat treatments and for the treatments with tied-ridges under rainfed conditions. Therefore, upland rice as an alternative to the more commonly used crops such as sorghum, maize, sunflower and pearl millet cannot be recommended under rainfed conditions for Dodoma, based on the data obtained from this study. For the interpretation of the results it needs to be taken into account that the rainfall amount within the rainy season 2015 was exceptionally low and poorly distributed. However, the other crops under investigation showed that they coped better with the prevailing natural conditions. An increase in yield was achieved for the plots with tied-ridges in comparison to the flat ones. This applied to all crops on both on-station fields except rice.

The drought events caused shifts in the onset of the growth stages compared to the corresponding treatments without drought. The effect of the timing of these droughts and the amount of the water input on the phenology will be examined in depth. Beyond that, the impact of changing water inputs, soil water availabilities and climatic factors on biomass production and partitioning, yield determining processes, harvest index and grain yield will be analysed.

3.2 Mother trials at Ilolo and Idifu, Chamwino district, Dodoma region

3.2.1 Location

Mother trials in Dodoma region were conducted at Ilolo and Idifu villages in Chamwino district. The trials at Idifu village were located at 6°24'698S and 35°58'641E while at Ilolo the trials were located at 60°20'776S and 35°54'263E. The land slope and altitude of the Idifu trials were about 2.2 % and 1006 m.a.s.l, respectively where as for the Ilolo trials the land slope and altitude were 3.7% and 1078 m.a.s.l, respectively. The food and cash crops grown in both villages are pearl millet, groundnuts, sunflower and sorghum in some parts as well as sesame. The main activities that most people depend on for income generation in both villages are crop production, livestock keeping and businesses such as small shops for selling homestead commodities. Crop production activities are much affected by dry spells during the rainy seasons as farmer totally depend on rainfall while livestock keeping is affected in the succeeding dry season due to shortage of water and animal feed.

3.2.2 Treatments

Three factors were tested in one of the mother trials: fertiliser dosage at three levels (0, 25 and 100 % of the recommended rates), water management practices (infiltration pits, tied-ridges and flat cultivation) as well as cropping systems (intercropping and mono cropping of pearl millet and sunflower). For improved sunflower mother trial, two factors were tested namely water management practices (flat and tied-ridges) and fertiliser dosage (0 %, 25 % and 100 % of the recommended rate). Fertiliser materials used were DAP containing 46 % P_2O_5 and 18 %N (basal fertiliser) and Urea of 46 % N for top dressing.

3.2.3 Experimental fields

The type of experiment used in the three factor trial was split-split plot experiment in randomised complete block design. It was a 3x3x3x5 trial, which makes a total of 135 plots. The improved sunflower trial was split plot experiment in a randomised complete block design, being a 2x3x5 trial making a total of 30 plots. The spacing used for both pearl millet and sunflower were 0.8 m row spacing by 0.3 m plant spacing. Each plot contained five rows and 18 plants per row, hence making a plot of 21.6 m^2 (giving a plant population of 41,600 plants/ha.

3.2.4 Data collection

3.2.4.1 Weather data

Precipitation data were recorded in mm using rain gauges installed at each trial site for 2014/2015 and 2015/2016 cropping season. For the daily gauge readings farmers were trained.

3.2.4.2 Soil data

Soil samples were taken and analysed for soil physical and chemical characteristics. The characteristics analysed included soil texture, soil moisture, soil pH, soil water content, total N %, extractable P (mg kg^{-1}) and exchangeable K^+ (cmolc kg^{-1}).

3.2.4.3 Plant data

Plant data collected were categorised into three groups. The first group was crop phenological data, which included days to reach major growth stages (i.e. 50 % crop emergence, 50 % crop flowering, 50 % crop maturity). The second group was crop growth data including leaf length, width and number of leaves per plant (for leaf area and leaf area index determination), plant height, plant tissue analysis and total dry matter at growth stage 2 (5^{th} leaf stage), stage 6 (50 % flowering stage) and stage 9 (physiological maturity). The third group of plant data recorded were crop yield variables and crop grain yield such as of number of reproductive tillers per plant, panicle length (cm) and the grain yield per plant (g $plant^{-1}$) and per unit area (g m^{-2}).

3.2.5 Preliminary results

In 2014/2015 cropping season the rainfall started rather unusually late resulting in erratic dry spells within the vegetative period, which impacted crop growth for the Dodoma sites. Despite the prolonged and repeatedly occurring dry spells throughout the growing season, the performance of the mother trial at Ilolo was comparatively good. The crops at the Idifu site suffered not only from the erratic distribution, but also from the fact that the total precipitation during the cropping season was only 100.7 mm from January to May, 2015, which was 71 mm less than the rainfall recorded at Ilolo village.

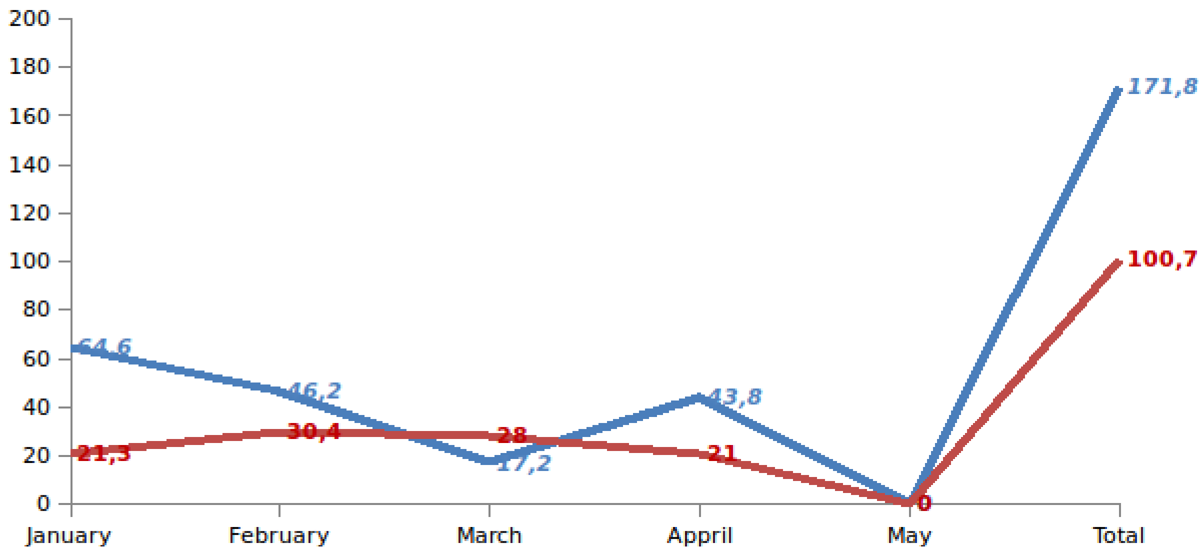

Fig. 8: Ammount of rainfall received per month and total ammount received per site

The soil particle size distribution in the experimental plots was 38 % clay, 25 %, silt 37 % and therefore named clay loam soil with pH of 6.27 for Ilolo site, while for Idifu the distribution was 52 % clay 17 %, silt 31 % sand hence named clay soil with pH of 5.56. In both sites, total nitrogen in the soil was very low at 0.05 and 0.06 % for Ilolo and Idifu respectively. Therefore practices for replenishment of soil nitrogen in these areas are very important.

There is a significant difference at $p<0.05$ on soil moisture when different moisture management practices are used. Tied-ridges and infiltration pits increase soil moisture (% vol) up 10 % and 38 % respectively with reference to flat cultivation which is the normal farmers practice and this makes the infiltration pits to be the best water management

Fig. 9: Sesame infested with pests, unreliable weather condition affecting sesame crop growth

practice among tested methods.

It was also observed that, the soil moisture increases as soil depth increases from 0 to 30 cm. Soil moisture under tied ridges were 13, 16 and 15 %vol from 0 to 10 cm, 10 to 20 and 20 to 30 cm soil depth respectively, while under infiltration pit the soil moisture were 15 %vol at 0 to 10 cm, 18 %vol at 10 to 20 cm and 20 %vol at 20 to 30 cm depth, respectively.

Pearl millet yield increased from 23 g m^{-2} to 130 g m^{-2} when grown as a sole crop with tied-ridges and fertiliser micro-dosing compared to control (flat cultivation without fertiliser). It was also observed that when pearl millet was inter-cropped on ridges with groundnut and fertiliser micro-dosing the yield improved from 23 to 155 g m^{-2}. Furthermore, inter-cropping of pearl millet with groundnut on infiltration pits with fertiliser micro-dosages can further improve the millet yield from 23 to 224 kg m^{-2}.

These results imply that yields differed significantly ($p<5\%$) when pearl millet was grown under different moisture management practices where flat cultivation gave the lowest yield of 66 g m^{-2}. The infiltration pit gives the highest yield of 150 g m^{-2}. Yield difference is attributed to the ability of infiltration pits to conserve soil moisture more compared to tied ridges and flat cultivation. Amount of moisture stored or water standing between ridges are much subjected to evaporation compared to the moisture stored into infiltration pits especially at earlier growth stages of a crop when the crop canopy is small and hence the soil is less covered by the plant canopy.

The effect of tied-ridges and fertiliser micro-dosing on the groundnut yield was insignificant, with a yield increase from 57 to 71 g m^{-2} due to tied-ridges and fertiliser micro-dosage application.

The yield of sunflower was increased from 63 g m^{-2} (farmer practice) to 142 kg m^{-2} by the implementation of tied-ridges and fertiliser micro-dosing.

The following delays and difficulties were encountered:

- Unpredictable on set of rainfall for proper planting time,
- Low rainfall amount and poor distribution in both trials sites which leads to crop failure in Idifu village,
- Tedious work, time consuming and high costs for preparation of infiltration pits.

Work still planned:

- Data analysis and interpretation for 2014/2015 growing season.
- Data collection and management for 2015/2016 growing season.

3.2.6 Preliminary conclusions

Pearl millet yield in areas with semi arid characteristics similar to Chamwino district in Dodoma can be improved by integration of water management technologies like the use of tied-ridges and infiltration pits in combination with micro-dose fertiliser application.

Pearl millet yield can increase by 130 g m^{-2} when tied ridges are used with micro dose fertiliser rate, yield can be further increased by 200 g m^{-2} when infiltration pits are integrated with fertiliser micro-dosages. However, the tediousness of implementing or preparation of ridges and pits by resource poor farmers can limit the rate of adoption of these technologies by farmer's communities located in drought prone areas.

Hence further research is needed on how to minimize the labour input for making infiltration pits and tied ridges for assured small holder farmers adoption and upscaling of the strategies.

3.3 Mother trials at Ilakala and Changarawe, Kilosa district, Morogoro region

The soil texture at Ilakala (7°8'7S 36°55'12E, 599 m.a.s.l.) was sand loamy with a soil pH of 6.5 and a total nitrogen content of 0.05 %, phosphorus 10.2 – 19 mg/kg of soil, and organic carbon 2.0 – 2.1 %. The slope of the terrain where the mother trial was established was 9.7 %.

In Changarawe (6°54'55S 36°57'11E, 504 m.a.s.l.) the soil texture was sandy loam with a pH of 5.5 and a total nitrogen content of 0.03 %, phosphorus 2.7 - 2.86 mg/kg of soil, and organic carbon 0.8 - 0.9 %. With 11.5 % the slope was steeper than in Ilakala.

The food and cash crops grown in both Ilakala and Changarawe villages are maize, pigeonpea, sesame, sunflower, sweet potato, beans, cowpea, rice especially in Changarawe and sorghum especially in Ilakala. The main activities in both villages are crop production, animal keeping and small shops for income generation.

3.3.1 Treatments

The main plots consist of three soil moisture management treatments (tied-ridges, open ridges and flat cultivation (control)), the sub-plots of three cropping pattern (maize [var. TMV-1] sole cropping, pigeonpea [var. babati white] sole cropping and maize-pigeonpea inter-cropping) and the sub-sub plots of three fertiliser rates (no fertiliser, fertiliser micro-dose at 25 % recommended and recommended rate). All treatments have five replications.

Fig. 10: Fertilizer micro-dose rates (12.5 %, 25.0 %, 50.0 %, 75.0 %, 100.0 % of recommended 80 kg N ha^{-1} and 40 kg P ha^{-1} for maize) per hole, fertiliser response curve plots during preparation in January 2016

3.3.2 Experimental fields

A split-split plot design was used for the maize-pigeonpea intercropping experiment with 3x3x3=27 plots per replication and total of five replications per case study site. Each plot measured 5 m x 4 m covering 20m².

3.3.3 Data collection

3.3.3.1 Weather data

Rainfall data were recorded using a manual rain gauge installed in the field during 2014/15 and 2015/16 cropping seasons.

3.3.3.2 Soil data

Soil physical properties such as particle size distribution and textural class were determined. Also, chemical properties such as soil pH and total nitrogen (%) were determined in soil laboratory at SUA.

3.3.3.3 Plant data

The plant density at emergence/ seedling stage, soil moisture (%), tissue analysis for nutrient concentration and uptake still going on in SUA Laboratory, plant height, stem girth at vegetative (V6-8) and reproductive (R1), leaf area and leaf area index at vegetative and reproductive, photosynthetically active radiation (PAR) at reproductive stage (R1-3). Also, yield components such as number of seeds and seed size were collected and finally the grain yield data was collected as proposed by CIMMYT (2013) guideline for yield and yield components.

3.3.4 Preliminary results

The rainfall trends in the study site in 2015 continued to be erratic with different start dates for Ilakala and Changarawe. In Ilakala village, rainfall started on 12th January but there was a dry spell of two weeks in February while in Changarawe rainfall started effectively on 1st March and stopped in late May.

Rainfall results for 2014/15 and 2015/16 cropping seasons are presented in Figure 9. At Ilakala, a total amount of rainfall in 2014/15 cropping season was 496 mm while in 2015/16 was 805 mm. There was inter- as well as intra- seasonal variations in rainfall amount. Distribution was not evenly during both cropping seasons. In 2015, there were no rains which coincided with seedling and sixth leaf growth stages while at boot and tasseling there was high rainfall (7 – 9 weeks after planting). From silking (11 week after planting) to dough stage (13 week after planting) there was moderately amount of rainfall (30 – 50 mm) and well distributed rainfall pattern. In 2016, rainfall increased from 25 mm to 110 mm at emergency and fourth leaf stages respectively and decreased to 35 mm at boot and tasseling stage (7 to 9 weeks after planting).

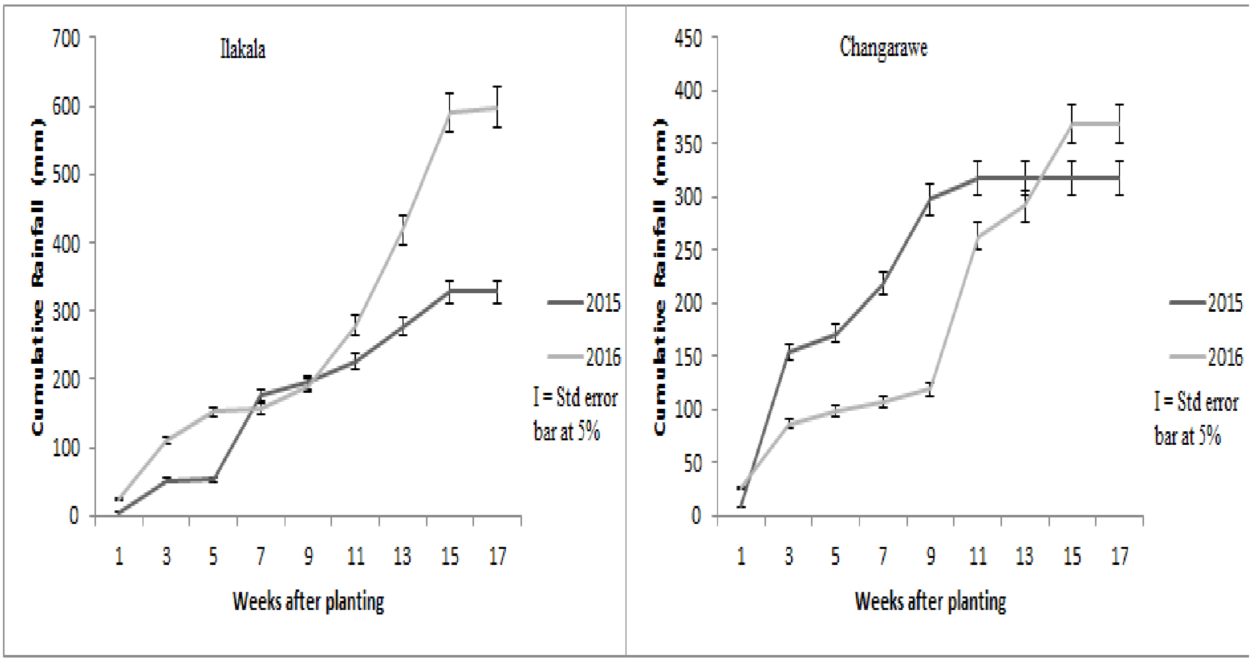

Fig. 11: Rainfall during main season after planting maize crop in 2015 and 2016

In Changarawe, in 2016, the amount of rainfall increased from sowing to third week after planting (27 to 86 mm) and decreased rapidly to about 10 mm between sixth leaf and silking stage (5th and 9th weeks after planting).

Tied-ridges were the best in soil moisture conservation (tied-ridges: 22 % and 24 %; flat: 18 and 21 %) in both sites Ilakala and Changarawe respectively. Tied-ridges conserves 20 % in Ilakala and 12 % in Changarawe more soil moisture than in flat cultivation, this was observed at vegetative crop growth stages.

The maize yield in plots with tied-ridges with micro-dose fertiliser at 25 % of recommended rate was 243 g m^{-2} and 230 g m^{-2}; flat cultivation without fertiliser as farmers' practices was 96 g m^{-2} and 100 g m^{-2} in Ilakala and Changarawe sites respectively. The increase in maize yield with tied ridges and micro-dose fertiliser from farmers' practices is 147 g m^{-2} in Ilakala and 129 g m^{-2} in Changarawe.

Fig. 12: Maize crop attasseling/silking stage, data collection in fertilizer trial and Effect of fertilizer micro-dosing and tied ridges on maize pigeonpea intercropping at vegetative stage

Following delays and difficulties were encountered:

- Pigeonpea Babati White variety chosen is long maturing taking 9 months and is still in the field at mid-pod and late-pod formation stages;
- Also unreliable rainfall/ drought is a serious challenge in rain-fed farming Kilosa;
- Sesame is very sensitive to weather conditions and pests/diseases. Therefore, it is important to plant sesame between November and January and not later;
- Pest and disease especially vermin in maize.
- Data management and analysis.

Work still planned:

- Harvesting maize in mid May to June 2016.
- Management of pigeonpea in the field until harvest in September/ October 2016.

3.3.5 Preliminary conclusions

For Kilosa case study site, Morogoro tied-ridges harvest rainwater in the field and have ability to conserve soil moisture for a short period of time up to two weeks. Fertiliser micro-dosing and tied ridging increase crop production more than twice compared with flat cultivation without fertiliser application in sub-humid areas like Kilosa.

3.4 Fertiliser response curve trials at Ilakala and Changarawe, Kilosa district, Morogoro region

3.4.1 Treatments

3 fertiliser types as main plots namely diammonium phosphate (DAP), triple super phosphate (TSP) and Minjingu Mazao (MM); rates of fertilisers as nitrogen and phosphorus (NP) from 0, 12.5, 25, 50, 75 and 100% of recommended 80 kg N ha^{-1} and 40 kg P ha^{-1} in maize crop Morogoro (Marandu et al., 2014). DAP $(NH_4)2HPO_4$) a granulated solid fertiliser contains 18 % N and 46 % P_2O_5. MM containing 10 % N and 20 % P_2O_5, 25 % CaO, 5 % S, 1.5 % MgO, 0.5 % Zn and 0.1 % B. TSP contains 46 % P_2O_5. These fertilisers were applied at sowing while urea containing 46 % N was applied at vegetative crop growth stage (V-4). The test crop was maize variety TMV-1.

3.4.2 Experimental fields

Split-plot design with three fertilisers types and six fertiliser rates per replication. Five replication were established per site. Each plot measured 6 m x 3 m covering 18 m².

3.4.3 Data collection

3.4.3.1Weather data

Rainfall data were collected using rain gauge installed in the field.

3.4.3.2Soil data

Physical properties such as soil texture were determined, soil chemical properties such as pH, organic carbon and total nitrogen were determined in Soil Science Laboratory at SUA.

3.4.3.3Plant data

Plant density at emergence/seedling stage, soil moisture (%), tissue analysis for nutrient concentration and uptake still going on in SUA Laboratory, plant height, stem girth at vegetative (V6-8) and reproductive (R1), leaf area and leaf area index at vegetative and reproductive, photosynthetically active radiation (PAR) at reproductive stage (R1-3). Also, yield components such as number of seeds and seed size were collected and finally the grain yield data was collected as proposed by CIMMYT (2013) guideline for yield and yield components.

3.4.4 Preliminary results

The maximum LAI attained at silking growth stage (R1) was 4.1 followed by 3.99 and 3.75

from MM 6 (80 kg N and 40 kg P/ha), DAP 4 (40 kg N and 20 kg P/ha) and DAP 5 (60 kg N and 30 kg P/ha) respectively. Phosphatic fertilizer produced grain yield of 2173 kg/ha DAP, 2317 kg/ha MM and 2115 kg/ha TSP. The highest grain yield was 3910 kg/ha followed by 3573 kg/ha and 3543 kg/ha from MM4 (40 kg N and 20 kg P/ha), TSP6 (80 kg N and 40 kg P/ha) and MM5 (60 kg N and 30 kg P/ha) respectively. A combination of fertilizer rates of 10 kg N and 5 kg P ha-1 (12.5 %) as well as 20 kg N and 10 kg P ha-1 (25 %) micro-doses doubled the yield from 1012 kg/ha in control to 1928 kg/ha and 2394 kg/ha, suggesting that these would be micro-dose rates for maize production in Morogoro and other areas with similar conditions.

3.4.4.1Preliminary conclusion

Fertiliser micro-dosing is increasing crop yield more than twice than no fertiliser use. Fertiliser micro-dosing rate at 25 % of recommended nitrogen and phosphorus is the best and economical than recommended rate to smallholder resource poor farmers. However, synthetic fertilisers like diammonium phosphate (DAP), triple super phosphate (TSP), Minjingu Mazao (MM) and urea require sufficient moisture for absorption and uptake of nutrients by plants.

Micro-dose rate can be used as an entry point to promote adoption of fertilizer due to low investment risk relative to agronomic recommended rate and more benefit than the farmer practice of unfertilized control. Also, a combination of 40 kg N and 20 kg P ha-1 (50 %) as well as 60 kg N and 30 kg P ha-1 (75 %) produced an average grain yield of 2629 and 2647 kg/ha more than recommended rate (80 kg N and 40 kg P ha-1) which produced 2601 kg/ha. These rates are recommended for resource endowed farmers who can afford higher application rates.

3.5 Baby trials at Ilolo and Idifu, Chamwino district, Dodoma region

These trials were conducted at the farmer's field where farmers select the upgrading strategies of their interest to test in their field under their management. The crops involved in the baby plot trials were pearl millet, sunflower and groundnut, these crops were tested under different water management practices (including tied-ridges, infiltration pits and flat cultivation) and fertilizer rates including micro dose fertiliser application. The size of tied-ridges used was 60 cm width and 20 cm height while size of pits was of 40 cm diameter by 40 cm depth. Amount of fertiliser used in baby plot for pearl millet were 60 kg N ha^{-1} and 30 kg P_2O_5 ha^{-1} for recommended amount (100 %) and 15 kg N ha^{-1} and 7.5 kg P_2O_5 ha^{-1} for micro dose rates (25 %) while for sunflower the rate used where 30 kg N ha^{-1} and 10 kg

P_2O_5 ha^{-1} for recommended rate (100 %) and 7.5 kg N ha^{-1} and 2.5 kg P_2O_5 ha^{-1} for micro dose rate (25 %).

Table 8: Yield achieved in the 2014/2015 cropping season by different upgrading strategy combinations at Idifu

Technology used	*plots*	*Pearl millet yield (g m^{-2})*	*Groundnut yield (g m^{-2})*	*Sunflower yield (g m^{-2})*
PM+PT+F1	5	82		
PM+FT+F2	3	63		
PM+TR+F0	3	74		
PM+TR+F1	5	99		
PM+TR+F2	3	124		
IT+FT+F1	2	26	30	
IT+FT+F0	1	28	21	
IT+TR+F0	2	34	23	
IT+TR+F1	3	63	21	
IT+TR+F2	3	134	26	
SF+TR+F1	5			64
SF+TR+F2	2			117
SF+FT+F2	2			24
SF+FT+FO	2			26
SF+FT+F1	1			36
G+FT+F1	1		46	
G+TR+F0	1		28	
G+TR+F1	1		88	
Total / Avg	**45**	**73**	**35**	**53**

PM = Pearl millet, SF = Sunflower, G = Groundnut, FT = Flat cultivation, TR = Tied ridges, PT = Infiltration pits, FO = Zero fertiliser application, F1 = Micro-dose rate (25%), F2 = Recommended rate (100%)

3.5.1 Preliminary results

In the 2014/2015 cropping season, the baby plot trials were sown in late December 2014 to end of January 2015 and harvested on mid of May to early June, 2015 where a total of 45 plots at Ilolo and 45 plots at Idifu were harvested. The crop performance and yield for farmers plot were very poor due prolonged drought condition.

In the 2015/2016 cropping season sowing took place from late December 2015 to the end of February 2016 with a total of 42 farmers in Ilolo and 62 farmers in Idifu. In this cropping season the technology which is mostly selected by the farmer is the combination of tie ridges with micro dose fertiliser application for pearl millet production. The crop growth stage on baby plots among farmers in each location varies because the plots were planted at different time.

Table 9: Yield achieved in the 2014/2015 cropping season by different upgrading strategy combinations at Ilolo

Technology used	*plots*	*Pearl millet yield (g m^{-2})*	*Groundnut yield (g m^{-2})*	*Sunflower yield (g m^{-2})*
PM+TR+F1	4	73		
PM+TR+F2	3	103		
PM+TR+F0	1	67		
PM+FT+F0	1	53		
PM+PT+F1	1	104		
IT+TR+F1	4	136	42	
IT+TR+F2	1	73	31	
IT+PT+F1	2	96	52	
IT+FT+F2	1	70	28	
SF+FT+F0/	3			88
SF+FT+F1	6			70
SF+TR+F1	13			77
SF+FT+F0	1			38
SF+TR+F0	2			55
G+TR+T1	1		103	
G+FT+F1	1		54	
Total (Avg)	**45**	**86**	**52**	**66**

3.6 Baby trials at Ilakala and Changarawe, Kilosa district, Morogoro region

Participating farmers selected a section of their field where they established one or more baby plots measuring 100 m^2 each. On these plots farmers applied one or a combination of the two upgrading strategies that they had chosen. Most farmers who were interested in rainwater harvesting choose tied-ridges. Those who were worried about their soil fertility opted for fertiliser micro-dosing either in maize or maize-pigeonpea inter-crop.

3.6.1 Preliminary results

Harvesting of the 2015 maize and sesame crop was done in July, but pigeonpea remained in the field till end of September and early October.

A total of about 35 baby plots were sown from mid-January to February 2016 in Ilakala, some were at physiological maturity stage of maize growth especially those that were planted much earlier in January.

A total of 20 baby plots were planted in Changarawe, of which 14 were planted in February 2016 while six were planted April 2016. Growth stages in maize vary a lot, those that were planted in February were already at reproductive stages by 9th April 2016 while those that were planted in April were still in the early vegetative growth stages. Some farmers' fields located in valley bottoms were frequently flooded after heavy rains.

Fig. 13: Researchers getting information from a farmer at his baby plot with sesame in Changarawe, two baby plots (maize sole and intercropping with pigeonpea) in Ilakala

Table 10: Maize grain yield achieved in farmer (baby) plots in 2015

UPS	*Ilakala*		*Changarawe*	
	No of plots	*g m^{-2}*	*No of plots*	*g m^{-2}*
TR+ M+ Fert	8	241	8	199
TR+ M+PP+Fert	8	192	6	267
TR+ M+ PP	9	189	10	188
FLAT+ M+ Fert	6	277	12	231
FLAT+ M+PP+ Fert	3	298	6	203
No. plots / Avg. yield	34	239	42	217

TR is tied ridges, M is maize crop, PP is pigeonpea crop and Fert is a fertiliser use. (Treatments definition same as in Table 8).

The following delays and difficulties were encountered:

- Similar to mother trial: Drought in late February and March 2016, Livestock (cattle) affected most of baby plots in Changarawe resulting into loss of yield data for pigeonpea in 2015, pests and diseases, long maturing pigeonpea variety 9 months in the field.
- Excessive / heavy rains especially in early February and early April 2016.

Planned activities:

- Data collection at maize roasting stage (R4) in April 2016.
- Harvesting maize in baby plots to get yield data by Mayand June 2016.
- Data management.

3.7 Climate

Tanzania lies just south of the Equator, at 1-12°S, with a tropical climate and regional variations arising from elevation and topography. A narrow coastal strip (<200 m.a.s.l) leads to a central plateau of around 900-1800 m.a.s.l. with the Eastern Arc Mountains (EAM) rising up to 2600 m.a.s.l. The mountains intercept moisture-laden easterly trade winds coming from the Indian Ocean, resulting in adiabatic cooling and higher precipitation in these mountains (average annual rainfall greater than 2000 mm) relative to other parts of the country. The spatial distribution of rainfall is seen in Figure 2-2 with the highest rainfall present along the EAM, followed by the coasts along the Indian Ocean (east) and Lake Victoria (northwest), then the southern highlands around Mbeya and Lake Nyasa, and finally the semi-arid central plateau lying in the rain shadow of the EAM. The most arid zones are around Dodoma (GLOWS–FIU 2014).

Long-term precipitation data for Morogoro and Dodoma regions from 1970 to 2000 were provided by the Potsdam Institute for Climate Impact Research. Morogoro is characterized by a bimodal precipitation regime with an average of 111 rain days and an average total precipitation of 849 mm.

4 Overall conclusions

A combination of fertilizer rates of 10 kg N and 5 kg P ha-1 (12.5%) as well as 20 kg N and 10 kg P ha-1 (25%) micro-doses doubled the yield from 1012 kg/ha in control to 1928 kg/ha and 2394 kg/ha, suggesting that these would be micro-dose rates for maize production in Morogoro and other areas with similar conditions. This micro-dose rate can be used as an entry point to promote adoption of fertilizer due to low investment risk relative to agronomic recommended rate and more benefit than the farmer practice of unfertilized control.

Also, a combination of 40 kg N and 20 kg P ha-1 (50 %) as well as 60 kg N and 30 kg P ha-1 (75 %) produced an average grain yield of 2629 and 2647 kg/ha more than recommended rate (80 kg N and 40 kg P ha-1) which produced 2601 kg/ha. These rates are recommended for resource endowed farmers who can afford higher application rates.

5 Recommendations

The current recommendations in Eastern zone seems to be higher in Kilosa and use of these new and locally derived rates would increase precision and reduce investment costs even for resource endowed farmers. MM fertilizer was the most agronomically effective compared to DAP and TSP fertilizers possibly because it contains both macro and micro-nutrients. Thus new brands of Minjingu fertilizer (NAFAKA plus and Minjingu top dressing can also be used to address nutrient limitation, including Zn which was deficient in the study sites. However, there is a need for economic analysis on these fertilizer rates for the profitability.

Tied ridges conserve soil moisture for up to two weeks compared to flat cultivation with a difference of 11-20% soil moisture conservation. Hence it is recommend that areas receiving lower than normal rainfall should consider using tied ridges for increased soil moisture conservation and hence yields.

6 Messages

There is a need for economic analysis on fertilizer rates obtained in these studies for ensuring profitability.

Fertilizer use efficiency is much higher on tied ridges due to increased soil moisture conservation.

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