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Improving Adaptive Water and Nutrient Management in Food Value Chains for Climate Change Adaptation: A Case of Sensor Technology in Malawi

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Abstract

Soil water and nutrient management for climate-smart agriculture by smallholder farmers have typically been by trial and error. Studies were conducted to adapt the use of sensor farmer–friendly monitoring technology in measuring soil water and nutrients with the aim of improving the efficiency of resources in the food value chain. Simple monitoring tools (chameleon and Wetting Front Detector) which were designed to fit the mental model of African farmers and to give an output that is linked to action were deployed to farmers in nine irrigation schemes in Malawi. Chameleon illustrates information on soil moisture status by colours - blue, green and red colours representing adequate moisture, moderate and dry soil status, respectively. The use of colours and not numbers promoted inclusiveness across illiterate and all gender categories. Farmers participated in sensors' installation, soil moisture measurement, data visualization and learning platform to get insights from their participation. The chameleon was combined with an online communication and learning system to improve adaptive water management at scheme level. The results indicated that: (1) the tools gave farmers new frames of reference; (2) it improved farmers on time, labour and water-saving by reducing irrigation intervals; (3) it gave farmers new reference of experience to change their irrigation traditions; (4) it also reduced conflict for water in irrigation schemes between users apart from generally improving the efficiency of soil water and nutrient use in various value chains. Use of sensor technologies became a rigor that made scientists easily communicate science to lay farmers and initiated the movement of farmers who know how to use water in times of climate change. It can be concluded that combined use of sensors, online communication and learning system is adaptive and helps to improve climate change adaptation to water scarcity whilst improving efficiencies in food chain.

Keywords: Irrigation; Soil water; Nutrient; Climate change

1. Introduction

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Soil is a media of plant growth and hence fundamental in the food value chain as it acts as a reservoir of water, gases and nutrients for good plant growth. The soil is greatly reliant on the interactions between water and gaseous phases which stimulates plant roots access to mineral nutrients (Mengel *et al.* 2001). A well-managed soil allows more water and nutrients to be infiltrated and reserved with plant reach by minimising run-off and less to be leached by permitting a deep rooting zone. For this reason, soil water must be maximised regardless of the farming system, as it can help optimise the trade between water and carbon that can improve crop yield at the farm level. Passioura and Angus (2010) accentuated that only water and nutrients that is transpired and utilised by the crop contribute to crop production. For this reason, all runoff, direct evaporation from the soil surface, leaching below the root zone, and residual moisture at harvest reduce crop yield, water and nutrient use efficiency below its potential. Henceforth, if farmers in Africa want to turn all the soil water and nutrient into crop yield at potential level, there is the need for them to learn how to manage the soil, crop and other inputs in a way that maximises transpiration and hence maximised crop yields (Passioura and Angus, 2010). However, soil water and nutrient management by smallholder farmers especially under irrigation have typically been by trial and error resulting in great crop yield losses in the sub – Saharan Africa (Guy Sela, 2019).

Consequently, great investment efforts in irrigation have performed poorly as it faces several constraints among smallholder farmers on water and nutrient management. Sela (2019) concluded that fertilization and irrigation are the two most important exercises in crop production whose essential practices and theory need to be adhered to for maximised production. However, most irrigation projects in sub-Saharan Africa, Malawi inclusive, have been more costly than elsewhere, with a total cost of $14 500/ha compared to $ 6500/ha in the other developing regions due to improper fertilization and irrigation management. Consequently, they have a lower chance of achieving an adequate return on investment: 56% compared with an average of 72% in the other regions (Inocencio *et al.* 2007). The impact of climate change may increase this effect. If African farmers pay attention to sustainable water management, irrigation would not be more expensive.

Experience shows that there is a long history of measuring soil water and nutrient in the irrigation industry to control water inputs using sophisticated equipment (gypsum block, tensiometer and neutron probe), however, most farmers still use tacit knowledge (soil feel) and equipment is just used as a guide as reported in Australia (Stirzaker *et al.* 2014; Charlesworth, 2005)). It has been proven in other studies that prior experiential knowledge is priority over the use of the tools thus adaptive management (Whittenbury and Davidson, 2010). Meffe *et al.* (2002) defined adaptive management as 'the process of treating natural resource management as an experiment such that the practicality of trial and error is added to the rigour and explicitness of the scientific experiment, producing learning that is both relevant and valid'. Hsaio *et al.* (2007) commended that a learning-by-doing approach that relies on farmers having access to monitoring tools improves water use efficiency in agricultural systems. Adaptive management assists in avoiding scientific' approaches to try completely displace subjective experiences (Whittenbury and Davidson, 2010). A study was implemented with a hypothesis that simple soil water and nutrient monitoring tools that provide information that farmers can easily understand are essential for the practice of adaptive management (AM) in irrigated agriculture. The aim of the study was to adapt the use of sensor farmer–friendly monitoring technology in measuring soil water and nutrients for improved efficiency of resources in the food value chain for climate change adaptation.

2. Materials and Methods

Location

The project consisted of on – station experiments and on – farm demonstration trials for adaptation purposes. The on-station experiments were conducted at Kasinthula Agricultural Research Station (16º 0'S, 34 º 5' E, 70m *asl*.,) from 2016 to 2018. On – farm demonstrations trials were implemented at Bwanje Irrigation Scheme, Kasinthula Cane Growers (KCGL) from 2015 – 2018 in Chikwawa, Nanzolo Irrigation Scheme in Chikwawa (2015 – 2018), Bwanje Irrigation Scheme in Dedza (2015 – 2018), Tadala Irrigation scheme in Dedza (2016 – 2018), Mthumba irrigation scheme (2016 – 2018), Matabwa Irrigation scheme (2016 – 2018), Tiphunzire irrigation scheme in Dedza (2018), Mwalija Irrigation Scheme in Chikwawa (2018) and Likhubula irrigation Scheme in Chikwawa (2018), Mpitilira Irrigation Scheme in Salima (2018) and Prescane Fields in Chikwawa (2018). Various crops – maize, sugarcane, common beans, and tomatoes were used in the study.

Study Description

Series of experiments and on-farm demonstrations were conducted to find ways of improving adaptive water management in food value chains for climate change adaptation using simple tools as follows: Trial 1 – Evaluation of chameleon and Fullstop Wetting Front Detector performance in intercropped maize – bean crop under furrow irrigation; Trial 2 – Determining depths of placing soil moisture sensors arrays in tomatoes at Kasinthula Research Station; Trial 3 - Evaluation of chameleon and Fullstop Wetting Front Detector in monitoring use of stored water for maize at Bwanje irrigation scheme; Trial 4 - Evaluation of chameleon and Fullstop Wetting Front Detector in monitoring use of stored water for beans at Bwanje irrigation scheme; Trial 5- Effect of shallow groundwater on sugar cane yield at Kasinthula: transects of piezometers; Trial 6 -Field evaluation of Chameleon and Fullstop Wetting Front Detector in maize, sweet potatoes and onions under furrow irrigation.

Description of the simple soil moisture tools used and Data Collection

Chameleon and Chameleon sensor array

The Chameleon Reader (Fig. 1) measure soil water status and displays the level of soil water suction as blue (wet soil), green (intermediate soil moist) and red lights (dry soil). Chameleon illustrates information on soil moisture status by colours - blue, green and red colours representing adequate moisture, moderate and dry soil status, respectively (Stirzaker *et al.* 2014). The use of colours and not numbers promotes inclusiveness across illiterate and all gender categories. The switch points between blue, green and red lights were based on the extensive literature for avoiding crop water stress for most of the irrigated crops. Hence all sensors used were well tested based on their original wire electrode sensors, with switch point as detailed in Figure 2.

The chameleon sensor arrays were soaked in water before installation and then three holes augured to three different depths each where chameleon sensors were installed – 15cm, 30cm and 45cm. The sensor arrays were placed and compacted. The temperature ID on each array of three sensors was placed between depths of 15 and 30 cm. The installation of Chameleon sensors followed order: 1. Blue wire-shallowest, 2. White wire in the middle, 3. Red – deepest placement. The black cable which was the temperature ID was placed at the middle sensor (Via.farm 2016). All installation involved farmers.

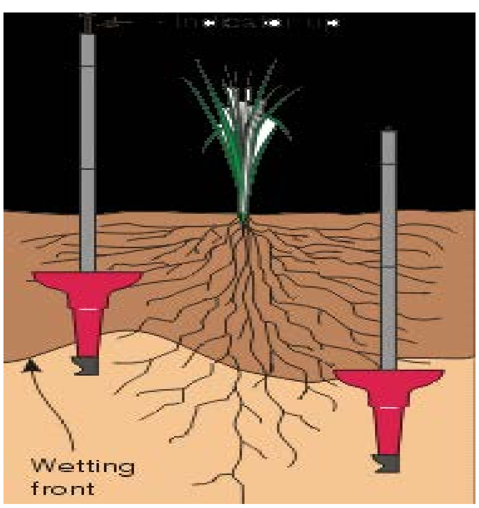
Full stop Wetting Front Detector Assembling and installation

At least a 20 cm or larger in diameter hole was augured for the wide end of the detector funnel and another 5-20cm in diameter for the narrow end of the funnel. Poured filter sand into the funnel until it covered the locking ring by at least 1 cm. Lowered the detector into the hole and measured the distance to the locking ring. Then fullstop wetting front detector (Fig. 3) was buried. The site over the detector was watered with at least 20 litres or more after installation to trigger the float.

The chameleon and Fullstop wetting front detector were refined and evaluated in combination with an online communication and learning system to improve water management at irrigation scheme level (https://via.farm). Therefore, several experiments were conducted on various crops and crop management to evaluate the use of chameleon reader, chameleon sensor arrays, chameleon salinity tester and Fullstop Wetting Front Detector in monitoring soil water and nutrients under irrigation. Trial 1 evaluated chameleon and Fullstop Wetting Front Detector performance in intercropped maize – bean crop, Trial 2 evaluated depth of sensor installation in tomatoes under drip and field demonstrations tested the use of the tools in monitoring soil moisture and nutrients in sweet potato, maize and onion. Almost 198 farmers were greatly involved in installation and measurement at the nine irrigation schemes to facilitate learning by doing for adaptive management purposes.

Plate 1 - Chameleon Reader   Plate 2 - Chameleon Sensor arrays

Figure 1: The wi-fi chameleon reader (plate 1) and chameleon sensor arrays set (plate 2)



Single full-stop wetting front detector

Figure 2: Full-stop wetting front detector for monitoring nutrients and determining irrigation depth

Figure 3: Nitrate strip (4a) and Chameleon EC meter (4b) used to show how much nitrate is there within a particular soil depth and electrical conductivity respectively

Learning and Adaptive Management

These water management studies brought together gendered oriented tools mentioned above to facilitate people–centred learning for irrigation as it involved guided practical field-based investigations through which farmers learnt for themselves on how to identify ways of addressing these challenges through observation, testing and monitoring of different treatments as well as reviewing and sharing findings through subgroups and plenary discussions within common interest groups (CAADP, 2009). Each irrigation scheme formed three "learning coalitions" consisting of farmers, extension workers, a district irrigation officer and research and project staff. Each coalition built its case studies based on experiential learning and interactive approaches using the Gender Action Learning Systems (GALS) methodology. The learning coalition was required to train and mentor at least one additional irrigation scheme each year using the tools they learnt. At least nine irrigation communities consisting of between 20-50 farming households were set starting with three in year 1 then 6 and 9 in year 3 using this approach. Women and youth who are often marginalised and excluded from the development initiatives were prioritised in the selection of 22 farmers per scheme. The study method was in accordance with FARA that advocated IAR4D, thus contextualised experiential learning (FARA, 2006).

Data collection and Analysis

During data collection, the green 8 pin plug was being connected to the chameleon Wi-Fi Field Reader, either direct into the reader or via a length of blue cable. The plug was shielded when unplugged to protect it from dirt and rain. Resetting was through the reset button on the base to start the readings. The chameleon Wi-Fi Field Reader was being connected to a sensor array, and paired to a Wi-Fi connection, to send data to the web twice or once every week. Chameleon reader had a lithium battery which could last for over three months. The chameleon reader had a wi-fi whereby if connected to a phone with hotspot the data would automatically be uploaded on the VIA web site which could instantly visualized as raw data or as a pattern. Field data collectors facilitated field data collection and uploading on the website with farmers involvement.

Data Uploading and Visualization

The chameleon had been combined with an online communication and learning system to improve water management at scheme level. Once connected, a Chameleon Wi-Fi Field Reader is connected to a sensor array, and paired to a Wi-Fi connection, the CR sent data to the web instantly. Data collected by CR would be visualized on the website as soil moisture colour patterns and irrigation graphs in patterns (Fig. 8). Chameleon illustrated information on soil moisture status by colours - blue, green and red colours representing adequate moisture, moderate and dry soil status, respectively at different soil depths (depths commonly used 15 cm, 30 cm and 45 cm depths). The farmers were able to decide based on the colour being shown on the chameleon reader. On the other hand, the nitrate leaching and salinity state was also monitored using wetting front detector and results shown as colour patterns after entered manually from nitrate strip and chameleon EC meter (Fig. 4).

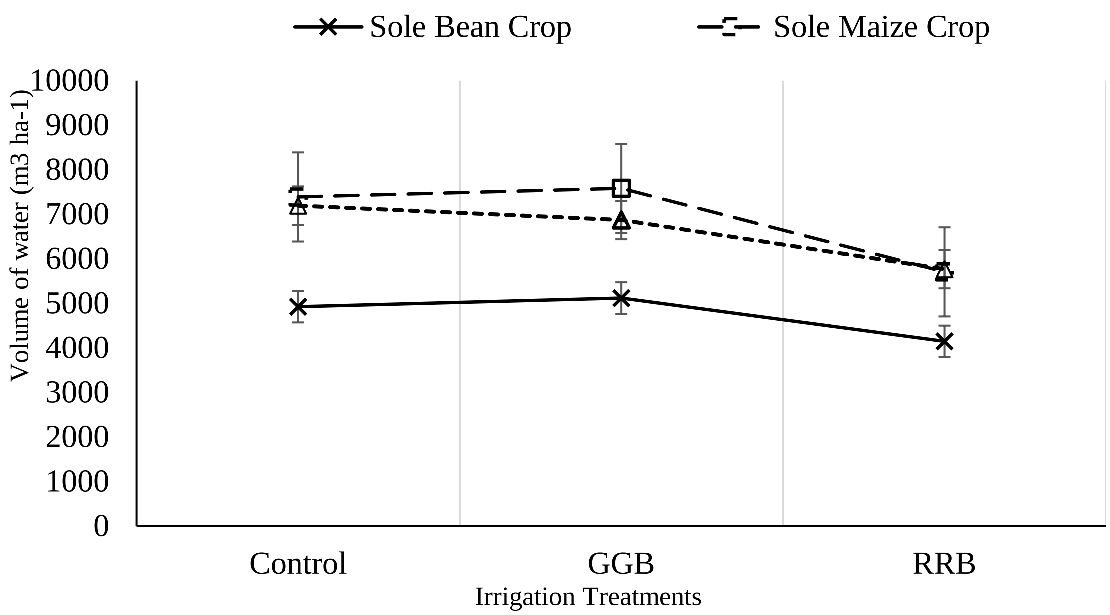


Fig. 4: Interaction between irrigation and cropping system on number and amount of irrigation.

3. Results

Effect of application of chameleon sensors on number of irrigation and amount of water applied to maize – bean cropping system

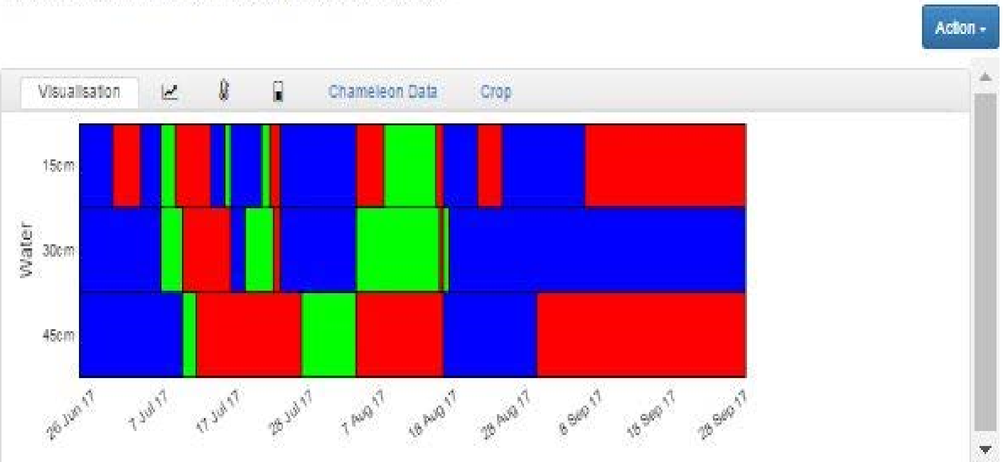
Number of irrigation and amount of irrigation water was significantly different between irrigation ($p<0.0001$), cropping system ($p<0.001$) but not between nitrogen levels ($p>0.05$) (Table 1). Irrigation and cropping system strongly influenced the number of irrigation and the amount of water applied during the growing season. More number and amount of irrigation water were realized under control thus water balance scheduling at 40% depletion though not significantly different to application of water when chameleon reader indicated Green – Green – Blue (GGB) at 15, 30 and 45 cm depth ($p>0.05$). Application of irrigation when chameleon reader indicated Red – Red - Blue (RRB) at 15, 30 and 45 cm depth had the lowest number and amount of irrigation which was significantly different to control and to application of water when chameleon reader indicated Green – Green – Blue.

Sole maize cropping system requires more irrigation and irrigation water with least in sole bean cropping system whilst maize – bean intercrop was intermediate as clearly illustrated by the interaction between irrigation and cropping system in figure 4. The interaction indicated that more irrigation number and amount was observed when applying irrigation at the time chameleon reader indicated Green – Green – Blue and steadily decreased when applying irrigation at the time chameleon reader indicated Red – Red – Blue at 15, 30 and 45 cm depth especially in sole maize and sole bean crop (Figure 5). However, the irrigation number and amount decreased from control to RRD in maize – bean intercrop. The reason for this cause could be a stabilization of water use by the maize – bean intercrop at the time chameleon reader indicated Green – Green – Blue resulting into control using more water.

a. Soil moisture color pattern and irrigation graphs

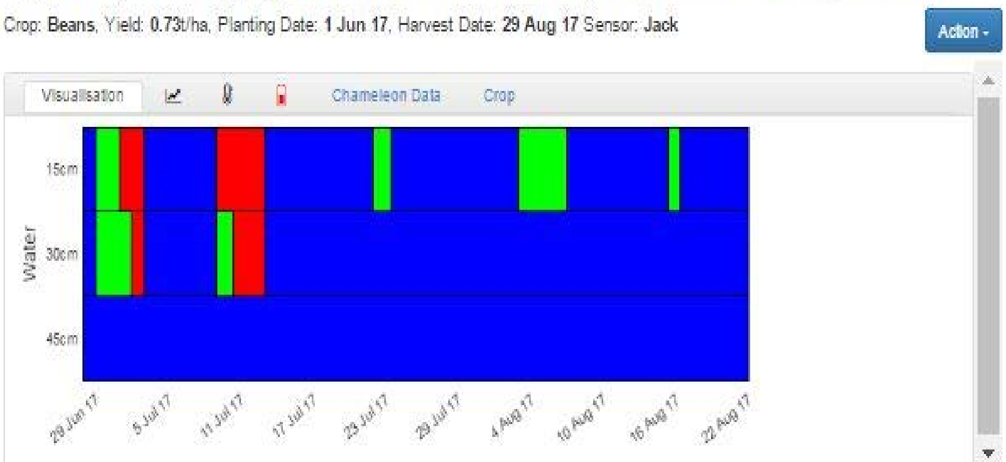
Irrigation Bay: **intercropping maize and beans**

Crop: **Maize**, Description: **intercropping of maize(mediummaturing variety) and beans(early maturing variety)**, Yield: **5.88t/ha**, Planting Date: **1 Jun 17**, Harvest Date: **9 Oct 17** Sensor: **Jack**



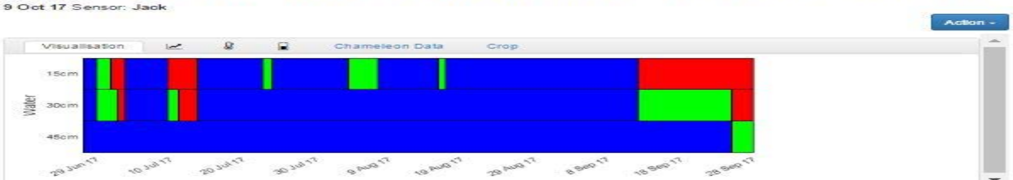
Irrigation Bay: **intercropping maize and beans area #2 irrigation when first two depths shows red**

Crop: **Beans**, Yield: **0.73t/ha**, Planting Date: **1 Jun 17**, Harvest Date: **29 Aug 17** Sensor: **Jack**



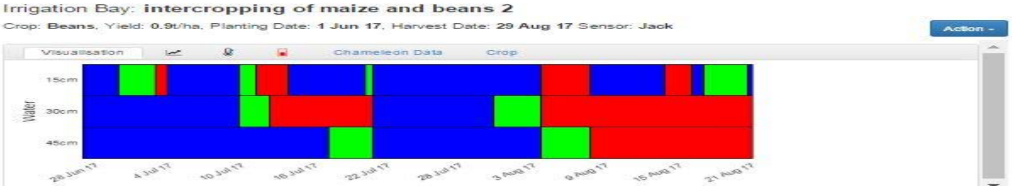
Irrigation Bay: **intercropping maize and beans area #2 irrigation when first two depths shows red**

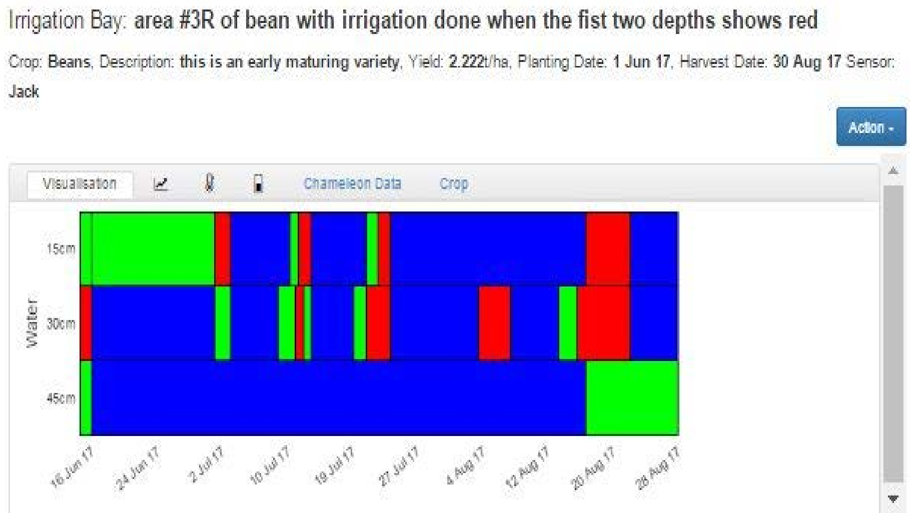
Crop: **Maize**, Description: **maize medium variety/ beans early maturing varity**, Yield: **3.45t/ha**, Planting Date: **12 Jun 17**, Harvest Date: **9 Oct 17** Sensor: **Jack**

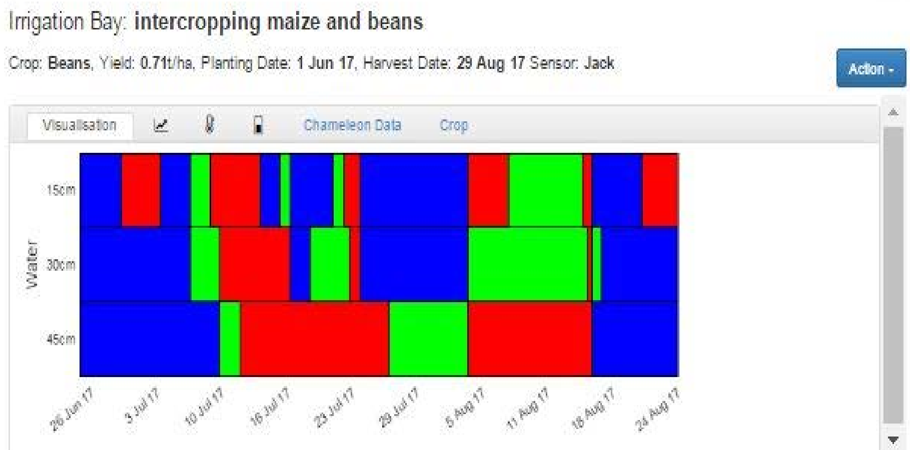


Irrigation Bay: **intercropping of maize and beans 2**

Crop: **Beans**, Yield: **0.9t/ha**, Planting Date: **1 Jun 17**, Harvest Date: **29 Aug 17** Sensor: **Jack**

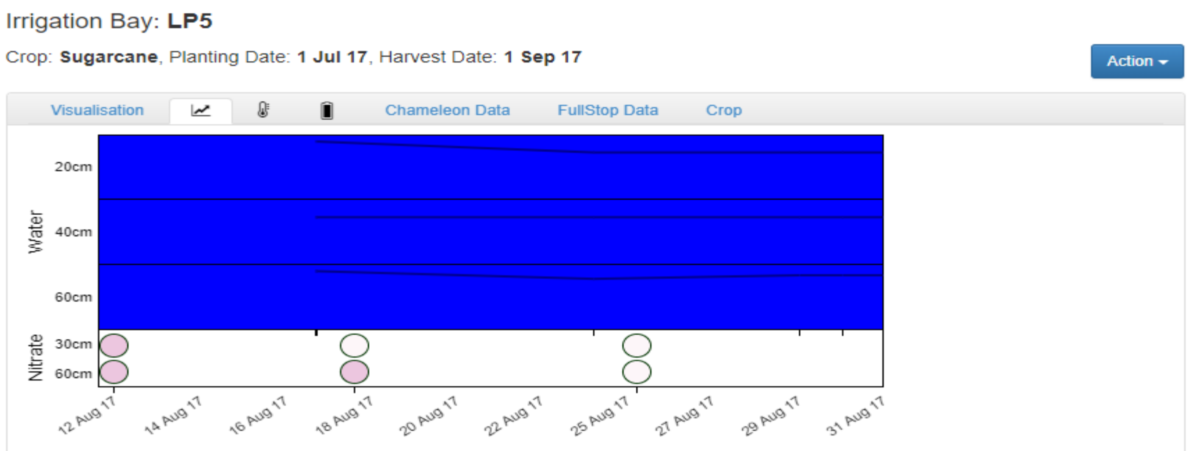






Irrigation Bay: intercropping maize and beans

b. Irrigation graphs within the pattern



The visualisations from the Chameleon Sensor readings for LP5 showing nitrate readings (https://via.farm/visualisefarm/138/past/2017/)

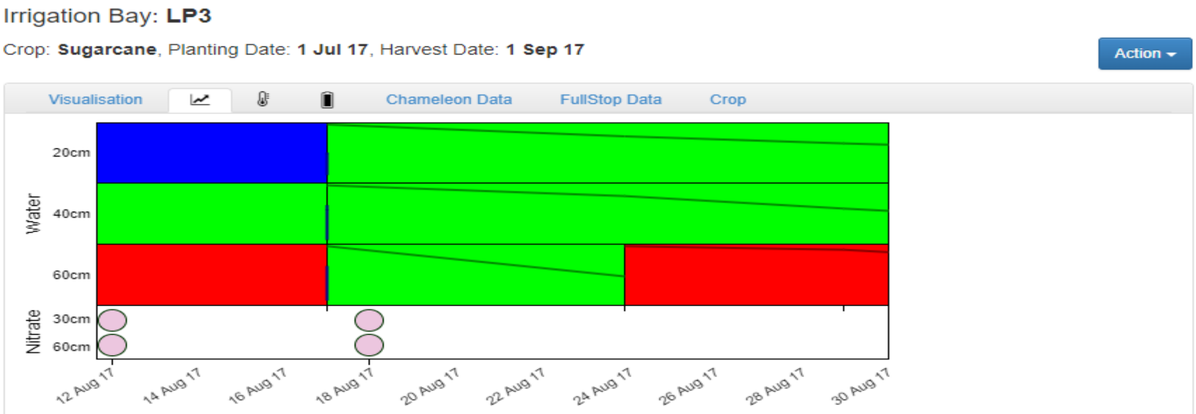


Figure 5: The visualisations from the Chameleon Sensor readings for LP3 showing nitrate readings (https://via.farm/visualisefarm/138/past/2017/)

Table 1: Effect of application of chameleon sensors on number of irrigation and amount of water applied to Maize - bean cropping system

Irrigation/Cropping System/Nitrogen Treatments	Number of irrigations			Mean	Amount of water applied (m^3/ha)			Mean
	N1	N2	N3		N1	N2	N3	
Control								
Maize – Bean Intercrop	12	13	13	12	6,806	7,389	7,389	7,195
Sole Maize Cropping	13	13	12	13	7,389	7,583	7,194	7,389
Sole Bean Cropping	9	8	8	8	5,056	4,861	4,861	4,926
Mean (n =)	**11**	**11**	**11**	**11**	**6,417**	**6,611**	**6,481**	**6,503**
Green-Green-Blue (GGB)								
Maize – Bean Intercrop	12	12	11	12	7,000	7,000	6,611	6,870
Sole Maize Cropping	12	14	13	13	7,194	8,167	7,389	7,583
Sole Bean Cropping	9	9	9	9	5,056	5,056	5,250	5,121
Mean (n =)	**11**	**12**	**11**	**11**	**6,417**	**6,741**	**6,417**	**6,525**
Red – Red – Blue (RRB)								
Maize – Bean Intercrop	10	10	10	10	5,833	5,639	5,833	5,768
Sole Maize Cropping	10	10	10	10	5,833	5,639	5,639	5,704
Sole Bean Cropping	7	8	7	7	3,889	4,667	3,889	4,148
Mean (n =)	**7**	**7**	**7**	**7**	**5,185**	**5,315**	**5,120**	**5,207**
CV (%)								9.3
Significance level								
Irrigation treatments				$p<0.001$				$p<0.001$
Cropping system				<p0.001				$p<0.001$
Nitrogen				NS				NS
Irrigation * Cropping system				$p<0.05$				$P<0.05$
Irrigation * Nitrogen				NS				NS
Irrigation*Nitrogen*Crop system				NS				NS
LSD								
Irrigation				0.648				377.8
Cropping system				0.427				249.1
Nitrogen				0.557				325.0
Irrigation * Cropping system				0.777				453.3

Effect of application of chameleon sensors on total income and economic water productivity of maize – bean cropping system

Total income of maize – bean cropping system significantly differed between cropping system ($p<0.001$) and not between irrigation and nitrogen treatments. Maize - bean intercrop had the highest income which was significantly different from sole beans crop and sole maize crop. The total income of sole bean crop and sole maize crop were not significantly different ($p>0.05$, Table 2). On the other hand, Economic Water Productivity was significantly differed between irrigation ($p<0.05$) and between cropping system (p,0.001). On the other hand, total income and EWP were both not influenced by nitrogen under maize – bean cropping systems ($p>0.05$) and none of the two indicated interaction effects by the treatments ($p>0.05$). An irrigation treatment where water was applied when chameleon reader indicated Red – Red – Blue at 15, 30 and 45 cm, had the highest EWP which was significantly different to control and to irrigation where water was applied when chameleon reader indicated Green – Green– Blue at 15, 30 and 45 cm. But GGB and control were significantly different.

Table 2: Effect of application of chameleon sensors on total income and economic water productivity of maize-bean cropping system

Irrigation/Cropping system/Nitrogen Treatments	Total income (MK)			Mean	Economic Water Productivity (MK/m^3)			Mean
	N1	N2	N3		N1	N2	N3	
Control								
Maize–Bean Inter.	1,507,891	1,439,300	1,549,939	1,499,043	222.4	194.2	210.7	209.1
Sole Maize Crop	1,071,630	928,861	1,052,111	1,017,534	145.8	126.8	145.3	139.3
Sole Bean crop	1,302,000	1,037,711	1,147,819	1,162,510	257.3	212.0	236.1	235.1
Mean (n =)	**1293840**	**1,135,291**	**1,249,956**		**208.5**	**167.7**	**197.4**	
Green – Green – Blue (GGB)								
Maize–Bean Inter.	1,559,226	1,868,367	1,488,419	1,638,671	222.7	268.1	225.3	238.7
Sole Maize Crop	1,073,833	1,064,704	1,303,019	1,147,185	149.0	130.4	177.9	152.4
Sole Bean crop	1,235,111	990,033	1,187,667	1,137,604	244.1	204.0	227.7	225.3
Mean (n =)	**1,289,390**	**1,307,701**	**1,326,368**		**205.3**	**200.8**	**210.3**	
Red – Red – Blue (RRB)								
Maize–Bean Inter.	1,276,046	1,260,207	1,630,883	1,389,045	219.9	228.3	281.9	243.4
Sole Maize Crop	1,109,407	848,457	1,190,315	1,049,393	194.2	152.3	212.5	186.3
Sole Bean crop	1,228,422	1,056,806	1,074,759	1,119,996	318.4	226.5	290.1	278.3
Mean (n =)	**1,204,625**	**1,055,157**	**1,298,652**		**244.2**	**202.4**	**261.5**	
Significance level								
Irrigation treatments				NS				0.043
Cropping system				<0.001				<0.001
Nitrogen				NS				NS
Irrigation * Cropping system				NS				NS
Irrigation * Nitrogen				NS				NS
Irrigation*N*Crop sys.				NS				NS
LSD								
Irrigation				105227.3				30.57
Cropping system				137566.6				25.41
Nitrogen				128447.7				27.02

Effect of application of chameleon sensors on gross margins and governance at nine irrigation schemes

Farmer discussion groups regularly reported substantial increases in yield post introduction of the tools at the nine irrigation schemes in Malawi (figure 6 and 7). Although there have been a large number of written farmer testimonies, it was hard to know how widespread success is, since it is often the lead group who volunteer such information. However, the project collected data from 198 farmers and provided robust data on environmental, social and economic impacts. The figure 6 gives some insight into data collected on the nine irrigation schemes: A plot of gross margin of maize against fertiliser applied in Malawi showed that many farmers used to waste nutrients (left) before the project by over irrigation (figure 7). For example, see the optimum N to apply to irrigation maize based on a 3:1 return on investment for good irrigation (red line) and poor irrigation (blue line) derived from APSIM (centre). A gross margin probability distribution for maize in Malawi based on current practice.

Effect of irrigation scheduling techniques on bean grain yield and mean height of bean plants

The study that looked at the response of beans irrigated with different irrigation scheduling techniques under greenhouse conditions demonstrated that irrigation scheduling techniques of chameleon, WFD and Tensiometers were appropriate technique in terms of yield since the bean yield was in range with potential yield of Kalima beans (Table 3). Furthermore, it was found that the amount of water used throughout the growth period was not significantly different as such all the irrigation scheduling techniques were appropriate in terms of water-saving. In addition, it was observed that (nutrient leaching) leaching losses from the irrigation scheduling techniques were not different hence all irrigation scheduling techniques were appropriate.

Table 3: Effect of irrigation scheduling techniques on bean yield and mean height of bean plants

Treatment	Yield (ton/ha)	Plant height (cm) at harvest
T1 – Chameleon Sensor	2.643	73.47
T2 – Tensiometers	2.222	73.77
T3 – Fixed Irrigation	2.175	72.40
Grand mean	2.347	73.21
Lsd	0.5582	2.274
Cv%	8	0.8
Fpr	0.143	0.319
Sign	NS	NS
SE	0.1889	0.587

Sign = Significance, NS= Not significant, CV= Coefficient of Variation, SE= Standard Error, Lsd = Least significant difference at P< 5%, Fpr=probability value Trt = Treatment

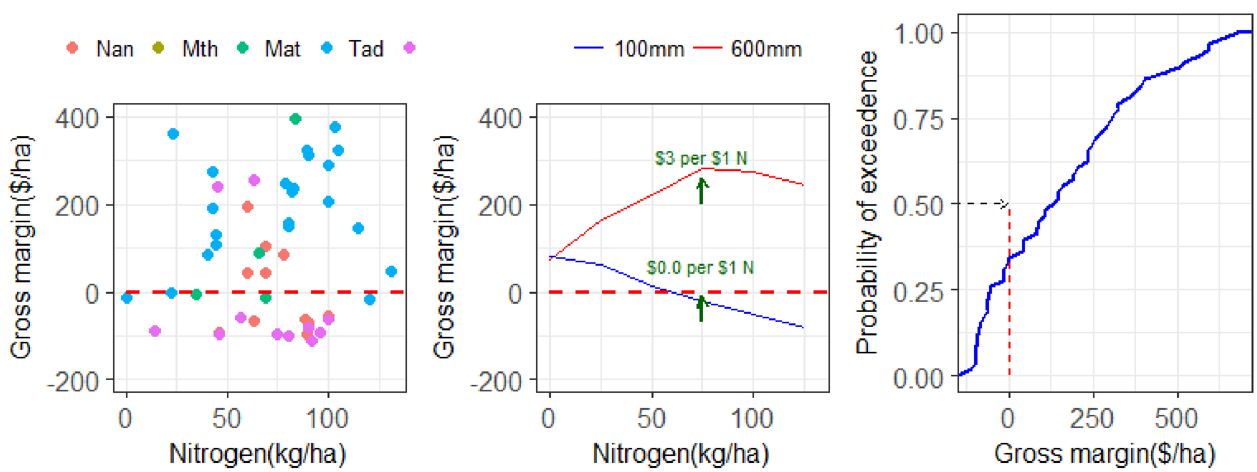


Figure 6: Gross margin analysis of Maize against fertilizer applied

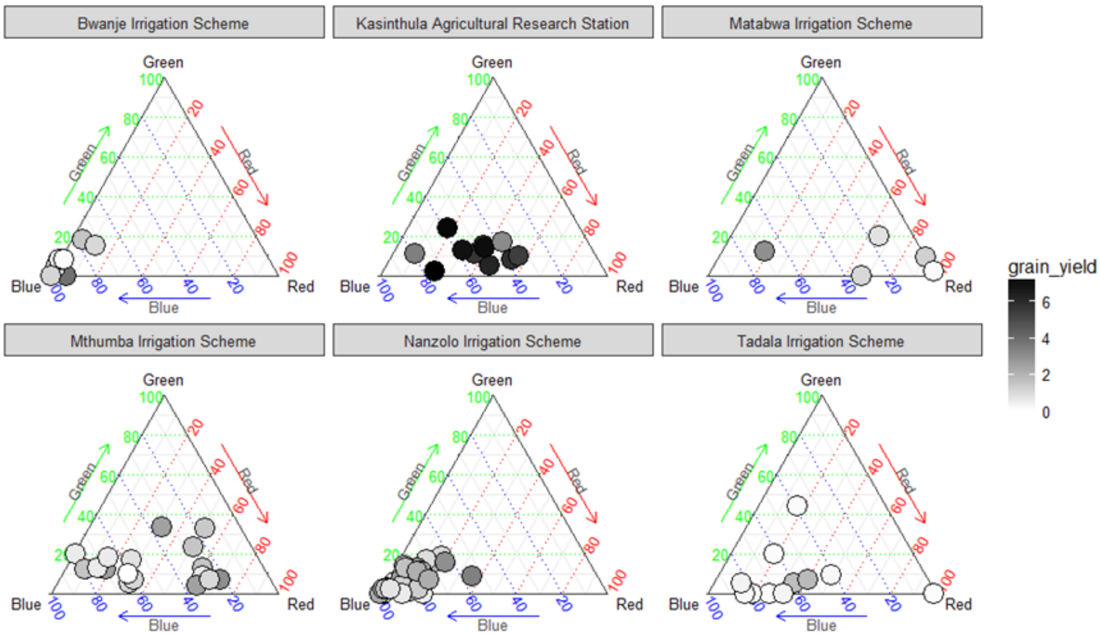


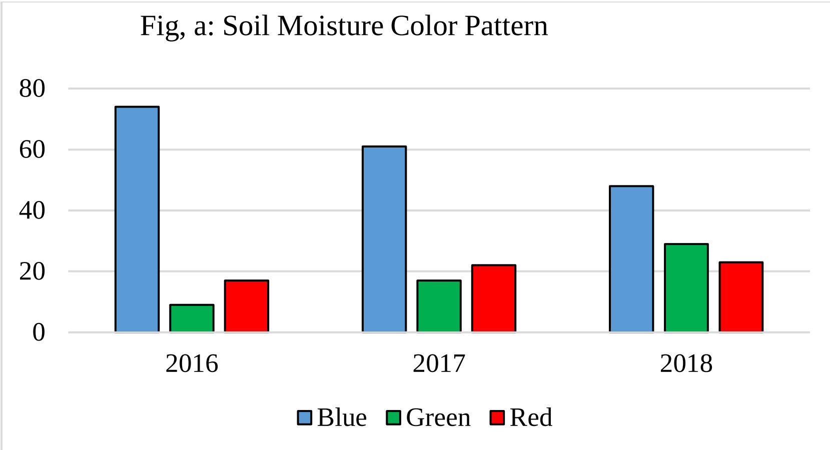
Fig. 7: Triads highlighting issues of equity and governance at three irrigation schemes in Malawi.

Influence of the tools on Water and nitrate leaching and number of irrigations among smallholder farmers in nine irrigation schemes

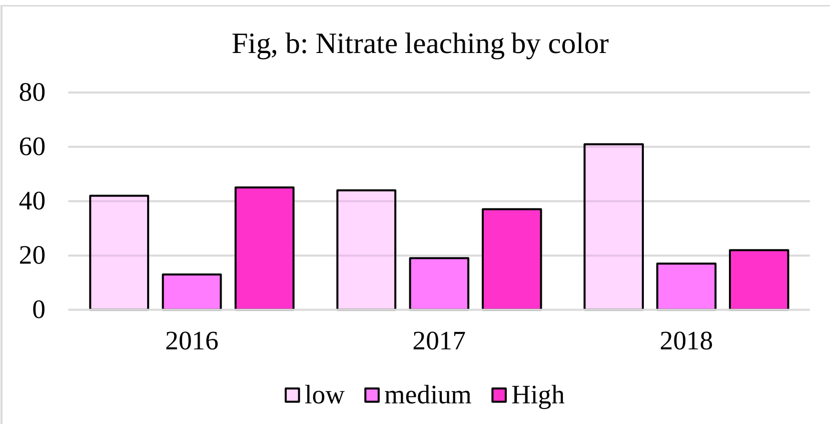
Preliminary observation by farmers who used the tools in the four seasons – it was reported that tools helped them to reduce the frequency of irrigation. Farmers did not need to irrigate when there was adequate moisture monitored using chameleon sensors. This led to saving water and time and minimises leaching of nutrients (that is associated with over-irrigation). This meant the community could increase crop production and optimal nutrients usage by the crops. However, it was too early to document community impacts on year 1 but later included collective purchase of monitoring equipment, collective marketing, and collective scheme management plans in the context of use of irrigation water. Tools facilitated a change in community attitudes towards irrigation – from the current *ritual irrigation* to irrigation that is based on crop water/moisture demand. This change in attitude is noticeable among the farmers in the nine schemes in Malawi.

In 2016, 74% of the farmers overirrigated (blue), 9% green (moist) and 17% red (dry). Over – irrigation increased Nitrate leaching (45% of fields) at the time that farmers started learning using tools in 2015 – 2016. With time of learning using tools in 2017 and 2018, farmers started reducing irrigation resulting in less nitrate leaching from the irrigated fields (Figure 8). Once the 198 farmers got information with the use of the soil moisture and nutrient monitoring tools they made the decision to improve water and nutrient management. Other farmers used to irrigate 13 times in maize and 9 in beans per season before the tools. Use of tools has helped them to decrease the number of irrigation events in each season (Fig. 8). A reduction in number of irrigation led to decreased amount of water used to irrigate crops (Figure 8c). The estimated amount of water applied reduced steadily between 2017 and 2018 after learning to make irrigation decision with tools (Fig 8d). Similarly, new schemes - Tadala, Matabwa and Mthumba started saving water after learning by doing from the early adopting schemes of Bwanje, Nanzolo and KCGL.

A baseline survey findings (2015) showed that (33.04%, n=40) had been involved in a conflict and 66.4% (n=69) reported that they had heard of conflict in their communities pertaining to water use. In 2017 only 16.8% of farmers under intervention have been involved in a conflict while 33.4% of farmers under control were involved in water related conflict within the implementing schemes (Figure 9).



Fig, a: Soil Moisture Color Pattern
80
60
40
20
0
2016
2017
2018
Blue
Green
Red



Fig, b: Nitrate leaching by color
80
60
40
20
0
2016
2017
2018
low
medium
High

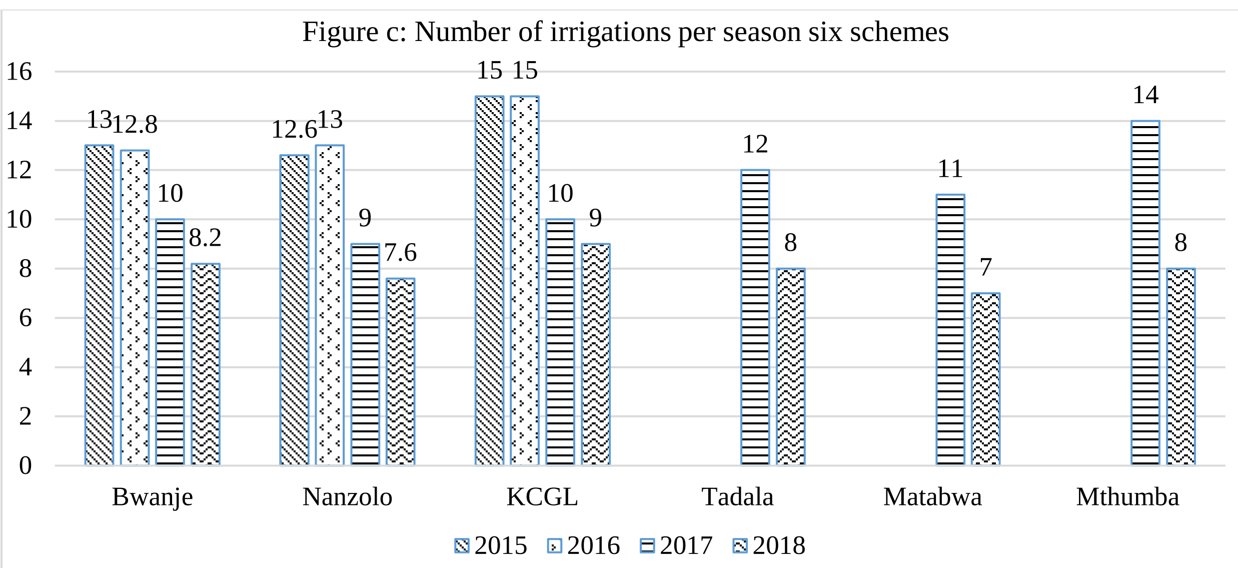


Figure c: Number of irrigations per season six schemes
16
14
12
10
8
6
4
2
0
13
12.8
10
8.2
12.6
13
9
7.6
15
15
10
9
12
8
11
7
14
8
Bwanje
Nanzolo
KCGL
Tadala
Matabwa
Mthumba
2015
2016
2017
2018

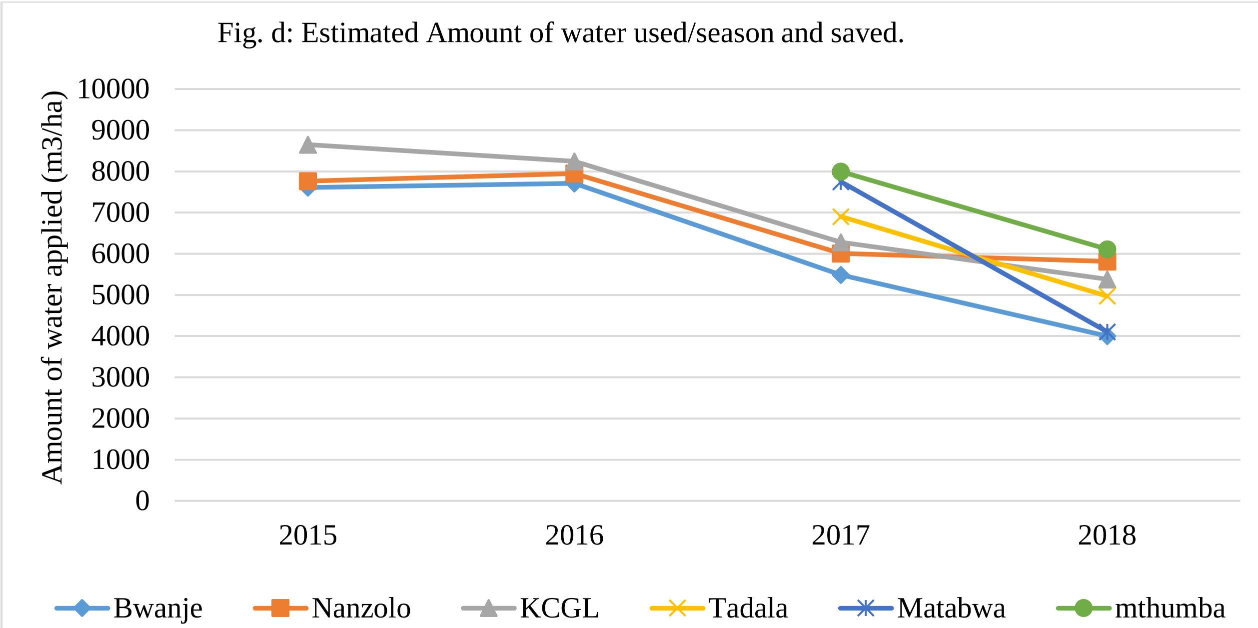
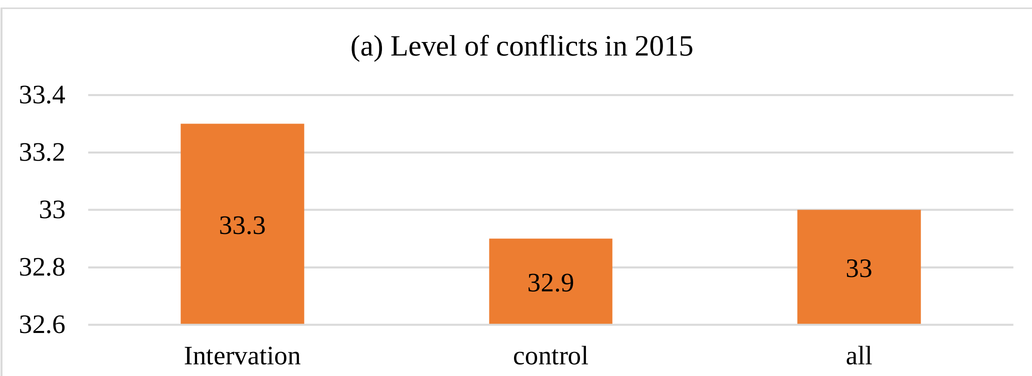


Figure 8: Influence of the tools on Water and nitrate leaching and number of irrigations among smallholder farmers in Nine irrigation schemes



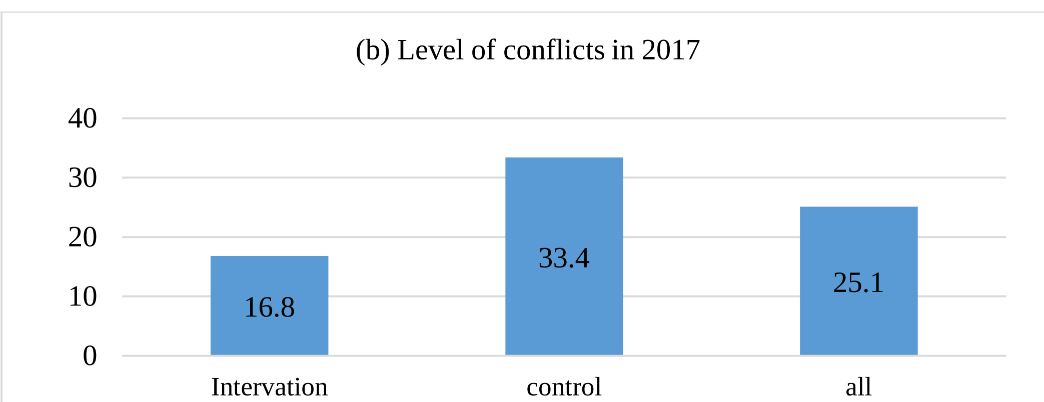


Figure 9: Influence of the tools on conflict management among smallholder farmers in Nine irrigation schemes.

4. Discussion

This study revealed a great economic, social and environmental benefits that can be realised by learning by doing at irrigation community level using adaptive water and nutrient management in food value chains with simple soil moisture and nutrient tools as the focal point of learning. On station and on–farm trials demonstrated that use of the tools can economically help smallholder farmers to improve crop yields, reduce amount of irrigation water (water-9olsaving), labour and time to irrigate (time and labour saving) consequently crops can be grown based on their actual water requirement and limited financial input for labour and water pumping costs. With such tools, a well-managed soil is realised as it allows more water and nutrients to be infiltrated and reserved with plant reach by minimising run-off and less to be leached by permitting a deep rooting zone (Passioura and Angus, 2010). The results for trial 1 on the effect of the application of chameleon sensors on EWP confirmed that use of chameleon sensors in monitoring soil moisture improved irrigation water management resulting in increased economic productivity or water use efficiency (WUE). The EWP result agreed with the result on the effect of application of chameleon sensors on irrigation amount and number as observed above. In line with on-farm trials, these results prove that application of chameleon reader and sensor can easily help improve adaptive water management at farm level for climate change adaptation.

Adaptive water management for climate change adaptation is realised from the knowledge – learnt from the use of tools that it helped improve crop yields through better management of irrigation water, soil nutrients, and salt by using simple tools. In the case of trial 1 it was found that Green - Green – Blue colour pattern (an intuitive) and using the scientific method (objective method) were equivalent whilst using Red – Red – Blue (an intuitive) at 15, 30 and 45 cm had more saving on irrigation. Therefore explicit knowledge and implicit knowledge was combined as farmers and scientist learned together that using chameleon when colour indicates RRB improved irrigation water management resulting in increased economic productivity in intercropped maize – bean whilst sole maize was found to use more water than crop diversification itself. A combination of intuitive and objective method during the study brought great social interaction between farmers, extension workers and irrigation scheme managers that well managed irrigation and nutrients can result into great social benefits at irrigation community level.

Possibly one of the most unexpected outcomes from the introduction of the tools in the irrigation schemes is a greater understanding of conflict on the schemes. Well-functioning schemes need coordinated action – not only for shared responsibilities like paying for water fees and contribution to canal maintenance but also for coordinated buying on inputs and marketing of produce. The social capital necessary to underpin such activities is probably our least understood aspect of smallholder schemes. The use of chameleon sensors in an adaptive way exposed bad management (those denied sufficient water by the governance system) and also those who break the rules (use water out of turn or take too long to irrigation thus delaying others access). For example, one farmer reported that “there was favouritism as far as water distribution is concerned. The authority of water distribution fall in the hands of the Group Village Headman as such once you crossways with him then you hardly receive water in your field hence much red was recorded.” Another reported that she “is among farmers who are close to the water hydrant thus giving her easy access to irrigation water as such getting water for her field was easy hence the blue being the majority state.”

Use of tools in irrigation water and nutrient management provided a novel way to condense large amounts of information to give new insights into equity and governance of water and how it relates to crop yield at scheme level. Each triangle in figure 7 represents an irrigation scheme or research station. Each circle represents a crop. Each crop is placed in the triad depending on the time and depth-averaged blue, green and red colours. Hence circles in the bottom left corner denote crops that are predominantly blue (wet) whereas those on the bottom right are dry. The colour of the circle represents yield, with a darker colour representing a higher yield. In this way many crops can be compared for their water use (over–use) and productivity. Not only are the large difference in how wet the soil is between schemes, there are also large differences within certain schemes, highlighting issues of equity and governance.

With such information, adaptive management using the tools can be explored to enhance equity and governance for climate change adaptation sake.

Similarly, efficient irrigation and nutrient management by the simple tools helped to reduce environmental impact and promoted sustainable use of resources (Montesano *et al.* 2015) which is very important in reducing green gas emission in climate change adaptation. Smallholder farmers avoided stressing their crops on the one hand and over-irrigation, loss of nutrients and water lodging on the other when they properly learnt chameleon sensors and wetting front in monitoring irrigation by doing themselves.

5. Conclusion and Recommendations

The study aimed at improving adaptive water and nutrient management using simple farmer–friendly monitoring technology in measuring soil water and nutrients for improved efficiency of resources in the food value chain for climate change adaptation. The study combined objective and subjective knowledge to generate enough scientific, economic and social testimonies that the use of tools in monitoring soil moisture from farmers through focus groups and farmer discussion groups improve water management and crop productivity. The main findings include:

1. Farmers using less water in response to persistent blue colour on the Chameleon. This usually takes the form of increasing the time between irrigation events.
2. Reduction in conflict over water in the schemes as more water becomes available, particularly to downstream users.
3. Time saved from not irrigating invested in weeding or off-farm income-generating activities.
4. Greater responses to fertilizer as a function of reduced leaching of nutrients.
5. Higher crop yields (up to double).
6. Greater investment into farm inputs such as seed and fertilizer.
7. Reduced workloads for women and encouragement of youth to enter farming.

The chameleon sensors and WFD gave satisfactory results in monitoring and managing soil water as the colour patterns helped to show when to irrigate. It can, therefore, be seen as a useful tool in irrigation water management through continuous soil water monitoring in Malawi. The studied tools (chameleon reader/sensors and Wetting Front Detectors) were therefore officially recommended for farmer use in monitoring soil water and nutrients of field irrigated crops for adaptation to the impact of climate change on water resources.

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