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Full Length Article

In Situ Rain Water Harvesting Techniques Increase Maize Growth and Grain Yield in a Semi-arid Agro-ecology of Nyagatare, Rwanda

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Abstract

Droughts, short growing seasons and poorly distributed rainfall are major constraints to maize production in eastern semi-arid region of Rwanda. *In situ* rain water harvesting offers an alternative option to reduce rainwater runoff, increase infiltration and storage of water in soil and reduce the effects of drought stress on maize grain yield. The objective of the study was to assess the effects of *in situ* water harvesting techniques on soil moisture content, maize growth and grain yield in Nyagatare, Rwanda in the 2011-2012 seasons. The study comprised of four treatments: pot holing, tied-ridging and mulching compared to control treatment of planting on the flat. The experimental design was randomized complete block with three replicates. Soil moisture content and maize plant dry weight were measured at 8, 11 and 14 weeks after emergence (WAE). There was a significant increase ($P<0.001$) in soil moisture content and maize plant dry weight from planting on the flat (control), pot hole, tied ridges to mulching at 8, 11 and 14 WAE. Yield components (ear mass, number of grains per ear and 100 grain weight) and grain yield significantly increased ($P<0.001$) from planting on the flat, pot holes, tied ridges and were highest in the mulched treatment. Maize grain yield increased($P<0.001$) by 49.6, 103 and 136% of the maize grain yield harvested from the flat planting(1593.36 kg ha^{-1}) in the pot-holing, tied ridging and mulching treatments, respectively. The results of this study indicate that mulching, tied ridges and pot holes, in decreasing order of effectiveness, have potential to increase soil moisture content and reduce the damage caused by drought stress to maize growth and grain yield and therefore recommended for farmers in Nyagatare and other drought prone regions.

Keywords: Water harvesting; Percent soil water; Growth; Grain yield

Introduction

Moisture stress is a major limiting factor to maize grain production in semi-arid parts of the world (Bruce *et al*., 2002). Water deficits are triggered when the soil is drying from field capacity and evaporative loss of water exceeds passive water movement into plant roots. The evaporative demand of the atmosphere depends on its relative humidity and temperature. Hot dry conditions accompanied by drying soil are associated with water deficits that cause stress and damage to plant processes and growth. Recurrent droughts, mid-season droughts and delayed start and premature end of the season are the major cause of water stress to plants and are responsible of widespread food shortages in semi-arid areas in sub-Saharan Africa (SSA).

Climate change scenarios generally indicate higher temperatures for most of Africa, although projections for precipitation vary from slight increases in West Africa and slight decreases in Southern Africa (Washington *et al*., 2004; Stige *et al*., 2006). However, there is greater consensus about a higher climate variability which will lead to an increase in both intra- and inter-seasonal drought and flood events and greater uncertainty about the onset and end of the rainy season. Climate change is posing the greatest threat to agriculture and food security in the 21st century, particularly in many of the poor, agriculture-based countries of SSA with their low capacity to effectively cope (Shah *et al*., 2008; Nellemann *et al*., 2009).

Irrigation is poorly developed in SSA compared to other regions of the world. African countries only irrigate 6 percent of their total cropland compared to a world average of 18 per cent mainly due to low investments in irrigation infrastructure (Svendsen *et al*., 2009). Water harvesting using *in situ* techniques constitutes a simpler, more affordable and adoptable technology for resource poor smallholder farmers in SSA compared to irrigation with its large investments in water impoundments and delivery systems. *In situ* water harvesting techniques increase the amount of water stored in the soil profile by trapping or holding rainwater where it falls, it involves small movements of rainwater as surface runoff, in order to concentrate the water where it is required in the root zone of

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the crop (UNEP, 1997). *In situ* water harvesting techniques such as pot-holing, ridging, tied ridging, pit planting and mulch ripping reduce runoff and hold water long enough to allow most of it infiltrate into the soil. The benefits of *in situ* water harvesting are reduction in runoff and erosion and increased infiltration and storage of water in the soil profile which delay the onset and occurrence of severe water stress thereby buffering the crop against damage caused by water deficits during dry periods (Nyamadzawo *et al*., 2013).

In situ water harvesting improved crop yields, food security and livelihoods in SSA. Mmbaga and Lyamchai (2001) reported maize grain yield increased from 0.8 t ha^{-1} on flat planting to 2.3t ha^{-1} with tied ridges in northern Tanzania in a season with less than 500 mm rainfall. However with higher rainfall of 800 mm, there was no maize grain yield advantage recorded with tied ridges, ridges and pit planting when compared to flat planting (Mmbaga and Lyamchai, 2001). Other studies have shown that the effectiveness of *in situ* water harvesting techniques was dependent on soil textural class because of its influence on water holding capacity and drainage characteristics of the soil. Dagg and McCartney (1968) showed that tied ridges produced significantly more grain yield than flat planting only on vertisols but not on alfisols and andisols. Belay *et al*. (1998) recorded higher maize grain yield in Ethiopia on tied ridges than flat planting in two soil types (entisols and vertisols), with the effect of the tied ridges generally better in drier seasons and when the ends of the ridges were tied.

Maize (*Zea mays* L.) is one of the most important food crops grown in Rwanda. It ranks second to sorghum among cereals and third to all crops, covering 10% of the total cultivated land after beans (25%) and banana (22%). Maize production is rapidly expanding from the highlands (>1700 m altitude) where it was mainly grown before 1996 to the moist mid-altitude (1450-1700 m altitude) and the semi-arid low altitude zone (900-1450 m altitude) (ISAR, 2009) where temperatures are higher and more suitable for maize. Most of the maize in Rwanda is now grown in the semi-arid low altitude agro-ecologies of the Eastern Province which contributed 45% of the total maize grain harvest (79 500 t) produced in the 2008 season in Rwanda compared to 33% from highlands (National Institute of Statistics of Rwanda, 2010). The shift in maize production from the highlands and moist middle altitude to the semi-arid low altitude agro-ecologies has greatly increased the risk of crop failure due to droughts. Maize production decreased by 60.3% from a peak production of 508,000 t in 2011 to 200,000 t in 2012 (www.indexmundi.com) due to widespread crop failures caused by low and erratic rainfall in 2012 season in the low altitude semi-arid agro-ecology of the Eastern province where maize is now mainly grown. There is no information on the potential benefits from the use of *in situ* water harvesting techniques to trap rainfall, increase infiltration and soil water content on maize growth and yield in the semi-arid low altitude agro-ecologies of Rwanda. The objective of this study was determine the effect of *in situ* rain water harvesting techniques (pot-holes, tied ridges and mulching) on soil moisture content, maize growth and grain yield at Nyagatare, Rwanda.

Materials and Methods

The study was carried out at Agricultural Processing Industry (API) farm owned by the Rwandan army at Gabiro (1° 18' 0.00"S, 30° 19' 30.00"E, altitude 1400 m) in Nyagatare district in the Eastern Province of Rwanda. The district of Nyagatare is located in the north-east of Rwanda and shares a border with Uganda to the north and Tanzania to the east (Fig. 1). Soils are fersiallitic oxisols loams with 30% clay, pH of 5.8 and 3.2% organic matter (Table 1) and have been under continuous cultivation for less than twenty years as Nyagatare district was only settled after the 1994 war in Rwanda. Rainfall ranges between 800-1000 mm with a bimodal distribution consisting of season A (September to January) and season B (February to May) with approximately half the rainfall (400-500 mm) received in each season.

Three *in situ* water harvesting treatments (pot-holes, tied ridges and mulching) were compared to control treatment with planting on the flat. The experiment was laid out as randomized complete block design of treatments replicated three times. The experiment was planted in season A in 2011/2012 season on 10^{th} October 2011. The land was disc ploughed using a tractor to a depth of 25cm and plots were marked. Plots were 4.5 m × 4.5m in size with 5m wide pathways around each plot within a block to avoid inter-plot treatments effects. A short season open pollinated variety ZM 607® (Crop Breeding Institute, Zimbabwe) was planted at 75 cm × 25 cm spacing for a target maize population of 53333 plants ha^{-1}. A basal compound fertilizer (N 17%, P_2O_5 17% and K_2O 17%) was applied into the planting station at 200 kg ha^{-1} at planting before two maize seeds were placed to one side of the fertilizer and the planting station covered. The maize crop was thinned to one plant per station three weeks after emergence (WAE). At the same time, all plots were hoe weeded and *in situ* water harvesting treatments were applied. Pot holes consisted of 30 cm long × 20 cm wide × 15 cm deep holes on alternate row centers spaced 50 cm apart. Tied ridges were produced by scooping soil towards the maize plants in the row, forming a 15cm deep furrow between the rows and placing a cross-tie to hold water within the furrow every meter. The mulching treatment consisted of application of soybean crop residues to achieve 100% soil cover. At five WAE, the crop was hoe-weeded and top dressed with urea (46% N) nitrogen fertilizer at 200 kg ha^{-1} and a third hoe weeding was done at 9 WAE.

Percent soil moisture content was measured using the gravimetric method at 8, 11 and 14 WAE. Soil samples were collected to a depth of 25 cm using a soil auger at five randomly distributed points within each plot and immediately sealed in plastic bags. The soil samples were weighed using a precision balance, oven dried for 48 h at

105°C and re-weighed. The difference in mass between the wet and the dry soil sample was expressed as percent soil moisture content. The mean percent moisture content from five samples is presented. Two maize plants were randomly selected from the two border rows at 8, 11 and 14 WAE, cut at ground level and dried for 24 h at 85°C to a constant mass and then weighed. Maize grain yield was measured after physiological maturity from 3 m × 4.5 m net plot consisting of four middle rows in each gross plot. A random sample of five ears were selected from each plot and ear mass, number of grains per ear and 100 grain weight determined. Grain moisture content was measured using a moisture meter and grain yield and 100 grain weight adjusted to 12.5% moisture content before statistical analysis.

Data from the study was subjected to analysis of variance (ANOVA) using Genstat Discovery 12th Edition statistical package. Means were separated using ± standard error of the difference when F-test showed significant treatment effects at P<0.05.

Results

Season A in the 2011/2012 growing season at Gabiro, Nyagatare was characterized by low monthly rainfall totals of below 100 mm per month and premature end of the season with little rain falling in January when the crop was at grain filling stages (Fig. 2). Total rainfall in season A was 228.1 mm in comparison to 400-500 mm which is normally expected.

Percent soil moisture significantly increased (P<0.001) from flat planting, pot-holing to tied ridging and was highest in the mulching treatment at 8, 11 and 14 WAE. There was no difference in percent soil moisture content at 14 WAE between the pot-holing and tied ridging treatments (Fig. 3). The dry weight of maize plants significantly increased (P<0.001) from flat planting, pot-holing to tied ridging treatment and was highest in the mulching treatment at 8, 11 and 14 WAE (Fig. 4). Maize grain yield followed the soil moisture and maize plant dry weight trends and significantly increased (P<0.001) by 49.6, 103 and 136 percent of the maize grain yield harvested from the flat planting control in the pot-holing, tied ridging and mulching treatments respectively (Table 2). Maize yield components viz. ear mass, number of grain per ear and 100 grain weight were similarly increased (P<0.001) by the *in situ* water harvesting techniques, with highest values obtained in the mulching treatment and the lowest in the flat planted control (Table 2).

Correlation coefficients (Pearson r) between maize grain yield and percent soil water content (PWC) showed that maize grain yield was significantly correlated (P<0.05) with percent soil water content with *in situ* water harvesting treatments at 8 and 11 WAE but not at 14 WAE (P>0.05). Maize grain yield was significantly correlated (P<0.05) to number of grains per ear but not to ear mass and 100 grain weight. Ear mass was only significantly correlated

Table 1: Mineral composition of soil at Gabiro site, Nyagatare, Rwanda before planting the experiment in October 2011

Soil property	Value	Soil property	Value	Soil property	Value	Soil property	Value
pH (1.1)	5.8	OM (%)	3.2	Mg (meq 100 g^{-1})	1.8	Zn (mg kg^{-1})	1.6
E.C.(1.1) (nmhos/cm)	0.50	P (mg kg^{-1})	15	Na (meq 100 g^{-1})	0.14	Mn (mg kg^{-1})	323.1
NH_4-N (mg kg^{-1})	16.0	K (mg kg^{-1})	349	S (mg kg^{-1})	43	Cu (mg kg^{-1})	3.0
NO_3-N (mg kg^{-1})	13.6	Ca (meq 100 g^{-1})	4.6	B (mg kg^{-1})	0.61	Fe (mg kg^{-1})	133

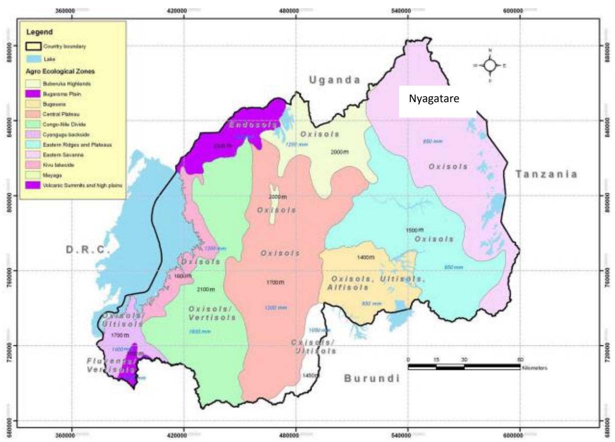

Fig. 1: Soil and altitude map of Rwanda showing the location of Nyagatare in the semi-arid low altitude savanna agro-ecology on oxisols

(P<0.05) to late season percent water content of soil at 14 WAE and not mid-season at 8 and 11 WAE. In contrast, number of grains per ear was significantly correlated to mid-season soil moisture content at 8 WAE (P<0.05) and 11 WAE (P<0.01) and not (P>0.05) in the late season at 14 WAE. The 100 grain weight was not significantly correlated (P>0.05) to percent soil moisture mid-season at 8 and 11 WAE but had a highly significant relationship (P<0.01) to late season percent soil moisture content at 14 WAE. The 100 grain weight was highly related (P<0.001) to ear mass but did not have a significant relationship with number of grains per ear (Table 3).

Discussion

This study demonstrated the beneficial effects of *in situ* water harvesting techniques on percent soil water, maize growth and grain yield in a below-normal rainfall season that ended early in a semi-arid low altitude agro-ecological zone in Rwanda.

Maize grain yield was increased by 50, 103 and 136 percent compared to flat planting in the pot-holing, tied ridging and mulching treatments in this study. Further, the

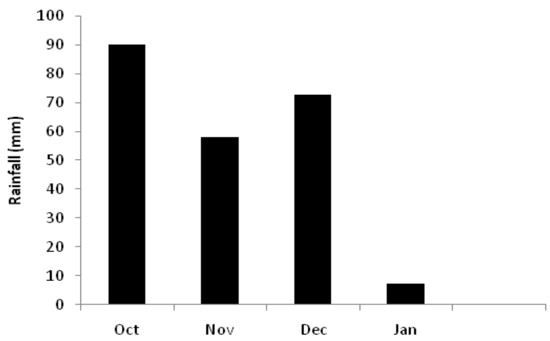

Fig. 2: Monthly rainfall in season A at Gabiro, Nyagatare district, Rwanda in the 2011-2012 growing season

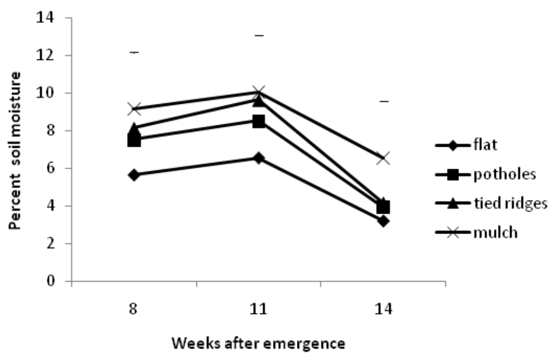

Fig. 3: Percent soil moisture to 25 cm depth in *in situ* water harvesting treatments in season A in the 2011-2012 growing season. Error bars represent ± standard error of the difference at 8 WAE (±0.131, 6 d.f.), 11 WAE (±0.106, 6 d.f.) and 14 WAE (±0.088, 6 d.f.) for comparison of in-situ water harvesting technique means at each week.

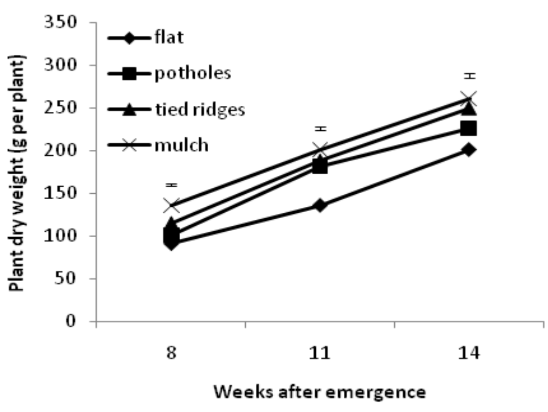

Fig. 4: Dry weight of maize plants in *in situ* water harvesting treatments in season A in the 2011-2012 season. Error bars represent ± standard error of the difference at 8 WAE (±1.468, 6 d.f.), 11 WAE (±2.807, 6 d.f.) and 14 WAE (±5.52, 6 d.f.) for comparison of in-situ water harvesting technique means at each week

differences in effectiveness in the capture and storage of rainfall within the soil recorded in these *in situ* water

Table 2: Effect of in-situ water harvesting treatments on grain yield and its yield components at Gabiro, Nyagatare district, Rwanda in season A in the 2011-2012 growing season

Treatment	Grain yield (kg per ha)	Ear mass (kg per ear)	No. of grains per ear	100 grain weight (g)
Pot holes	2384.51 b	0.12 b	350.10 b	26.10 b
Tied ridges	3233.35 c	0.15 c	423.50 c	27.05 c
Mulch	3770.80 d	0.22 d	450.90 c	30.33 d
Flat	1593.36 a	0.09 a	237.70 a	24.58 a
P value	<.001	<.001	<.001	<.001
± S.e.d	195.323	0.0123	27.71	0.650
CV (%)	8.4	1.7	2.9	1.3

Means followed by the same letter in a column are not significantly different at P<0.05

Table 3: Correlation coefficients (Pearson r) among maize grain yield, percent soil water content (PWC) at 8, 11 and 14 WAE and yield components of maize

	Grain yield	PWC at 8 WAE	PWC at 11 WAE	PWC at 14 WAE	Ear mass	No of grains per ear	100 grains weight
Grain yield	X	X	X	X	X	X	X
PWC at 8 WAE	0.98*	X	X	X	X	X	X
PWC at 11 WAE	0.98*	0.98*	X	X	X	X	X
PWC at 14 WAE	0.87 ns	0.87 ns	0.78 ns	X	X	X	X
Ear mass	0.94 ns	0.92 ns	0.86 ns	0.94*	X	X	X
No of grains per ear	0.98*	0.98*	0.99***	0.98 ns	0.98 ns	X	X
100 grain weight	0.94 ns	0.92 ns	0.86 ns	0.93**	0.92***	0.87 ns	X

*significant at P<0.05, **significant at P<0.01, ***significant at P<0.001, ns not significant

harvesting treatments at 8 and 11 WAE was significantly correlated to the maize grain yield. *In situ* water harvesting techniques therefore, increased crop growth and economic yield by increasing soil available water. Tied ridges (Belay *et al*., 1998; Mmbaga and Lyamchai, 2001; Araya and Stroosnijder, 2010) and mulching (Lal, 1974; Ramakrishna *et al*., 2006) were beneficial in increasing crop yields in seasons with below-normal rainfall in semi-arid environments. Pot-holes were relatively less effective than tied ridges in increasing maize grain yield compared to the control, most probably, because they were placed on every alternate row, while tied ridges were placed on every row and potholes captured and stored less water in the soil. Mulching was the most effective treatment in capturing and storing moisture in the soil and concomitantly had the highest maize dry weights and grain yield among the three *in situ* water harvesting treatments. The maize crop residues not only reduced runoff and allowed the rain water to infiltrate into the soil but reduced soil temperatures and loss of water from the soil caused by evaporation as reported by Lal (1974) and Ramakrishna *et al*. (2006). Pot-holes and tied ridges only reduced runoff and enhanced infiltration of water into the soil and did not reduce evaporation of water from the soil, hence the lower percent soil moisture, plant dry weights and grain yield recorded in these treatments compared to mulching in this study.

Maize grain yield was significantly correlated to soil moisture content mid-season at 8 and 11 WAE but not late season at 14 WAE. No meaningful rainfall was received after 11 WAE and by 14 WAE, low soil moisture levels most likely reduced grain filling equally across all *in situ* water harvesting treatments, explaining the lack of correlation between maize grain yield and percent soil moisture recorded at 14 WAE in this study. Number of grains per ear was the only yield component that was significantly correlated to maize grain yield in this study. Tollenaar (1977) and Fischer and Palmer (1984) also reported that kernel number per unit area was the most important determinant of maize grain yield. Number of grains per ear was significantly correlated to percent soil moisture content at 8 and 11 WAE but not at 14 WAE, similar to grain yield. Number of grains per ear is strongly correlated to crop growth rate during the critical period bracketing silking (Aluko and Fischer, 1987; Cirilo and Andrade, 1994) which occurred at 10 WAE. Our results not only confirmed the strong relationship between number of grains per ear and grain yield but indicate that positive effects of *in situ* water harvesting techniques on maize grain yield were expressed through increases in number of grains per ear. Ear mass and 100 grain weight were significantly correlated with percent moisture content late season at 14 WAE but not at 8 and 11 WAE because ear formation and grain filling (100 grain weight) occur late in the season after pollination at 10 WAE. Pollination was followed by ear growth and grain filling which were affected by percent soil water content at 14 WAE. The highly significant correlation between number of grains per ear and ear mass show that number of grains was a more important determinant of ear mass than 100 grain weight in this study.

The results of this study suggest that pot holing can increase maize grain yield by 50 percent and tied ridging and mulching can potentially double it in the semi-arid agro-ecology where maize is increasingly being grown in Rwanda. These *in situ* water harvesting techniques are recommended for incorporation into the production practices of smallholder farmers in semi-arid areas to increase the resilience of crop production systems against droughts that are predicted to increase in frequency and severity because of climate change in SSA.

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References

Aluko, G.K. and K.S. Fischer, 1987. The effect of changes of assimilate supply around flowering on grain sink size and yield of maize (*Zea mays* L.) cultivars of tropical and temperate adaptation. *Aus. J. Agric. Res.,* 38: 153–161

Araya, A. and L. Stroosnijder, 2010. Effects of tied ridges and mulch on barley (*Hordeum vulgare*) rainwater use efficiency and production in northern Ethiopia. *Agric. Water Manag.,* 97: 841–847

Belay, A., H. Gebrekidan and Y. Uloro, 1998. Effect of tied ridges on grain yield response of maize (*Zea mays* L.) to application of crop residue and residual N and P on two soil types at Alemaya, Ethopia. *S. Afr. J. Plant Soil*, 15: 123–129

Bruce, W.B., G.O. Edmeades and T.C. Barker, 2002. Molecular and physiological approaches to maize improvement for drought tolerance. *J. Exp. Bot.,* 53: 13–25

Cirilo, A.G. and F.H. Andrade, 1994. Sowing date and maize productivity II: kernel number determination. *Crop Sci.,* 34: 1044–1046

Dagg, M. and J.D. McCartney, 1968. The agronomic efficiency of the NAE mechanized tied ridge system of cultivation. *Exp. Agric.,* 4: 279–294

Fischer, K.S. and A.F.E. Palmer, 1984. Tropical maize. *In: The Physiol. Trop. Field Crops*. Pp: 213–248. P.G. Goldsworthy and N.M. Fisher (eds). John Wiley and Sons, New York

Lal, R., 1974. Soil temperature, soil moisture and maize yield from mulched and unmulched tropical soils. *Plant Soil,* 40: 129–143

Mmbaga, T.E. and C.Y. Lyamchai, 2001. Drought management options in maize production in northern Tanzania. *In: Seventh Eastern and Southern Africa Regional Maize Conference*. Pp: 281–287, 11–15th February 2011, Nairobi, Kenya

National Institute of Statistics of Rwanda, 2010. *National Agricultural Survey (NAS*) 2008. Pp: 1–249, Kigali, Rwanda

Nellemann, C., M. MacDevette, T. Manders, B. Eickhout, B. Svihus, A. Prins, A. and B. Kaltenborn, 2009. *The Environmental Food Crisis. The environment's role in averting future food crises. A UNEP rapid response assessment. GRID–Arendal Publishers,* United Nations Environment Programme

Nyamadzawo, G., M. Wuta, J. Nyamangara and D. Gumbo, 2013. Opportunities for optimizing in–field water harvesting to cope with changing climate in semi–arid smallholder farming areas of Zimbabwe. *Springerplus,* 2: 1–9

Ramakrishna, A., H.M. Tam, S.P. Wani and T.D. Long, 2006. Effect of mulch on soil temperature, moisture, weed infestation and yield of groundnuts in northern Veitnam. *Field Crop Res.,* 95: 115–125

Shah, M., G. Fischer, and H. van Velthuizen, 2008. *Food Security and Sustainable Agriculture. The Challenges of Climate Change in Sub–Saharan Africa.* International Institute for Applied Systems Analysis, Laxenburg, Austria

Stige, L.C., J. Stave, K.S. Chan, L. Ciannelli, N. Pretorelli, M. Glantz, H.R. Herren and N.C. Stenseth, 2006. The effect of climate variation on agro–pastoral production in Africa. *Proc. Nat. Acad. Sci.,* 103: 3049–3053

Svendsen, M., M. Ewing and S. Msangi, 2009. Measuring irrigation performance in Africa. *International food policy research institute discussion paper 00894*. Washington DC, USA

Tollenaar, M., 1977. Sink source relationships during reproductive development in maize. Qa review. *Maydica,* 22: 49–75

UNEP, 1997. *Source book of alternative technologies for fresh water augmentation in Latin America and the Caribbean*. International Environmental Technology Center, United Nations Environment Programme, Washington DC, USA

Washington, R., M. Harrison and D. Conway, 2004. African climate report: A report commissioned by the UK Government to review African climate science, policy and options for action. Pp: 45, DFID/DEFRA, London, UK

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