Research article

Sorghum (*Sorghum bicolor L.*) yield response to rainwater harvesting practices in the semi-arid farming environments of Zimbabwe: A meta-analysis

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ABSTRACT

Rainwater harvesting practices are increasingly gaining recognition as viable adaptation strategies to overcome rainfall variability caused by climate change in semi-arid regions of Zimbabwe. A meta-analysis was conducted to provide a comprehensive quantitative synthesis of biophysical conditions (rainfall, soil texture, N fertility, mulch) under which basins, rippers, and tied ridges affected sorghum yields in semi-arid areas of Zimbabwe. Rainfall amount (<600 mm, 600–1000 mm), soil texture (20 % clay, 20–35 % clay), mulch (basin + mulch, ripper + mulch, tied ridges + mulch), and fertility (0–30 kg N/ha, 30–100 kg N/ha) were used to evaluate the response of sorghum grain yield to rainwater harvesting practices. Grain yield response was compared to the control (conventional practice) using the weighted mean yield difference approach. The results showed comparable sorghum grain yields in all the rainwater harvesting practices across the biophysical conditions, except under rainfall and soil textural classes. Tied ridges had a significant ($p < 0.05$) negative sorghum grain yield response (-0.25 t/ha) under <600 mm of rainfall, while ripper planting resulted in a substantial negative grain yield response (-0.32 t/ha) under 600–1000 mm of rainfall. Ripper planting reduced grain yield significantly ($p < 0.05$) (-1.06 t/ha) in soils with 20–35% clay. The results suggest that basins, rippers, and tied ridges did not improve sorghum grain yield across all agronomic conditions.

1. Introduction

Agriculture remains a source of livelihood and food security for the majority of sub-Saharan Africa's population with about 95% of agriculture being rain-fed (Singh et al., 2011; Unganai and Murwira, 2010) and subsistence-based (Ndlovu et al., 2020). In sub-Saharan Africa agricultural productivity has not increased substantially over the past decades (Giller, 2020), with increases largely due to crop extensification rather than intensification (FAO, 2017). From an agronomic point, poor soil fertility and droughts are the primary factors that limit agricultural productivity. The seasonal and annual rainfalls in semi-arid regions are highly unpredictable and variable with more risk of crop failure (Gissila et al., 2004; Hadebe et al., 2020; Tesfaye and Walker, 2004), which increased the challenge of food, nutrition, and income security among the smallholder farmers (Gernot et al., 2015).

In Zimbabwe, more than 70 % of smallholder farmers depend on rainfed agriculture and live in semi-arid regions, covering about 23% of the total land area (Chuma and Hagmann, 1998) having 40% of the population being food insecure (WHO, 2020). Farming under the semi-arid smallholder system is characterized by low levels of production technology and production is primarily subsistence with a little marketable surplus. Drought causes severe reductions in grain yields and significant economic losses to farmers. To overcome the deterioration in food security in Zimbabwe, the government gave agricultural input aid in the form of seed and fertilizers to communal and resettled farmers as an agricultural recovery strategy (Foti et al., 2007). However, not much benefit has been achieved from the subsidized input scheme especially in the semi-arid regions because input type and variety did not tally with the agro-ecological location of the farmer (Foti et al., 2007; Mukarumbwa and Mushunje, 2010). Production of traditional cereal crops and

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equipping farmers with improved soil, water, and crop management practices served as an important strategy to achieve food security in the semi-arid farming regions (Ndlovu et al., 2020).

Sorghum (*Sorghum bicolor L.*) is one of the most important food crops promoted in semi-arid regions where precipitation and fertility are low and highly variable. It is highly adapted to marginal, complex, and difficult environments and contributes significantly to the diversification and resilience of agro-ecologies (Chivenge et al., 2015). Although the crop is widely recognized as well as adapted to semi-arid environments it fails in some years (Nyamudeza and Maringa, 1992) because production is entirely rain-fed in small-scale farming systems (Ndlovu et al., 2020). The yield of sorghum had not increased over the years because small-holder growers lack adequate sustainable production knowledge to increase yields above subsistence level even in years of good rainfall. Productivity has stagnated below 0.5 t/ha which is below the average yield of 3–5 t/ha that can be produced under rain-fed agriculture (Magombeyi et al., 2018). To overcome the hydro-climatic risks and soil-related constraints to crop production, farmers employed a variety of soil and water management technologies to reduce the yield gap between the actual and maximum yield (Mupangwa et al., 2006, 2012a; Musiyiwa et al., 2017). Increasing water productivity through adoption of rain-water harvesting practices was an option that focused on manipulating water balance to minimize runoff and soil erosion while enhancing land and crop water productivity (Kahinda et al., 2007; Motsi et al., 2004; Musiyiwa et al., 2017; Rockström et al., 2009). The technologies are classified into systems that prolong the duration of moisture availability in the soil e.g., conservation agriculture and mulching practices; systems that promote infiltration of rainwater into the soil which include pitting, ridging/furrowing, and terracing, and systems that store surface and subsurface runoff water for later use (Mupangwa et al., 2006; Musiyiwa et al., 2017; Rockström et al., 2002). The practices may include improving soil fertility to optimize plant water uptake and increase productivity through organic matter and mulching (Rockström et al., 2009).

Water management techniques were promoted by government extension agencies and various non-governmental organizations in Zimbabwe to make rain-fed agriculture production a source of food and livelihood security for the rural communities (Ndlovu et al., 2020). However, results from studies on rainwater harvesting in sorghum farming systems in Zimbabwe under on-farm and on-station showed different grain yields (Magombeyi et al., 2018; Nyamangara et al., 2014; Nyamudeza, 1993). In most semi-arid regions of Zimbabwe, rainwater harvesting practices considered effective include tied ridges/furrows (Motsi et al., 2004; Rockström et al., 2009; Unganai and Murwira, 2010), reduced tillage (Mupangwa et al., 2006; Rockström et al., 2009), and infiltration pits (Mupangwa et al., 2008). Dead level contours with and without infiltration pits have also been reported to increase moisture retention and crop yield (Mhizha and Ndiritu, 2013; Mugabe, 2004; Mupangwa et al., 2012a). On the contrary, ridges and tied ridges showed failures and successes (Nyamudeza, 1993). Early studies by Vogel (1993) reported no advantage on granite sands of Zimbabwe while Walton (1962) found conflicting results in Uganda. Seasonal experiments done by Nyamudeza (1993) at Chiredzi and Chisumbanje (Nyamudeza, 1993) showed varied sorghum grain yields annually for six seasons (1984/85–1990/91 under tied ridges and flat furrows). Minimum moisture benefits were reported on the use of dead level contours with and without infiltration pits (1m upslope and 3m downslope) (Mupangwa et al., 2012a). Contrasting results were also observed by Nyakudya et al. (2014) who showed that combining infiltration pits and planting pits did not improve soil moisture and yields in the Rushinga district of Zimbabwe, a semi-arid farming area with heterogeneous soils. Soko (2012) also reported sorghum grain yield variation among varieties and across locations and seasons due to rainfall variability, soil fertility, and farming systems.

Quantitative data on the contribution of rainwater harvesting practices on grain yield of sorghum and the conditions under which the technologies perform well is not fully explored considering the heterogeneity of the biophysical farming environment and socio-economic factors of the farmers (Magombeyi et al., 2018; Munamati and Nyagumbo, 2010). Despite some studies being conducted globally, to attempt to identify and understand the benefits, challenges as well as factors affecting the performance of the rainwater harvesting practices on sorghum grain yield, the results are still fragmented (Mupangwa et al., 2006; Nyamadzawo et al., 2013). Limited research studies exist with significant detail in space and time on sorghum grain yield response under rainwater harvesting practices (Tonitto and Ricker-Gilbert, 2016). The experiments did not permit the determination of robust conclusions on sorghum grain yield under the rainwater harvesting practices due to variability in soil dynamics, nutrients, varieties, management, weather processes, and their interactions. In this study, a meta-analysis was done to quantitatively analyze sorghum yield performance under basin planting, tied ridges, and ripper planting rainwater harvesting practices under variable rainfall, soils, nutrient fertility.

2. Materials and methods

2.1. Inclusion criteria for meta-analysis

Data were collected from peer-reviewed articles (journal articles, refereed book chapters and books, and published refereed conference papers). The selection criteria for research studies were based on field experiments that reported sorghum grain yield from a conventional farming-based treatment (control) compared with sorghum grain yield from a rainwater harvesting-based treatment, where at least the effects of tied ridges, planting basins, and ripper were tested (Table 1). In this study, conventional practice/farmer's practice referred to a farming practice with no rainwater harvesting or water retention techniques being used. The experiments selected were conducted in Zimbabwe under semi-arid rain-fed field conditions, where the means, standard deviations or standard errors, and samples sizes are reported directly or can be computed from the given data. Research data from the same experiment that was published in many publications were not duplicated, and the research article with the most complete dataset was chosen.

2.2. Meta-analysis treatments

Rainwater harvesting technologies were classified into categories partly based on Bayala et al. (2012), McCarthy et al. (2001), and Thiombiano and Meshack (2009). These categories were reduced tillage (ripper) and in situ water retention (tied ridges, planting basins). The conventional farming system (no rainwater harvesting) was used as the control against which the experimental rainwater harvesting practices (basins, ripper, and tied ridges) were compared.

Long-term mean annual precipitation, N fertilizer, and soil texture were used as covariate factors (Gotosa et al., 2019; Rusinamhodzi et al., 2011) for the response of sorghum grain yield to rainwater harvesting practice. Seasonal rainfall was categorized into three classes based on Rusinamhodzi et al. (2011) namely low (<600 mm) and medium (600–1000 mm). The N application rates were categorized according to Chivenge et al. (2011) into low (0–30 kg N/ha) medium (30–100 kg N/ha). Soil texture was categorized according to Chivenge et al. (2011) into Sand (<20 % clay), Loam (20–35 % clay), and Clay (>35 % clay).

2.3. Meta-analysis

The treatment means, standard deviation, and the number of replicates data sets were used to compute meta-analysis. Where Standard deviations were not presented but standard error of the mean (SE) and coefficient of variation (CV, %), were reported, Standard deviation was computed from the SE and CV as follows:

$$SD = SE \; x \; \sqrt{n} \quad \text{(Merriam and Tisdell, 2015)} \quad \text{(I)}$$

Table 1. Summary of studies used in the meta-analysis, showing details on publication, growing season the experiment was conducted, soil texture, N rates, and sample size.

Reference	Season/RF	Soil type (%)	Rainwater harvesting practice	N rate (kg/ha N)/ Mulch (t/ha)	Experiment summary
Baudron et al. (2012)	2007/8–2009/10 845; 850; mm;	Sand 65 Clay 25 Silt 75	Conventional practice, Ripper, Ripper + Mulch	0	6 treatments × 3 reps (n = 18)
Masaka et al. (2020)	2015/16; 2016/17 408; 419 mm	Sand 35 Clay 40 Silt 25	Conventional practice, basins, ripper	0; 2; 4 t/ha (mulch)	3 × 3 factorial × 3 reps (n = 27)
Chiduza et al. (1995)	1984/85; 1985/86 790 mm; 580 mm	Sand 90 Clay 5 Silt 95	Conventional practice, Ripper	0; 28; 56; 84 (MN)	5 × 2 factorial × 3 reps (n = 30)
Siambi (2010)	2007/08 Gwanda −410 mm; Matopos −380 mm	Sand 65 Clay 10 Silt 90	Conventional practice, tied ridges, Basins	0; 17.5; 35; 52.5 MN	2 × 3 factorial × 3 reps (n = 18)
Dera (2018)	2013/14; 2014/15 403; 417 mm	Sand 60 Clay 15 Silt 85	Conventional practice, ripper, basins	0; 2; 4 t/ha (mulch)	3 × 3 factorial × 3 reps (n = 27)
Mashingaidze et al. (2009)	2004/05; 2005/06 290; 800 mm	Sand 25 Clay 35 Silt 65	Mulch residue retention	Mulch – 0; 25; 50; 75; 100 %	5 treatments × 3 reps (n = 15)
Mashingaidze et al. (2012)	2008/09; 2009/10 630; 600 mm	Sand 30 Clay 35 Silt 65	Conventional practice, ripper, basins	Mulch (0; 4 8 t/ha)	3 × 3 × 2 weeding × 3 reps (n = 54)
Mashingaidze et al. (2017)	2006/07 465 mm	Sand 30 Clay 35 Silt 65	Conventional planting, ripper, basin	Mulch (0; 2; 4 t/ha)	3 × 3 factorial × 3 reps (n = 27)
Mupangwa et al. (2012b)	2006/07 832 mm	Sand 25 Clay 35 Silt 65	Conventional practice, ripper, basins	Mulch (0; 0.5; 2; 4; 8; 10 t/ha)	3 × 7 factorial × 3 reps (n = 63)
Nyakatawa et al. (1996)	1987/88; 1988/89; 1989/90 117; 203; 504 mm	Sand 90 Clay 5 Silt 95	Conventional practice, tied ridges	0; 58; 66 kg/ha N	3 × 3 factorial × 3 reps (n = 27)
Nyakatawa (1996)	1990/91	Sand 90 Clay 5 Silt 95	Conventional practice, tied ridges	0; 25; 50 75 kg/ha N	3 × 4 factorial × 3 reps (n = 36)
Nyakatawa et al. (2001)	1995/96; 1996/97 540; 905 mm	Sand 90 Clay 5 Silt 95	Conventional practice, tied ridges	N (0; 30; 60; 90 kg/ha N)	2 × 4 factorial × 3 reps (n = 24)
Nyamudeza (1999)	1984/85–1990/91	Sand 90 Clay 5 Silt 95	Conventional practice, tied ridges		(n = 18)
Soko (2012)	500 mm; 750–1000 mm	Sand 65 Clay 25 Silt 75	Conventional practice, tied ridges	50; 75 kg/ha N	2 × 16 factorial × 3 reps (n = 96)

NB: RF – rainfall, MN – mineral nitrogen, reps – replications.

$SD = \frac{CV\%}{100} \times X$ (Nyamangara et al., 2014) (II)where X is the mean of the rainwater harvesting practice.

In cases where the LSD was not reported in the articles, the LSD was calculated by taking the smallest difference between the mean values of treatments that were still significant (Corbeels et al., 2014). Continuous or measurable variables are frequently reported as 'weighted mean difference (WMD)', and for ease of understanding and making inference, mean differences were used for the analysis (Corbeels et al., 2014; Nyamangara et al., 2014; Rusinamhodzi et al., 2011). Mean differences between treatments and control were used (Eq. (III)). Mean differences were weighted to determine overall effect estimates and to assess the consistency of treatment impact across studies. The reciprocal of the calculated variance was used to weight individual research (Eqs. (IV) and (V)) (Gotosa et al., 2019; Rusinamhodzi et al., 2011).

Mean difference (MD) $= Mean_{treat} - Mean_{control}$ (Nyamangara et al., 2014; Rusinamhodzi et al., 2011) (III)

$Weight_i = \frac{1}{variance_i} = \frac{1}{SD_i{}^2}$ (Gotosa et al., 2019) (IV)

Weighted mean difference (WMD)$_{overall} = \frac{\sum_{i=1}^{i=n}(weight_i \times MD_i)}{\sum_{n=1}^{i=n}(weight_i)}$ (Ellis, 2010) (V)

Confidence Interval$_{95\%} = Mean_{overall} \pm [1.96 \times (Variance_{overall})^{0.5}]$ (Merriam and Tisdell, 2015) (VI)

Where 1.96 is the z value for the 95% confidence interval.

$Variance_{overall} = \frac{1}{\sum_{n=1}^{i=n}(weight_i)}$ (Gotosa et al., 2019) (V)

The random-effect model was used to compute the effect size because it accounts for both within and between-study variance (Corbeels et al., 2014; Gotosa et al., 2019). In addition, the model can include covariates to reduce heterogeneity. The mean effect size was substantially different

from zero for the overall mean effect significance test if its 95 percent confidence interval does not overlap with zero (Eqs. (VI) and (V)). Stata/MP 16.0 statistical software was used to perform the effect size in meta-analysis.

3. Results

3.1. Sorghum yield responses to rainwater harvesting practices under different rainfall regimes

The results showed that the overall effect size of planting basins for rainfall less than 600 mm did not have a significant effect (p > 0.05) on the grain yield of sorghum (Figure 1a), while tied ridges showed a significant negative effect size (−0.25 t/ha) on sorghum grain yield under the same rainfall category (Figure 1b). There was no yield advantage for planting basins over conventional planting, while tied ridges showed considerable yield depression There was no experimental data on ripper planting in areas with less than 600 mm of rainfall.

In moderate rainfall (600–1000 mm), ripper planting had a significant overall effect size (p < 0.05) with a weighted mean difference of −0.32 t/ha (Figure 2a). Ripper planting showed no yield benefit over conventional planting since the effect size was in favor of conventional planting. The overall effect size was not significant on sorghum grain yield under tied ridges in areas receiving rainfall of 600–1000 mm (Figure 2b). A weighted mean difference of −0.29 t/ha was shown, implying no yield difference between tied ridges and conventional planting. There was no experimental data on basin planting in the 600–1000 mm rainfall range.
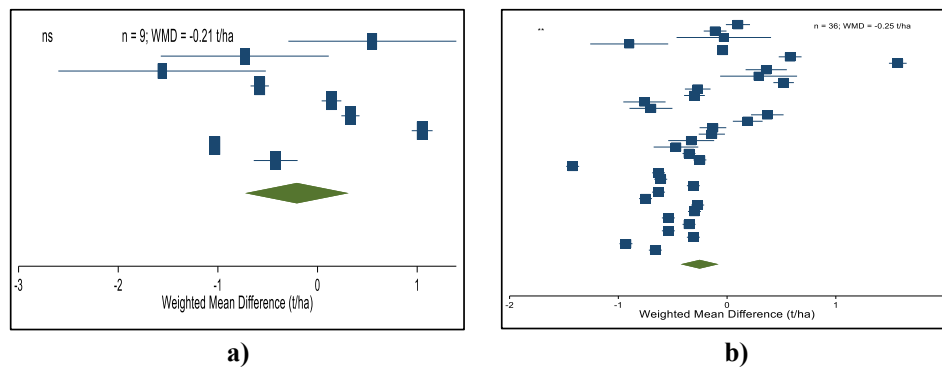
Figure 1. Weighted mean differences in sorghum grain yield in a) Planting basins and b) tied ridges in areas with <600 mm of rainfall. ns denote no significant differences, ** denote significant differences at p < 0.05.
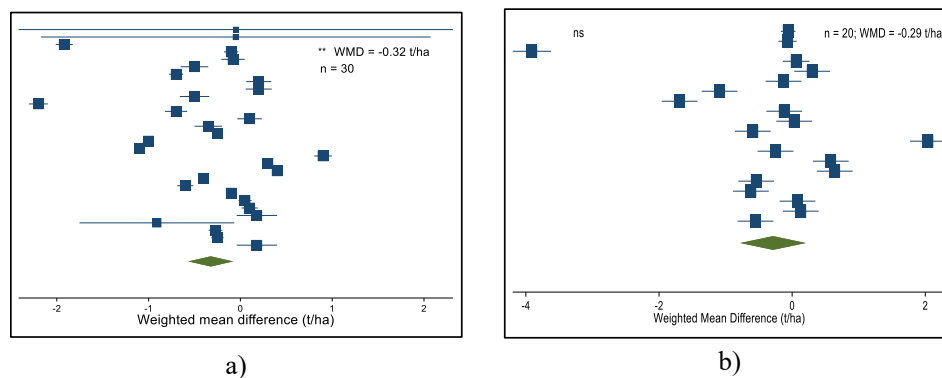

Figure 2. Weighted mean differences in sorghum grain yield in a) Ripper planting and b) tied ridges under 600–1000 mm rainfall range. ns denote no significant differences, ** denote significant differences at p < 0.05.

3.2. Sorghum yield responses to rainwater harvesting practices under different soil textural classes

Sorghum grain yield was not significantly affected (p < 0.05) by the overall effect size of planting basins, ripper planting, and tied ridges in soils with less than 20 % clay. The weighted mean differences in water retention methods of planting basins, ripper planting, and tied ridges were 0.11 t/ha (Figure 3a), −0.17 t/ha (Figure 3b), and 0.09 t/ha (Figure 3c), respectively.

A significant (p < 0.05) negative overall effect size was shown by ripper planting with a weighted mean difference of −1.06 t/ha under soil textural class of 20–35 % clay (Figure 4). There was no experimental data on sorghum grain yield under planting basins and tied ridges in soil textural class of 20–35 % clay.

Planting basins, ripper, and tied ridges had no significant effect size with weighted mean differences of −0.02 t/ha, −0.4 t/ha, and −0.11 t/ha, respectively, in soils with >35 % clay (Figure 5).

3.3. Sorghum yield responses to rainwater harvesting practices under mulch

The overall effect sizes on sorghum grain yield in planting basins, ripper planting, and tied ridges under mulch were not significant (p < 0.05), implying no yield gain over conventional planting (Figure 6). Mulch application to basin planting had a neutral WMD of 0 t/ha and lowered grain yield under ripper planting with a WMD of (−0.05 t/ha), while tied ridges had a positive WMD of 0.17 t/ha, albeit the impact sizes were not substantially different when compared with conventional farming systems.

3.4. Sorghum grain yield responses to rainwater harvesting practices under different N fertility categories

Soils with nitrogen fertility classes of <30 N kg/ha and 30–100 N kg/ha had no substantially different overall effect sizes (p < 0.05) (Figure 7), showing no yield advantage over conventional planting. The two soil fertility categories of <30 kg N/ha and 30–100 kg N/ha had WMD of 0.03 t/ha and 0.12 t/ha respectively. There was no experimental data on planting basins and ripper planting under the two fertility categories.

4. Discussion

Rainwater harvesting practices are arguably one of the crop intensification practices for enhancing crop productivity in Zimbabwe's rain-fed smallholder agriculture systems. The best growth responses and economic benefits are expected when moisture is not a limitation (Gotosa et al., 2019). However, the crop response to rainwater harvesting practices is influenced by factors such as rainfall variability, soil texture, mulch addition, and N fertility (Magombeyi et al., 2018). This study demonstrated that planting basins (Figure 1a) and tied ridges (Figure 1b) showed no sorghum grain yield advantage compared with the conventional farming practice when rainfall was <600 mm. Sorghum grain yield under planting basins was comparable to conventional planting. In low rainfall areas (<600 mm), poor distribution, and low short duration rainfall intensities affect the performance of rainwater harvesting techniques. Basins quickly dry up when rainfall interval is too long, and the rainfall intensity and duration are not sufficient to cause significant runoff collection leading to no grain yield differences between the rainwater harvesting technique and the conventional farming practice. In a
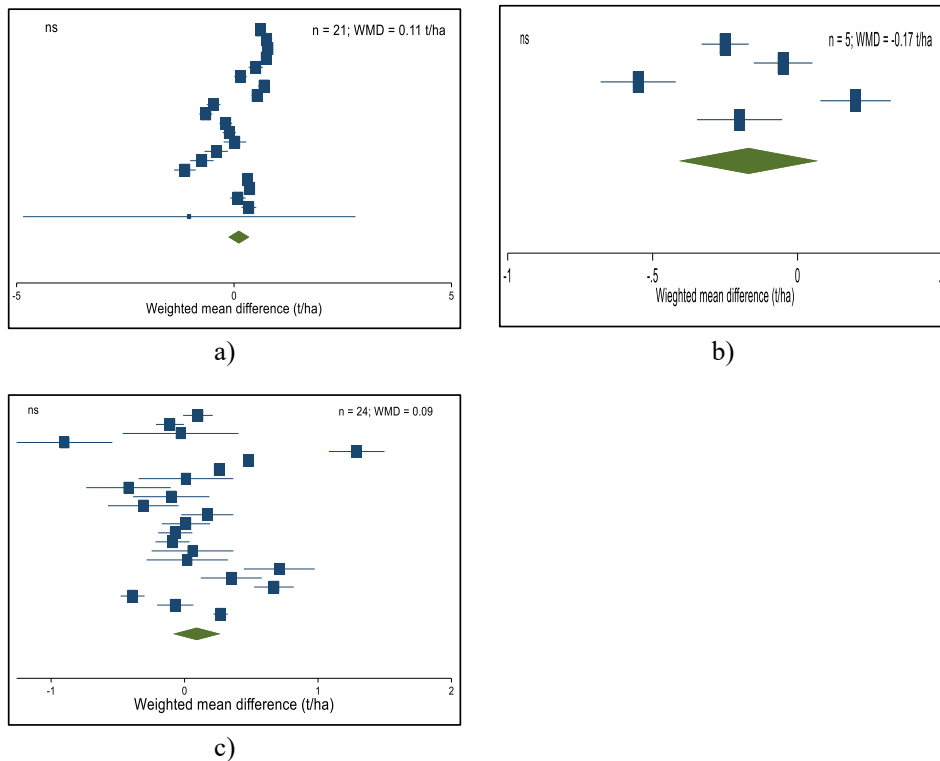
Figure 3. Weighted mean differences in sorghum grain yield under a) planting basins, b) ripper planting c) tied ridges in soils with <20 % clay. ns denotes no significant differences.
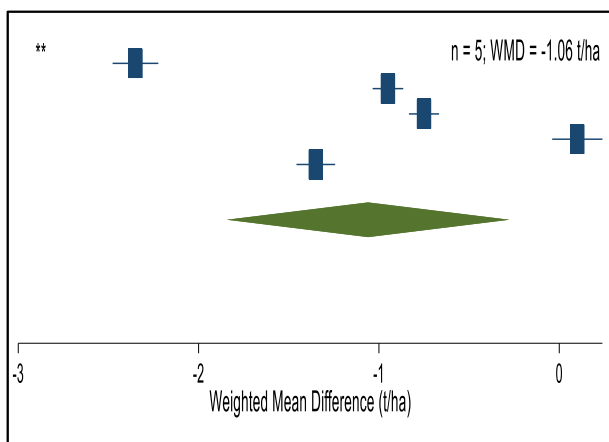

Figure 4. Weighted mean differences in sorghum grain yield in ripper planting under soil textural class of 20–35 % clay. ** denote significant differences at p < 0.05.

meta-analysis, Nyamangara et al. (2014) reported higher WMD under basin planting when the rainfall pattern was well distributed than when it was poorly distributed, showing that basins do not necessarily address the problems associated with poorly distributed rainfall. Studies by Mupangwa et al. (2008) and Rockström et al. (2009) found that in Zimbabwe, rainfall distribution is the major challenge to crop production rather than lack of it. Tied ridges showed considerable grain yield reduction compared with farmer's practice (conventional practice) when rainfall was <600 mm suggesting the absence of yield benefits of the rainwater harvesting practice. Tied ridges are made of ridges up to 20 cm high tied at intervals which allow significant water collection. Intense short-duration rainfall patterns which often occur in semi-arid regions

cause localized waterlogging making tied ridges undesirable to the crop. In high rainfall areas of 600–1000 mm, sorghum yield was significantly depressed under ripper planting (Figure 2a) while tied ridges (Figure 2b) showed negative grain yield response although not significant. The negative sorghum yield response is attributed to moisture conservation by the in-situ rainwater retention practice which compromised drainage leading to waterlogging. Waterlogging leads to aeration problems and affects nutrient uptake and crop growth (Manik et al., 2019).

There was no substantial improvement in sorghum grain yield in planting basins, ripper, and tied ridges rainwater harvesting practices compared with conventional farming practices under the different soil textural categories in Zimbabwe. The rainwater harvesting practices – basins, ripper, and tied ridges showed comparable grain yield in soils that had <20 % clay (Figure 3) implying no yield advantage over conventional planting. This may be attributed to high internal drainage exhibited by soils with low clay content rendering the rainwater retention techniques ineffective. Ripper planting showed a significant negative weighted mean difference in soils that had 20–35 % (Figure 4) implying significant yield reduction compared with conventional practice. Minimum soil disturbance in ripper planting favors termite activity which depresses yields in smallholder farming systems (Mutsamba et al., 2016). Comparable grain yields were shown by all the rainwater harvesting techniques (basins, ripper, tied ridges) when compared with conventional practice in the soil textural category with more clay content (>35 % clay) (Figure 5). However, negative yield responses were noted in all the rainwater harvesting techniques. This was attributed to clay soils exhibiting temporary waterlogging which reduces crop growth. Rainfall intensities in semi-arid areas can cause localized waterlogging and the effects are profound in heavy clays where internal drainage is relatively poor (Nyamangara et al., 2014). The reduction in crop yields on poorly drained soils under rainwater harvesting was also reported by Corbeels et al. (2014). Mupangwa et al. (2008) and Nyengerai (2010) reported the effect of waterlogging under basin planting being more
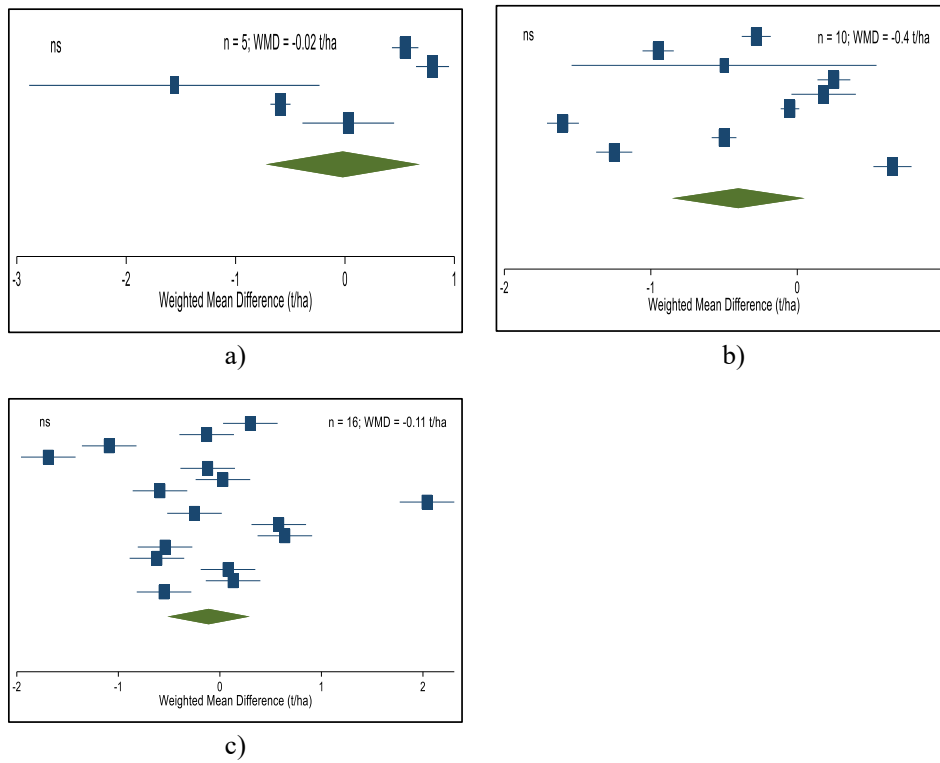
Figure 5. Weighted mean differences in sorghum grain yield under a) planting basins, b) ripper, c) tied ridges in soils with >35 % clay. ns denotes no significant differences at p < 0.05.
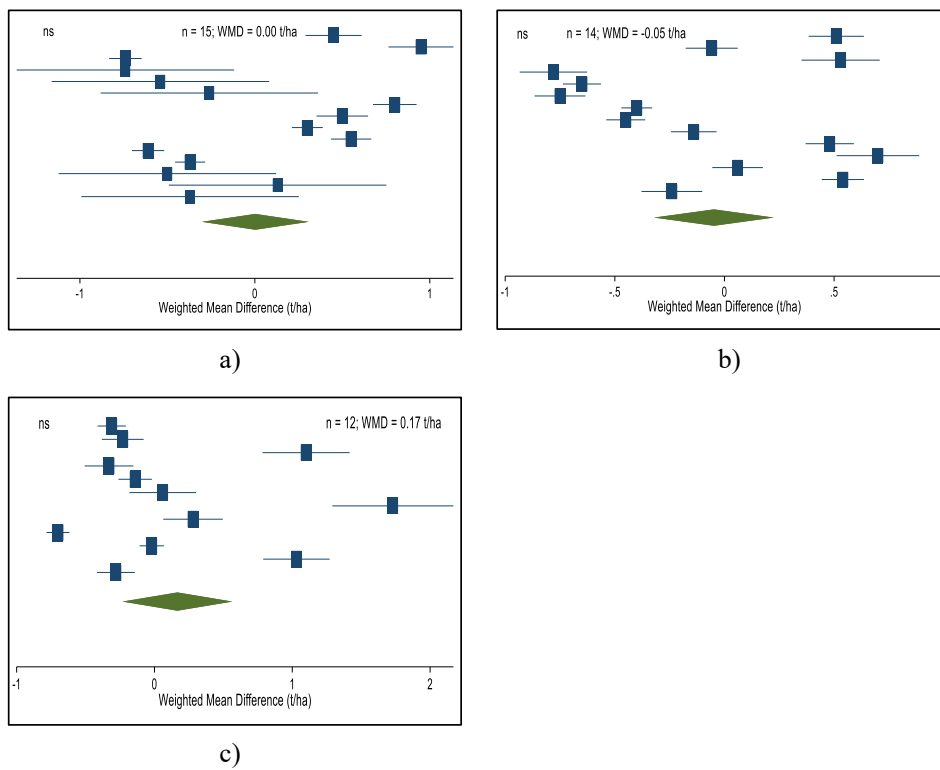

Figure 6. Weighted mean differences in sorghum grain yield under a) basin + mulch, b) ripper + mulch c) tied ridges + mulch. ns denotes no significant differences at p < 0.05.
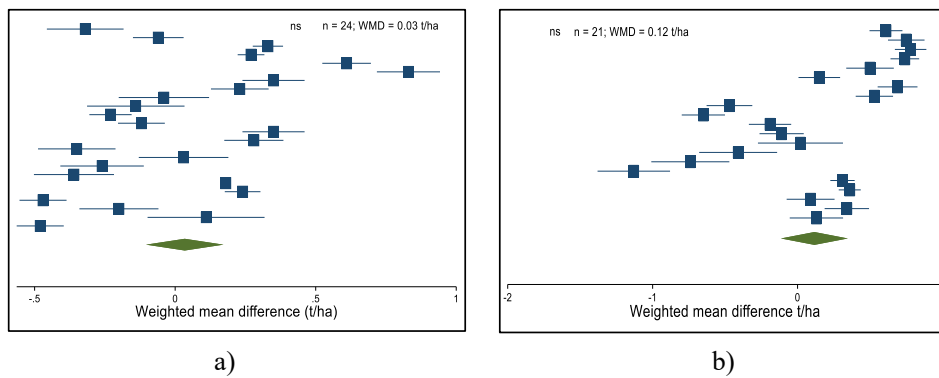
Figure 7. Weighted mean differences in sorghum grain yield in tied ridges under N fertility categories of a) 30 kg N/ha and b) 30–100 kg N/ha. ns denotes no significant differences at p < 0.05.

pronounced due to the tendency of water stagnating in plots under heavy rainfall during the early part of the season.

The addition of mulch to rainwater harvesting practices (basins, ripper, tied ridges) did not have substantial grain yield benefits over conventional farming practices (Figure 6). The use of mulch depressed yields and this was likely to be a result of the high C/N ratio in the mulch used by smallholder farmers. Micro-fauna activity incorporates the mulch into the soil and immobilizes the available N (Mandal and Neenu, 2012; Truong et al., 2019). The results on ripper + mulch farming practice were in tandem with findings by Masaka et al. (2020) who reported sorghum yield depression compared with the conventional farming practice while Mupangwa et al. (2012b) also found no substantial gain in sorghum grain yield under ripper + mulch and basin + mulch compared with the conventional practice. However, contrary to the findings, Masaka et al., (2020) reported substantial sorghum grain yield gains compared with conventional farming practice under basin + mulch farming practice.

Sorghum yield response under tied ridges did not improve despite changes in nutrient regimes (Figure 7). The yield remained comparable to conventional planting in all the nutrient categories despite N soil fertility being an important limiting factor in the smallholder farming systems. In low potential areas with very low and poorly distributed rainfall, rainfall may not be enough to cause a significant concentration of water in the furrows when needed by the crops. This causes low crop responses to rainwater harvesting and inorganic fertilizer use resulting in low benefits on crop yields as reflected by the marginal weighted mean difference under the two fertility categories. Due to inadequate soil moisture resulting from low and poorly distributed rainfall, fertilizer applications under rain-fed conditions may require extremely good timing to realize benefits in yield and economic returns under the rainwater harvesting practices. In a meta-analysis (Gotosa et al., 2019), reported that N application rates of <100 kg ha^{-1} had fewer advantages than application rates >100 kg N ha^{-1} under high potential conditions.

5. Conclusion

The rainwater harvesting practices (basins, ripper, and tied ridges) did not improve the grain yield potential of sorghum when compared with conventional farming practices under the different agronomic conditions (rainfall, soil texture, mulch, and N fertility). The rainwater harvesting practices showed comparable sorghum grain yield responses compared with farmers' practices under the different agronomic conditions. However, sorghum grain yields were depressed under tied ridges and ripper planting at < 600 mm and 600–1000 mm rainfall classes respectively. A negative grain yield response was also shown by ripper planting in soils that had 20–35 % clay. The variation in yields with varying rainfall intensities implies that farmers have to pay closer

attention to soil water management to avoid waterlogging. Similarly, the challenges caused by clay soils and mulch mean that smallholder farmers need better soil management strategies to improve sorghum's yield potential.

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