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Full Length Research Paper

Intercropping in Zimbabwe conservation agriculture systems using a farmer-participatory research approach

M. Salomons[1], A. Braul[2], L. Jazi[3] and M. H. Entz[4*]

[1]Canadian Foodgrains Bank, P. O. Box 767, Winnipeg, Manitoba, R3C 2L4, Canada.
[2]Hemp Genetics International, 906 Waterford Ave., Winnipeg, Manitoba, R3T 1G8, Canada.
[3]Score Against Poverty, P. O. Box 2732, Neshuro, Masvingo, Zimbabwe.
[4]Department of Plant Science, University of Manitoba, Winnipeg, Manitoba, R3T 2N2, Canada.

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Smallholder farmers in sub-Saharan Africa (SSA) are under increasing pressure due in part to climate change and soil degradation, with many farming households unable to achieve even basic food self-sufficiency. Conservation Agriculture (CA) is a possible solution to these challenges, but the lack of sufficient biomass for mulch has limited wide-scale adoption, and many farmers who practice CA resort to adding supplemental mulch to their CA plots. Legume intercropping would not only provide biological and nutritional diversity, it may also provide an *in situ* cover, thereby reducing the amount of mulch required for soil and water conservation. Farmer managed research experiments were used in two semi-arid areas of Zimbabwe to test whether intercropping a cereal crop [maize (*Zea mays*)] with a legume [cowpeas (*Vigna unguiculata*), lablab (*Lablab purpureus*) or pigeon pea (*Cajanus cajan*)] could increase the total amount of biomass produced. The experimental design included two replicates with legume species and presence or absence of mulch cover as factors in the design. Maize yields were increased more by adding mulch than by legume intercrops in the absence of mulch. Therefore, intercrops were not a substitute for mulch. However, adding intercrops did significantly increase the amount of total biomass (maize and intercrop dry matter) produced at the sites and therefore, in addition to contributing protein rich grains, intercrops may reduce the amount of mulch required for soil and water conservation in CA systems. Farmer participation allowed the research to be conducted in the context of small-holder CA.

Key words: Intercropping, cowpea, lablab, pigeon pea, soil conservation, farmer-based research.

INTRODUCTION

The majority of crop production in Zimbabwe is based on subsistence agriculture implemented by resource-poor smallholder farmers. Most of this crop production is characterized by limited application of inputs (due to the high cost and limited availability of agricultural inputs including seeds, fertilizers and agricultural chemicals),

*Corresponding author. E-mail: M_entz@umanitoba.ca

deteriorating soil conditions (Vagen et al., 2005) and increasingly uncertain weather patterns (Sennhenn et al., 2017).

Conservation agriculture (CA), based on crop diversity, soil cover and limited soil disturbance (Kassam et al., 2015), has been widely promoted as a solution to these challenges (Steward et al., 2018). An analysis of 48,000 smallholder farmer plots in Zambia over 3 years found overall yield benefits of CA, but only when combined with early planting (Ngoma et al., 2015). Although, global meta-analyses of the effects of CA on agricultural yields are inconclusive and sometimes controversial (Brouder and Gomez-Macpherson, 2014; Giller et al., 2015; Pittelkow et al., 2015), positive impacts have been found to be more likely under drier conditions (Pittelkow et al., 2015), which is perhaps why the evidence from southern Africa tends to be more positive. A meta-analysis of CA studies in sub-Saharan Africa showed that while crop grain yields are significantly higher in CA systems, this is dependent on including both soil surface mulch and crop rotations: the two components that are, for many smallholder farmers in SSA, the bottlenecks to adopting CA (Corbeels et al., 2014).

Researchers and farmers have experimented with CA in Africa for at least fifty years (Kannegieter, 1967; Lal, 1974). In Zimbabwe, CA trials were conducted at research stations starting in the 1950's (Smith, 1988), with up to 30% use of CA on commercial farms before 2000 (AGRITEX, 2016). Brian Oldrieve, a commercial Zimbabwean farmer, began experimenting with CA systems for smallholders in the late 1980's (Blank, 2012). This system involved using manually dug planting basins and often the use of supplemental mulching material, and was promoted as a relief intervention and as a climate smart agriculture technology starting in the early 2000's (AGRITEX, 2016).

Organizations that promoted CA in Zimbabwe (FAO, ICRISAT, ACF and Foundations for Farming) also recognized the importance of soil cover to capture the full benefits of a CA system and thus encouraged farmers to cut and carry mulch onto their CA plots. This importing of residues from outside the farm is feasible on small areas, and is practiced mainly by smallholders in search of family food security, but is rarely feasible on larger areas due to the high labor demands (Grabowski and Kerr, 2014) and availability of biomass for mulching (Giller et al., 2009), owing partly to low maize yields and also competition from livestock (Mtambanengwe and Mapfumo, 2005). An additional biophysical challenge is high mulch decomposition rates from termites, which are sometimes more active in CA systems (Nhamo, 2007). Further, mulching only tends to be viable when property rights over residual crop biomass are observed and tenure is secure (Erenstein, 2003). A recent ex-post evaluation of an extensive and long-term (10+ years) program of CA promotion in Zimbabwe also identified lack of mulch as the biggest obstacle to increasing area and number of farmers practicing CA (Nkala, 2017).

These limitations around mulch have resulted in a situation where farmers recognize the value of CA but only practice it on a relatively small (typically ¼ to ½ ha) plot with the rest of their farm under conventional management. In 2015, approximately 300,000 farmers used CA in Zimbabwe but overall hectarage remained low due to the small average size of CA plots (AGRITEX, 2016). In areas with large numbers of CA farmers, mulch has become an increasingly valued commodity, with high levels of competition for biomass as livestock feed, thatching, mulch, etc.

One possible solution to this challenge of lack of mulch is intercropping the main cereal crop with a (leguminous) cover crop (Rusinamhodzi et al., 2011). For example, a study from Cameroon demonstrated that crop biomass production can be doubled by intercropping a secondary leguminous crop with maize (*Zea mays*) or sorghum (*Sorghum bicolor*), without a yield penalty for the cereal (Naudin et al., 2010). Similar studies in Zimbabwe have also found that legume intercropping can contribute significantly to the production of mulch for subsequent crops also without a yield penalty for the cereal crop (Baudron et al., 2012; Naudin et al., 2010). Adding an intercropped legume may also decrease mulch decomposition rates. Sanaullaha et al. (2011) found the decomposition of plant residues and soil organic matter is slower under drought conditions when plants are grown in mixture as compared to monocultures, while Palm et al. (2001) found that mixing of nitrogen (N) rich residues (for example from intercropped legumes) with N poor sorghum residues may reduce the carbon : nitrogen (C:N) ratio of the combined mulch, therefore avoiding potential problems of temporary N immobilization by micro-organisms. Some researchers believe CA can result in nitrogen immobilization, particularly in areas of low quality crop residues (Droppelmann et al., 2017).

While intercropping is a traditional and common part of farming systems in southern Africa, settler and missionary practices and policies zealously discouraged such practices (Page and Page, 1991). This has led to a situation where monocropping by smallholder farmers is now common across much of southern Africa (Snapp et al., 2002). The growing interest in introducing or re-introducing intercropping to these regions to address some of the challenges to agricultural production (Snapp, 2017) together with the continued interest in CA as a climate smart agricultural technology in the region has led to a slowly growing number of studies in recent years that have directly addressed the integration of intercropping into CA systems.

Despite the fact that some advocates claims that legume intercropping in CA systems can eliminate the need for adding supplemental mulch in semi-arid areas of Africa, scientific studies verifying this claim could not be found. This study, which compares the effects of adding three different legume intercrops to maize grown under a

CA system for smallholders in Zimbabwe, has therefore been implemented in part to gather preliminary evidence on whether intercropping a cereal crop with a legume can increase the total level of biomass produced and provide sufficient cover for the practice of CA without adding additional mulch in semi-arid areas. It is hypothesized in this study that the living plant growth of the legume intercrop will have the same positive effect on maize yield as dead plant residue mulch amounts typically used by small-holders in Zimbabwe. Further, it is hypothesize in this study that including an intercropped legume in maize based CA systems will increase the total amount of biomass (total dry weight of legume and cereal crop production) per unit area.

In order to maximize the benefit to farmers themselves and to collaboratively learn from the experiences of farmers, this study was conducted together with small-holder farmers directly on the farmer's own fields and managed collaboratively with the farmers.

MATERIALS AND METHODS

Study sites

This study was conducted with three farmers from two different areas of Zimbabwe (Figure 1). Farms in the Lupane region (sites J1 and J2) are in agro-ecological zone IV, characterized by a mean annual rainfall of 450 to 600 mm, and a mean annual temperature of 18 to 24°C. The rainy season in the Lupane region typically starts in November and ends in March. Soils in this area are in the Regosol group - deep Kalahari sands, with very deep levels (up to 75 m) of fine to medium grained sand, extremely low sand/silt concentrations and little or no reserves of weatherable minerals (Department of the Surveyor-General, Causeway 1979). These soils face two major limitations for agricultural purposes: their low nutrient reserves and the relatively high permeability and associated low water holding capacity (Nyamapfene, 1991). The farm in the Neshuro region was on the border between agro-ecological zones IV and V. Soils in this area are in the Fersiallitic group - grey brown to reddish brown sandy loams, with silt percentages between 10 and 20%, clay percentages between 30 and 60%, and appreciable reserves of weatherable minerals ((Department of the Surveyor-General, Causeway 1979). These soils are of very high agricultural potential, with the main limitation being the semi-arid local environment (Nyamapfene, 1991).

Experimental design

The experiment was initiated in late 2015 and was followed for one cropping cycle. Farmers were selected by the local Non-Government Organization (NGO) partner in conjunction with a research technician from the University of Manitoba. A two-replicate split plot experiment with eight treatments was conducted on each of the three farmers' fields; the main-plot treatments were mulch and no mulch, while the sub-plot treatments were legume cover crop species planted between the rows of the maize main crop. Each farmer managed trial was established on a piece of land approximately 40 m × 12 m while each treatment was 5 m × 6 m. Initially, there were 8 farmer managed trials in three different locations, however the data from five sites was judged as not reliable and was not used in this analysis. The major limitation of this study was that the design was not randomized; the decision to do this was to make it easier for farmers to manage (pseudo-replication).

The seed types used for each trial were provided for by the partner NGO. The maize (*Zea mays L.)* used was ZM 521 OPV: an intermediate variety (63-66 days anthesis, 121-132 days maturity), semi-flint grain maize bred by CIMMYT, who claim that it yields 30 to 50% more than traditional varieties under drought and low soil fertility (Capstone Seeds, 2016). The cowpea (*Vigna unguiculata L.)* used was CBC3 - an upright bushy variety, chosen because grain yield for upright varieties such as CBC3 have been found to be 2-4 times higher than for more traditional climbing varieties in maize cowpea intercrops, as well as reduce the amount of competition with maize (Mashingaidze and Katsaruware, 2010). The Lablab (*Lablab purpureus L.*) and pigeon pea (*Cajanus cajan* L.) seeds were procured locally by the project staff from OPV varieties currently in use by local farmers.

Farmers received a copy of the trial design with explanations in their local language on how to establish the trial. No conventional check treatment was included, as farmers are well aware of the performance of their traditional systems (Ramisch, 2014). Seeding dates varied between all plots depending on rainfall and irrigation opportunities. For many farmers, their first maize planted in 2015/16 died which needed to be reseeded 2-3 times in some but not all planting stations. The cowpea and lablab did not require replanting. However, poor germination of pigeon pea resulted in several farmers replanting with still poor levels of germination.

Mulch was added to the plots using locally available sources. As farmers were told to plant according to their standard practice, the type and amount of mulch added to the mulched plots varied between farmers (from ~ 4000 kg/ha at site J2 to ~14,000 kg/ha at site N4). Mulch type was predominately grass sedges at J1 and J2 and a combination of maize and millet stover and unpalatable grasses from local hills and velds. Planting date also varied according to the farmers' typical practice. At J1, maize was planted on Nov 25, 2015 and legumes on Jan 5, 2016. At J2, all crops were planted on Jan 12, 2016. At N4, all crops were planted on Jan 21, 2016.

Planting basins were dug with hand hoes, with the basins spaced either 60 cm × 90 cm apart (sites J1 and J2) or 75 cm × 75 cm apart (site N4). Basins were 8 to 10 cm deep. Three maize seeds were planted per planting basin, and thinned to leave an average of two plants per basin. Maize plant population was 37,087 plants/ha at J1 and J2 and 35,555 plants/ha at N4. Farmers added an equal amount of composted cow manure to all the planting stations (generally two handfuls). None of the farmers applied inorganic fertilizer. No herbicides or insecticides were used, although this was not a condition of the experiment. Intercrops were planted mid-way between the rows of maize with a 50 cm spacing between legume hills (30 plants plot^{-1}; 1 plant m^{-2}). Total soil disturbance is estimated at ~40%. Farmers managed the plot as per their usual practice which primarily included hand weeding.

Experimental design

The data was analyzed assuming a randomized complete block design (n=2), despite the fact that randomization on main-plots and sub-plots did not occur. Though not ideal, justification for using this approach hinges upon the value of using farmers as research partners, and preliminary evidence for a concept, not conclusive results, is been looked for. Therefore, the results should not be interpreted as conclusive but as simply giving a preliminary response to the hypothesis.

At time of maize maturity, intercrop biomass and yield and maize biomass and yield were all determined from plant samples collected from a two-meter row section sample (one/treatment rep). Samples were stored in very porous canvas bags until air dry and then weighed with an electronic laboratory scale. Lablab and pigeon pea are both medium to long season crops, and therefore were still

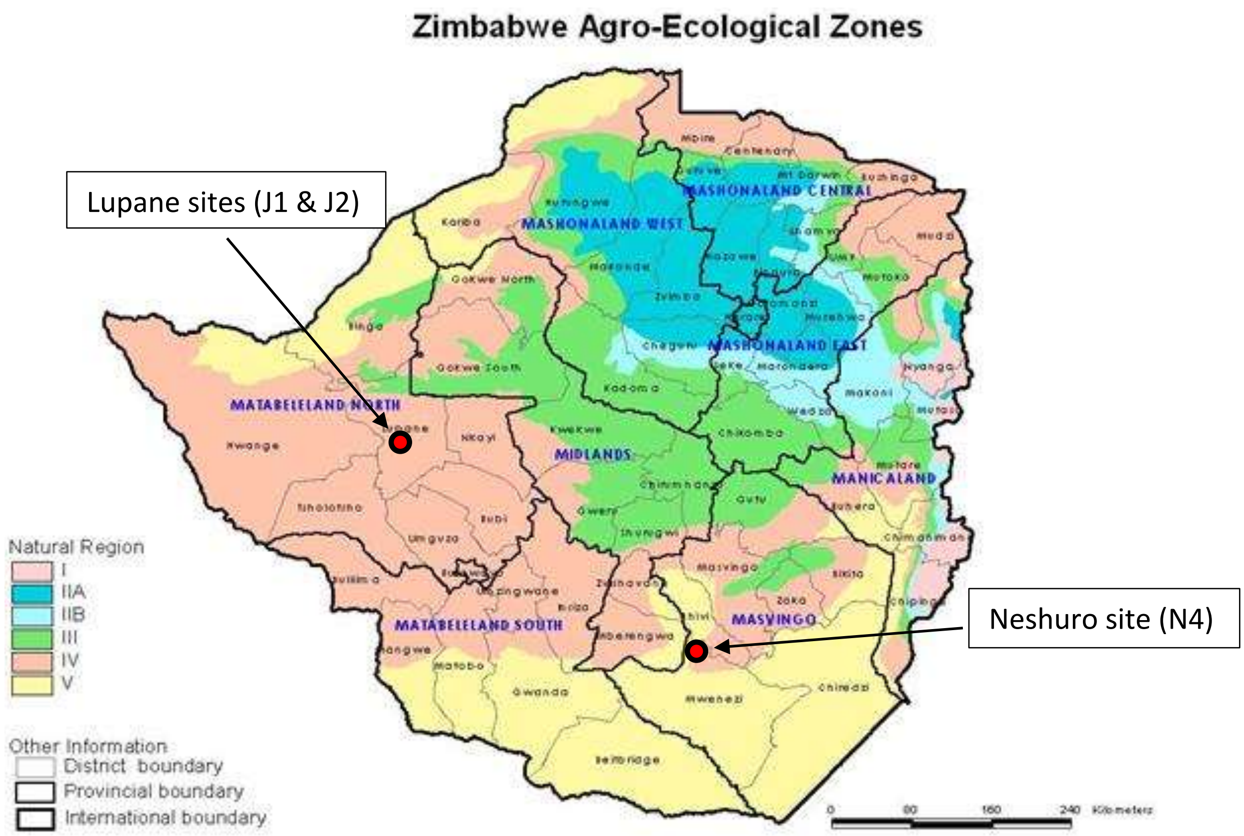

Figure 1. Zimbabwe Agro-Ecological Zones.
Source: http://www.fao.org.

growing (and providing additional biomass to the system) at the end of the experimental period. A final sampling of both lablab and pigeon pea growth was collected in July 2016, but as funds for the experiment had ended, these samples were not dried. To use these final results, a wet weight to dry weight ratio of 4:1 was assumed, which was the average of the lablab wet to dry weight ratios in the experiment. For the pigeon pea and lablab biomass samples that were not dried, the following equation was used to calculate dry weight:

Dry weight = [total wet weight] × 0.25

The lablab and pigeon pea varieties used were both longer-season varieties, and the grain did not mature at sites J1 and J2 before funding for the experiment was over. Cow pea yields were collected for all sites, and are the focus of an economic analysis in a follow up paper (Salomons et al., 2018).

Data analysis

Each data set was analyzed using the PROC Mixed procedure with the Statistical Analysis Software version 9.4 of the SAS System for Windows copyright 2013, considering treatments as fixed effects and replications as random effects. Normality distribution assumptions were tested using Shapiro-Wilks with PROC Univariate procedure and first tested for homogeneity of variance using Bartlett's test. Differences among treatments were tested using the protected least significant difference (LSD) test and considered statistically significant at p <0.05.

RESULTS AND DISCUSSION

Weather data

Precipitation and temperature data were not collected at the experimental sites themselves. Zimbabwe has few active weather stations, so the nearest reliable data to the plots were located at the Hwange Airport (~ 160 km NW of sites J1 and J2) and Chiredze/Buffalo Range located ~ 85 km east of site N4.

In Hwange, 585 mm of rain distributed over 122 days was received over the course of the experimental period (November 2015 to May 2016)[1]. The average rainfall for the Hwange weather station from 2000 - 2015 was 631.5 mm (Mazvimavi et al., 2017). Local staff noted several heat waves during the experimental period.

In Chiredze/Buffalo Range, 360 mm of rain distributed over 95 days was received over the course of the experiment (November 2015 to May 2016)[2]. Masvingo weather station, located approximately 100 km from the

[1]https://www.worldweatheronline.com/hwange-weather-averages/matabeleland-south/zw.aspx
[2]https://www.worldweatheronline.com/chiredzi-weather/matabeleland-south/zw.aspx

Table 1. Treatment means (n=2) and analysis of variance (ANOVA) for selected agronomic parameters from study sites in Zimbabwe. Numbers in columns followed by different letters are significantly different at P<0.05.

	Maize biomass (kg ha^{-1})	Maize grain (kg ha^{-1})	Intercrop biomass (kg ha^{-1})	Intercrop grain (kg ha^{-1})	Total biomass (kg ha^{-1})
Lablab (mulched)	13,629^{a}	5,636^{a}	4,576^{a}	941^{b}	18,206^{a}
Cowpea (mulched)	14,076^{a}	6,199^{a}	2,552^{b}	1,453^{a}	16,628^{ab}
Pigeon pea (mulched)	15,176^{a}	5,749^{a}	838^{c}	30c	16,013^{ab}
Maize only (mulched)	14,196^{a}	5,908^{a}	-	-	14,196^{b}
Lablab (un-mulched)	11,606^{a}	4,224^{a}	3,725^{a}	948^{a}	15,331^{a}
Cowpea (un-mulched)	9,960^{a}	5,041^{a}	2,404^{b}	1202^{a}	12,364^{a}
Pigeon pea (un-mulched)	10,193^{a}	4,208^{a}	617^{c}	163^{b}	10,810^{a}
Maize only (un-mulched)	10,453^{a}	3,986^{a}	-	-	10,453^{a}
Source of variation					
Site (mulched)	<0.0001	<0.0001	0.0053	<.0001	<.0001
Trt (mulched)	0.3542	0.5892	<.0001	<.0001	0.0054
Site-Trt (mulched)	0.0103	0.0163	0.0034	<.0001	0.0220
Site (un-mulched)	0.3038	0.3061	0.0001	<.0001	0.9077
Trt (un-mulched)	0.7543	0.5102	<.0001	0.0006	0.0639
Site-Trt (un-mulched)	0.5755	0.9166	0.0010	0.0017	0.5691

plots at Neshuro, received 500 mm of rain in 2015; the 15 year average for that weather station was 693.7 mm (Mazvimavi et al., 2017).

This data correlates well with harvest and food insecurity reports from June/July 2016. The Famine Early Warning Systems Network (FEWSNET), for example, found that the area surrounding sites J1 and J2 was in Integrated Phase Classification[3] (IPC) 2 (stressed) in terms of food security in June of 2016, while the area surrounding site N4 was in the more serious IPC phase 3 (crisis) phase (FEWSNET, 2017). This data also correlates well with the Zimbabwe Vulnerability Assessment Committee (ZimVac) report from July 2016[4], which found that in the area surrounding sites J1 and J2, maize production from the 2015-16 cropping season was estimated at levels ranging from 35-50% of the five-year average, and that poor households were mainly stressed (IPC Phase 2). Households in the area surrounding site N4, on the other hand, had none or very few crops to harvest due to the erratic and late start of the rains, below-average cropped area, and long dry spells.

Crop production

A summary of results for the mulched and un-mulched treatments are given in Table 1. Because of the significant site, treatment and site by treatment interactions encountered in the combined site analysis (data not shown), data was analyzed separately for all three sites.

Total maize grain production for individual sites is given in Figure 2. Average grain maize yields across all treatments were highest at site J1 and lowest at site N4. The average yield for each treatment at all three sites was much higher than average yields of Zimbabwean farmers in general, despite it being perceived as a drought year by the farmers involved. While any comparisons with national averages are perfunctory at best, these results do give a rough sense of the potential of the general system that was used by the farmers for all treatments: precision planting based on recommended maize spacing; micro-fertilization with composted cattle manure placed close to the growing-maize plant; minimal soil disturbance; and timely and thorough weeding.

The addition of mulch increased maize yields across all treatments at sites J1 (7,449 kg/ha mulched as compared to 4,954 kg un-mulched) and J2 (6,250 kg/ha mulched as compared to 4,060 kg/ha un-mulched) but had minimal impact at site N4 (3,920 kg/ha mulched as compared to 4,080 kg/ha un-mulched). While in general, maize yields were greatest where growing conditions were wettest, this seems at odds with the finding that the addition of mulch increased maize grain yield significantly at sites J1 and J2 (where conditions were wetter and slightly cooler) but had no overall impact on yield at site N4 where conditions were drier and slightly hotter. This may be related to the different soil types at the two sites: sites J1

[3]The IPC is an internationally recognized standard for measuring acute food insecurity, and ranges from 1 (minimal food insecurity) to 5 (famine). For more information see: http://www.fews.net/IPC

[4]http://reliefweb.int/sites/reliefweb.int/files/resources/zimvac_2016_rural_livelihoods_assessment.pdf

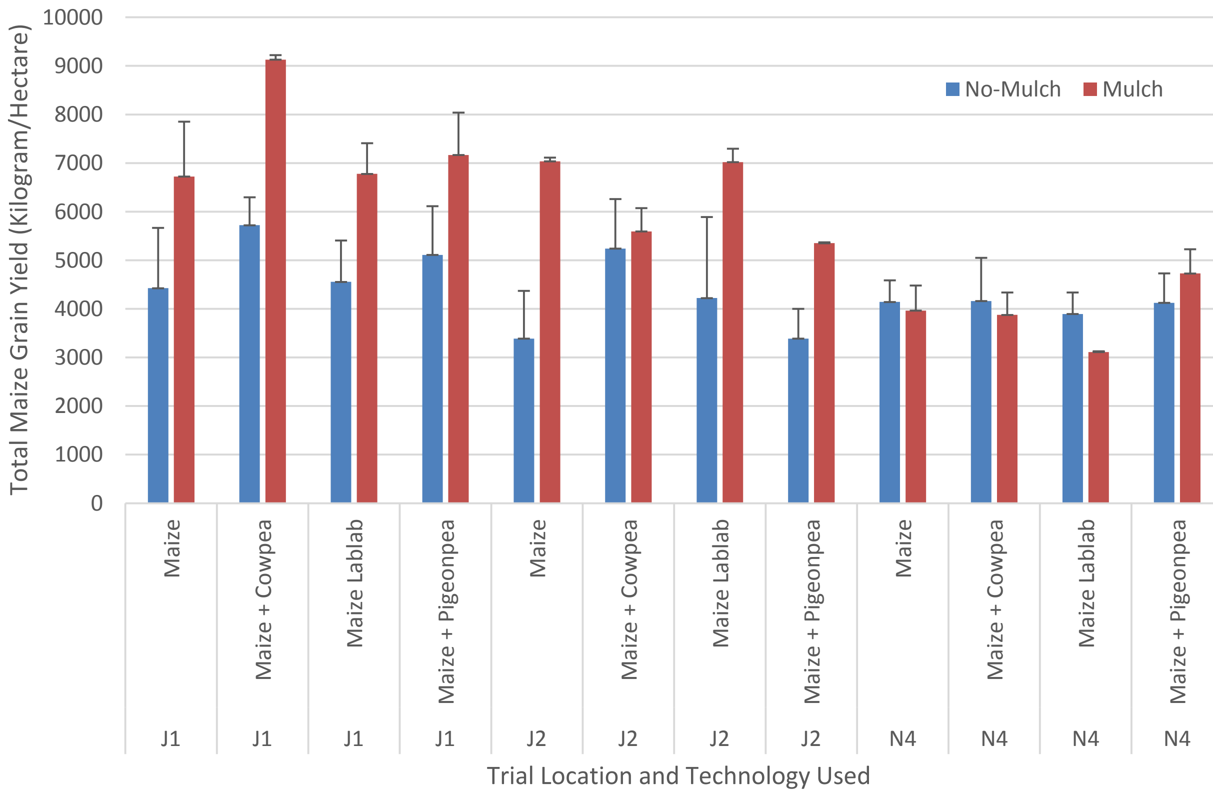

Figure 2. Total maize grain production from various treatments and locations. Error bars indicate standard error for each treatment.

and J2 being on sandy, relatively unfertile soil and site N4 being on a sandy loam of high agricultural potential. The farmer at N4 added supplemental water to keep maize plants alive, and this may explain the lack of difference between the mulched and un-mulched plots.

There were no clear differences in the impacts of the three different legumes on maize grain yields. While some of the legume treatment sites had higher maize grain yields than other legume treatment sites (notably cowpea at site J1 and lablab at site J2), this was not consistent across the different sites. These variable responses were likely due to differences between the sites in terms of farmer practice: the farmer at site J1, for example, planted all three legumes crops 40 days after his maize was planted, while the farmer at site J2 planted her legume crops at the same time as her maize (in both cases, the pigeon peas needed to be replanted as the initial plantings did not germinate). At site N4, the maize and the legume crops were all planted at the same time, but the maize in the un-mulched plots needed to be replanted several times, and by the time that maize had come up the lablab in the intercropped, un-mulched treatments needed to be pruned not to overly compete with the maize. The local research technician noted that the pigeon pea seeds distributed to farmers at all sites had low germination rates, and final density of pigeon pea plants was lower than the density of cowpea and lablab in the respective treatments.

In order to answer the question of whether an intercropped legume can increase maize yield without adding additional mulch in semi-arid areas of Zimbabwe, there were contrasts on a site by site basis of maize grain yields between the mulched, mono-cropped maize plots and the un-mulched, intercropped maize plots. There was a significant difference between these treatments for both sites J1 and J2. Site J1 had an overall estimated maize grain yield increase of 1,593 kg/ha ($P=0.007$) for the mulched, mono-cropped maize treatment as compared to the un-mulched, intercropped treatment. Similarly, Site J2 had an overall estimated maize grain yield increase of 2,753 kg/ha ($P=0.0235$) for the mulched, mono-cropped maize treatment as compared to the un-mulched, intercropped treatment.

Based on these results from sites J1 and J2, the hypothesis that adding a legume intercrop will eliminate the need to add supplemental mulch for increased maize (*Zea mays*) yield was rejected. For site N4, however, there was no significant difference between the maize grain yields from the mulched, mono-cropped plots and the un-mulched, intercropped plots. This was surprising given that this was the hotter, drier, site. In addition, even the un-mulched, mono-cropped maize plots from site N4

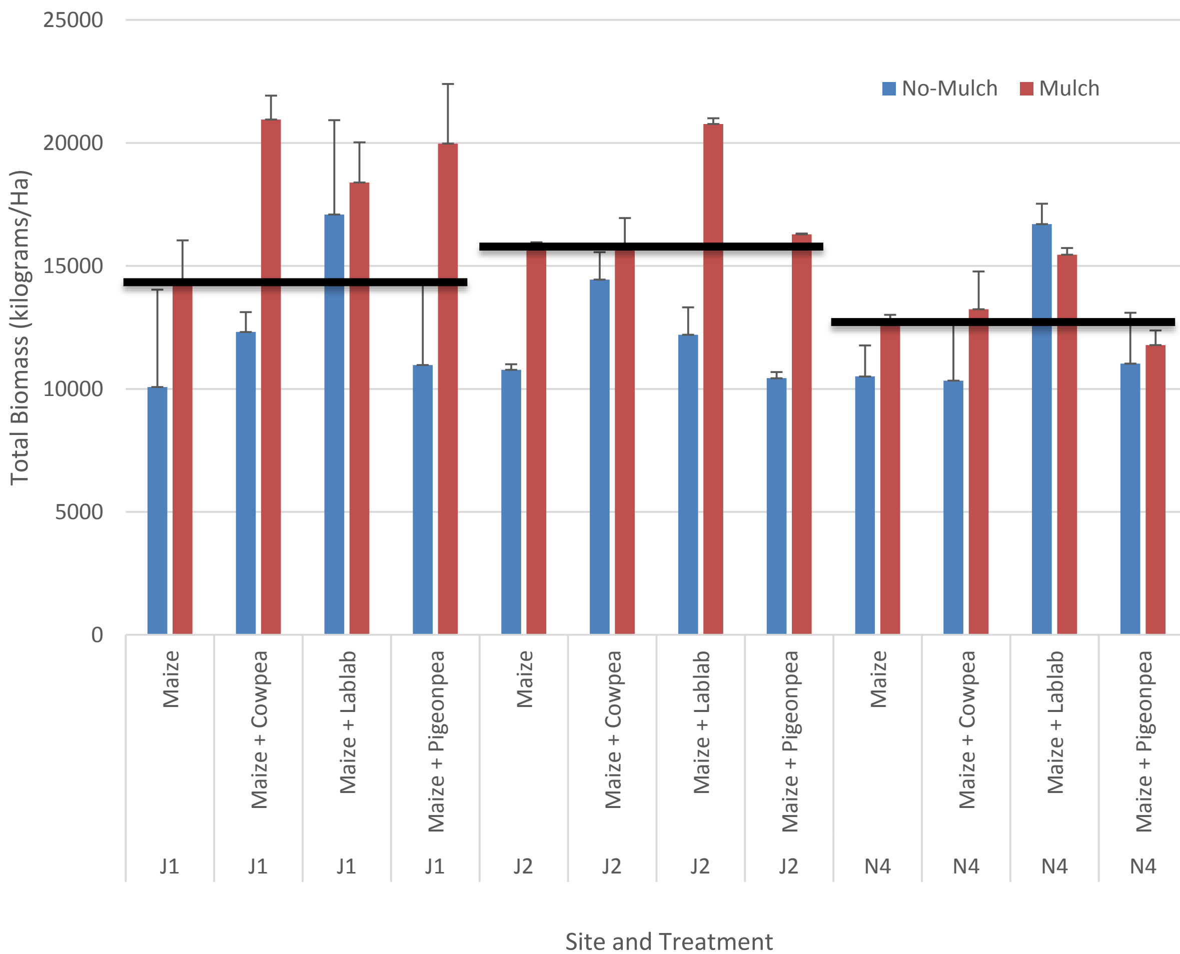

Figure 3. Total biomass production at sites J1, J2, and N4. Error bars indicate standard error for the treatments (n=2). Solid horizontal lines show total biomass production from the mulched, mono-cropped maize for the three sites.

averaged over 4,000 kg/ha in a year when there were widespread crop failures in the surrounding areas. Supplemental irrigation at N4 may explain good yields in the un-mulched plots.

Total biomass production

A second objective was to determine if adding an intercrop to a CA system has the potential to increase the total amount of biomass produced, thereby potentially reducing the need for added mulch for soil cover. Total biomass production (maize biomass plus intercrop biomass) is shown in Figure 3.

For site J1, there was a 5,043 kg/ha (p=0.014) increase in total biomass production when an intercrop was added to the standard, mulched mono-cropped CA maize crop. All three intercrop legumes contributed to the greater total biomass at J1 (Figure 3). At site J2, while there was a 1,843 kg/ha (p=0.049) increase in total biomass production, the biomass increase was almost exclusively due to lablab (Figure 3). No significant difference in total biomass production from adding a legume intercrop was observed at site N4, though once again lablab provided a small boost to biomass production.

The proportion of biomass from maize versus the legume is given in Table 2. Cowpea and lablab biomass represented less than 25% of total aboveground biomass at J1 and J2. However, at the dryer N4 site, the proportion of biomass attributed to the legume was 27 and 45% for mulched and un-mulched cowpea and 82 and 73% for mulched and un-mulched lablab (Table 2). A higher proportion of legume growth at N4 was attributed to greater drought tolerance of the legumes, especially lablab, as compared to maize.

In contrast to cowpea and lablab, pigeon pea contributed a negligible amount in terms of total biomass of the plots. This is surprizing given that pigeon pea is a very common and profitable intercrop species with maize in other parts of Africa (Senkoro et al., 2017) and that pigeon pea has been identified by some researchers as a recommended intercrop with maize under CA systems

Table 2. Ratio of intercrop biomass to maize biomass at experimental sites at time of maize harvest.

Site	Mulch	Cowpea : Maize biomass ratio (%)	Lablab : Maize biomass ratio (%)	Pigeon pea : Maize biomass ratio (%)
J1	Yes	9	11	2
J1	No	13	9	0
J2	Yes	25	25	0
J2	No	24	23	0
N4	Yes	27	82	4
N4	No	45	73	8

(Ngwira et al., 2012; Rusinamhodzi et al., 2017). An explanation for poor pigeon pea performance in the present study was attributed to low germination and slow growth under the maize in this experiment (field notes by research technicians). Traditional varieties of pigeon pea such as used in this experiment generally take much longer to mature than maize, and by the end of this experiment the pigeon peas just began to form green pods.

The greatest increase in biomass production from intercropping was observed at site J1. In the mulched treatments, total maize and intercrop biomass was 21.0 tons/ha for maize/cowpea, 17.4 tons/ha for maize/lablab and 19.5 tons/ha for maize/pigeon pea (Figure 3). One explanation for the impressive total biomass production was the planting pattern of maize and intercrops. The intercrops were planted 40 days after the maize crop, allowing time for maize to become established. Mpangane et al. (2004) observed that highly competitive legumes such as lablab can compete with maize crop production if planted at the same time; they recommended delaying lablab planting by 4 weeks after maize planting. Where lablab was planted at the same time as the maize (N4), the increase in biomass due to lablab was at the expense of maize biomass production (Table 2).

It is important to note that the lablab and pigeon peas will probably continue to grow and add additional biomass long into the dry season. This was corroborated by a report from the field technician at site J1 that there was a severe frost on June 22 that completely destroyed the lablab, however a month later, the lablab was re-growing and flowering while the pigeon pea was not affected by the frost. However, the potential of lablab and pigeon pea to continue growing well into the dry season needs to be tempered by the realization that it is difficult to protect these crops from free grazing livestock in the dry season.

Conclusions

This farmer-managed study showed that additions of mulch and inclusion of grain legumes in maize-based CA had the potential to increase maize yield at most locations. Among legume intercrops, cowpea provided the largest maize yield increase. However, maize yields were increased more by adding mulch than by legume intercrops in the absence of mulch. The implication here is that to increase maize yield, some sort of mulch was necessary, and intercrops alone were not an adequate substitute for this mulch. Therefore, farmers should continue to seek opportunities to ensure fields have some level of surface cover. Future research should seek to understand the optimum level of mulch required, especially after many years of CA when soil organic matter levels, and hence water holding capacity, may have increased. Such work may benefit from long-term controlled studies located in different agroecozones.

Adding a legume intercrop increased the total amount of biomass production, thereby reducing the amount of mulch required for surface cover. This means less labour for mulch collection. The greatest positive effect of intercropping on biomass production occurred where rainfall was higher and where the legume planting was delayed 40 days after maize planting. These results demonstrate the importance of site, including farmer management, in the success of intercropped based CA smallholder systems. This observation points to the importance of extension to train farmers on optimum intercropping planting regimes.

Farmer participation was critical to conducting these studies in the context of small-holders in Zimbabwe. Farmers in this study viewed their plots as their classrooms, and will continue to experiment on their own after the project. In the present study, only 3 of 8 sites were deemed appropriate for reporting (5 additional sites were conducted but problems were encountered). Greater involvement of research and extension workers in these on-farm studies will improve their success rate.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Full Length Research Paper

Response of maize (*Zea mays*L) inbred lines to different herbicide combinations

Nyasha Sakadzo[1*], Kasirayi Makaza[1], Ignatius Chagonda[1] and Jimmy Shanangura[2], and Tafadzwa T Haripo[2]

[1]Department of Agronomy, Faculty of Natural Resources Management and Agriculture, Midlands State University, P bag 9055, Gweru, Zimbabwe.

[2]Department of Soil and Plant Sciences. Faculty of Agricultural and Natural Sciences, Great Zimbabwe University, P.O. Box 1235 Masvingo, Zimbabwe.

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A field experiment was carried out at Agricultural Seed and Services Research Station in Zimbabwe to evaluate the response of maize inbred lines to different herbicide combinations. The trial was laid out in a 5×12 split plot design replicated three times. Herbicide combination was main plot factor with five levels; Hand-hoeing;metolachlor+ atrazine;metolachlor+ atrazine+ nicosulfuron; metolachlor+ atrazine+ halosulfuron and metolachlor +atrazine+ nicosulfuron+ halosulfuron. These combinations of herbicides have a broad spectrum activity and are able to control annual and perennial weeds with an inbred line as subplot factor with twelve levels; CML488, CML312, CML444, CML443, CML00001, CML395, CZL0610, CZL00003, CZL03014, L917 and N3.2.3.3. Data on germination, phytotoxicity, plant height, anthesis silking interval (ASI), ear height and grain yield were measured. There was a significant interaction (p<0.05) between herbicide combination and maize inbred line on germination, plant height (week 2 and 4), phytotoxicity, ASI, ear height and grain yield. There was no interaction (p>0.05) among herbicide combinations and maize inbred lines on plant height (week 12). That concluded metolachlor+ atrazine+ nicosulfuron and metolachlor +atrazine+nicosulfuron+ halosulfuron herbicides had a major effect on susceptible maize inbred lines. Inbred lines were grouped into three categories in relation to European Weed Research Council (EWRC) score, efficacy and survival rate into; tolerant (CML312, CML444, CML443 and CML00003), medium resistant (CML395, CZL0610, NAW5885 and CZL00003) and susceptible (CML488, CZL03014, L917 and N3.2.3.3). Therefore, the study recommends not using metolachlor+ atrazine+ nicosulfuron and metolachlor+ atrazine+ nicosulfuron+ halosulfuron herbicide combinations on susceptible maize inbred lines.

Key words: *Zea mays*, inbred lines, herbicide combinations, metolachlor, atrazine, nicosulfuron.

INTRODUCTION

Maize (*Zea mays L.*) is one of the most important staple food crop grown in Zimbabwe where it is ranked first in the number of producers, area grown and total cereal production (Mashingaidze, 2004). It is the mostly widely

*Corresponding author. E-mail: nsakadzo87@gmail.com. Tel:+263 775 985 724.

grown food crop in sub-Saharan Africa (SSA) and is produced on approximately 22 million hectares of land which is about 15.7% of the land area grown to maize globally (Pingali and Pandey, 2001).

Maize inbred lines are characterised by low vigour, slower growth and this makes them susceptible to various stress conditions (Stefanovic and Simici, 2007). These inbred lines can only compete successfully for light, water, nutrients and carbon dioxide if they are adequately protected against both annual and perennial (Johnson grass, wild sorghum and nutsedge) weeds. In order to keep the weed cover below the economic injury level, integrated weed management is often employed. However currently weed management is more centralised towards use of herbicides due to shortage of labour (Waddington and Karigwindi, 1996).

Sensitivity responses have been reported in maize inbred lines after treatment with Atrazine ® (triazine), an active agent considered being super-selective for maize (Shimabukiro et al., 1971). Rowe and Penner (1990) noted differences in tolerance of inbred lines when testing with Chloroacetamides. Similar tests conducted at Art farm (1999) using halosulfuron -75 % WG (sulfonylurea) on the maize inbred lines showed two genotypes to be sensitive. Herbicides tolerance tests done using 10 maize genotypes from CIMMYT at ART farm in 1999 showed three genotypes to be very sensitive, three very tolerant and four moderately sensitive to herbicides belonging to the sulfonylurea group and chloroacetamides (Eberlein et al., 1989; Stefanovic et al., 2010).

A continuous weed infestation has led to the adoption of Nicosulfuron-75%, Halosulfuron-75% and metolachlor-96% herbicides. These herbicides have proven to be very effective in reducing weed menace in certified seed maize production due to their broad spectrum activity. The response of maize inbred lines to various active agents depended on their genetic background (Stefanovic et al., 2000). Previous studies indicate that maize can metabolise nicosulfuron into harmless compounds by converting the parent herbicide to non phytotoxic-OH metabolite (Sun et al., 2017).

Certified seed production is greatly reduced by high weed pressure among other constraints. Weeds constantly interfere with the normal growth of crops (Patel, 2013). Maize production is inconceivable without herbicide being applied and this significantly depends on crop susceptibility. A shift in ear and tassel development phases caused by different herbicide combinations has directly resulted in reduced average yields and increased grain moisture. It is said some injuries could be induced by herbicides, which could result in yield losses (Tesfay et al., 2014). There is very little information which is known about the effect of herbicides especially 75% nicosulfuron WG, 75% halosulfuron WG and metolachlor-96 % on the current local maize inbred lines used to make commercial hybrid in Zimbabwe which are able to control annual and perennial weeds (Johnson grass, wild sorghum and nutsedge). Herbicide phytotoxicity symptoms are sometimes mistaken to fertiliser phytotoxicity and nutrient deficiency symptoms (Gaspar, 1998).

An essential component of certified maize production technology in Zimbabwe is weed control which is generally carried out using herbicides. A strong weed menace and labour shortages in certified seed maize production has led to an increase in the adoption of herbicides. Herbicides provide timely weed control thereby reducing competition for labour between weeding and other farming activities. It has served farmers of undue, repeated inter-cultivations and hoeing. This has helped farmers in obtaining satisfactory weed control where physical methods often fail. Herbicides can be employed to control weeds as they emerge from the soil to eliminate weed-crop interference even at early stage of growth. However, by physical methods weeds are removed after they have offered considerable competition to the crops, and rarely at the critical time.

To address the phytotoxicity currently associated with chloroacetamides and sulfonylurea herbicides on the current maize inbred lines, there is need to explore the sensitivity response of inbred lines used to make commercial hybrids against herbicides of these particular groups in Zimbabwe. The ever-widening choice of herbicides in maize necessitates regular herbicide tolerance tests. There is limited information on optimum herbicide combinations for effective weed control and phytotoxicity of herbicides in maize seed production. Therefore, the object of the study was to assess the response of maize (*Zea mays)* inbred lines to different herbicide combinations on yield parameters phytotoxicity.

MATERIALS AND METHODS

Study site

The experiment was conducted at Agricultural Seeds and Services (Agriseeds) Research Station, located 19 km North West of Harare town in Zimbabwe. It is located at latitude 17° and longitude 30° E and at an elevation of 1500 m above sea level. The site is in Natural Region IIa which receives an annual rainfall range of 750 to 1000 mm and average annual minimum and maximum temperatures of 15°C and 27°C respectively, summer temperatures range from 25°C to 27°C (Vincent and Thomasm, 1960; Mugandani et al., 2012).

Experimental layout and plot management

A 5×12 split plot design was used with three replications. The main plot factor was herbicide with five levels (Table 1) while sub-plot factor was variety with 12 levels which were CZL00001, CZL00003, CZL0610, CZL03014, CML395, CML312, CML443, CML444, CML488, NAW5885, N3.2.3.3 and L917.

Gross plot size measured 50 m × 30 m having 12 rows of maize inbred lines per each sub plot. Net plot size was 36m × 16m. Main plot size was 33×5(165m^2) and sub plot was 8.25×4 (33m^2) A

Table 1. Herbicide combinations and application rates of active ingredients (Synegenta, 2000).

Description	Application rate/ha
Control(hand hoeing)	-
96 % Metolachlor+Atrazine	1.5lt+4lt respectively
96 % Metolachlor+Atrazine+75% Nicosulfuron WG	1.5lt+4lt,60g respectively
96 % Metolachlor+Atrazine, 75 % Halosulfuron WG	1.5lt+4lt,50g respectively
96 % Metolachlor +Atrazine, 75 % Nicosulfuron WG, 75 % Halosulfuron WG	1.5lt+4lt,60g, 50g respectively

Table 2. European Weed Research Council (EWRC) rating scale for phytotoxicity (WSSA, 2002).

EWRC score	Crop tolerance	Efficacy (weed kill)	Weed control (%)
1	No effect	Complete kill	100
2	Very slight effects; some stunting and yellowing just visible.	Excellent	99.9-98
3	Slight effects, stunting and yellowing effects reversible.	Very good	97.9-95
4	Substantial chlorosis and or stunting; most effects probably reversible.	Good-acceptable	94.9-90
5	Strong chlorosis/stunting; thinning of stand.	Moderately but generally not acceptable	89.9-82
6	Increasing severity of damage.	Fair	81.9-70
7	Increasing severity of damage.	Poor	69.9-55
8	Increasing severity of damage.	Very poor	54.9-30
9	Total loss of plant yield	None	29.0-0

distance of four meters was left between each block (Mashingaidze, 2004).

Land was disc-ploughed and disc-harrowed to a fine tilth, before planting. Planting was achieved by sowing two maize seeds per planting station using an interow and inrowspacing of 0.75m and 0.25m respectively. The maize plants were later thinned two weeks after emergence (WAE) to one plant per station to give a plant population of 37,000 plants /ha (Mashingaidze, 2004).

Compound D (7% N, 14% P_2O_5, and 7% K_2) was dribbled as a basal fertiliser at a rate of 400 kg /ha into the planting furrows before planting. The maize inbred lines were top-dressed with 200 kg/ha ammonium nitrate (34.5% N) at five weeks after emergence (WAE) using hill placement method (Mashingaidze, 2004).

A knapsack sprayer with a flat fan nozzle (FS6503) was used in herbicide application. Herbicide application rates were determined by following the labelled recommended doses (LRDs) for each herbicide as presented on Table 1. These herbicides were applied immediately after irrigation whilst the soil was moist to allow good herbicide uptake by both the soil and plants. Metolachlor and Atrazine was applied as pre-emergence herbicide as tank mixture at the same time.

Post -emergence herbicideNicosulfuron-75% WG was applied three weeks after crop emergence when maize was at two to five leaf stages, whilst Halosulfuron-75% *WG* herbicide was applied three to five weeks after planting of the crop when weeds were actively growing at two to four leaf stages (Table 2).

Germination percentage of the 12 maize inbred varieties was taken eight days after crop emergence. This was done through physical counting of seedlings that has emerged then expressing it as a percent of total seed sown. The level of phytotoxicity (browning, stunting, tissue death) was determined by using the EWRC scale on Table 2. Crop tolerance, efficacy (weed kill), weed control (%) was also determined using the same scale. This was done first at second leaf stage after pre-emergence herbicide application to assess the level of phytotoxicity on herbicide sprayed plots and 10 days later after application of post emergence herbicides.

Plant height was recorded weekly from week one to week twelve. The number of days to mid pollen (DMP) was determined by counting the number of days as from planting up to when 50% of the plants have shed pollen. The number of days to mid silking was determined by using the same procedure as from planting up to when 50% of the plants per plot have silks 2-3cm long. Ear height was determined at 50% silking when ears of the plants had emerged. Anthesis Silking Interval (ASI) was determined by the difference between DMS and DMP. Grain moisture was recorded for each plot using a Dickey John moisture tester .Shelled grain weight was recorded by harvesting five plants per plot using an electric balance, adjusted to 12.5 % moisture content and converted to tonnes per hectare (Table 2).

Statistical analysis

Analysis of variance (ANOVA) was done using Genstart 2013. Fishers protected least significance test at 5 % was used to separate means where significance differences were noted (Steel et al., 1997).

RESULTS

Effects of herbicide combinations on germination of maize inbred lines

There was a significant interaction ($p < 0.05$) between

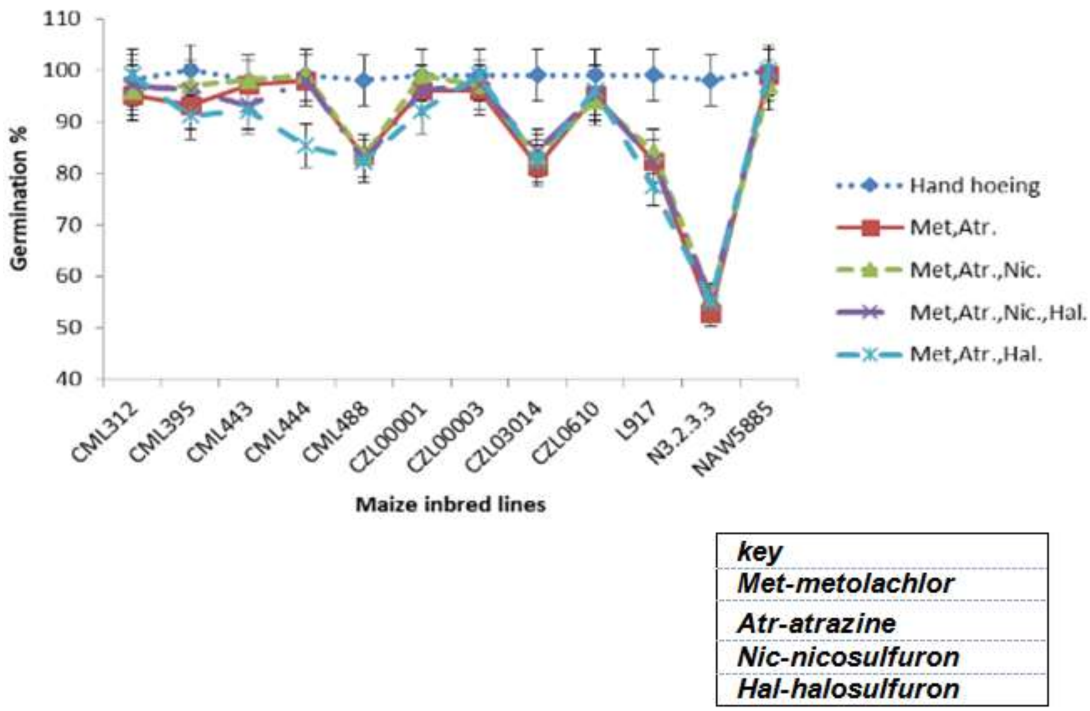

Figure1. Effect of herbicide combinations on germination of maize inbred lines.

herbicide combination and maize inbred line on germination. There was a significant difference ($p<0.05$) among weed control methods. The highest germination was observed in hand hoeing which recorded 100 % germination on inbred lines NAW5885 and CML312. However, there was a significant difference ($p<0.05$) among maize inbred lines. Inbred lines CML312, CML444, CML443 and CML00003 were tolerant; they recorded the highest germination percentage across all the herbicide combinations. CML488, CZL03014, L917 and N3.2.3.3 were susceptible they recorded the least germination percentage on metolachlor + atrazine herbicide combination (Figure 1).

Effects of herbicide combinations on plant height

Week 2

There was a significant interaction ($p<0.05$) between herbicide combination and inbred line on plant height. There was a significant difference ($p<0.05$) among weed control methods .The highest plant height was observed in hand hoeing on inbred line NAW5885 which recorded 29.1cm. There was also significant difference ($p<0.05$) among maize inbred lines. Inbred lines CML312, CML444, CML443 and CML00003 were tolerant; they recorded the highest plant height on metolachlor + atrazine + nicosulfuron + halosulfuron herbicide combination. CML488, CZL03014, L917 and N3.2.3.3 recorded the least plant height across different herbicide combinations (Figure 2).

Week 4

There was a significant interaction ($p<0.05$) between herbicide combination and inbred line on plant height. There was a significant difference ($p<0.05$) among weed control methods. The highest plant height was observed in hand hoeing on inbred lines CML443, CML444 andCZL0610 L917. However there was a significant difference ($p<0.05$) among maize inbred lines.CML312, CML444, CML443, CML00003 were tolerant, they recorded the highest plant height on metolachlor + atrazine + nicosulfuron + halosulfuron herbicide combination. Inbred lines CML488, CZL03014, L917 and N3.2.3.3 recorded the least plant height on metolachlor + atrazine + nicosulfuron + halosulfuron herbicide combination (Figure 3).

Week 12

There was no interaction ($p>0.05$) between herbicide combination and inbred line on plant height. There was a significant difference ($p<0.05$) among different weed control methods. Hand hoeing significantly ($p<0.05$)

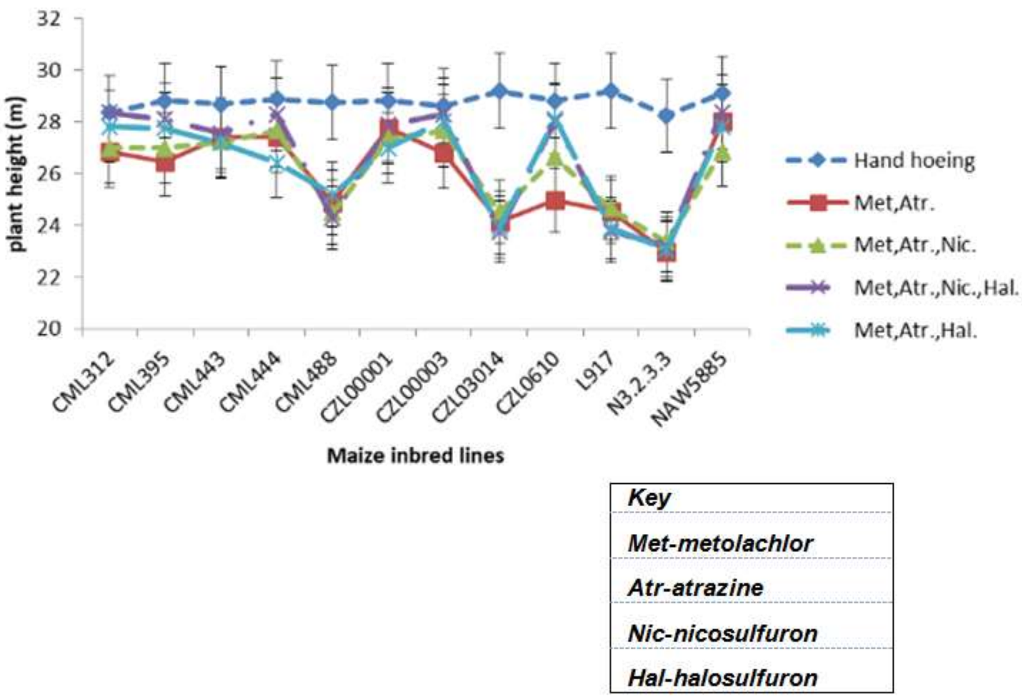

Figure 2. Effect of herbicides combinations on plant height of maize inbred lines, Week 2.

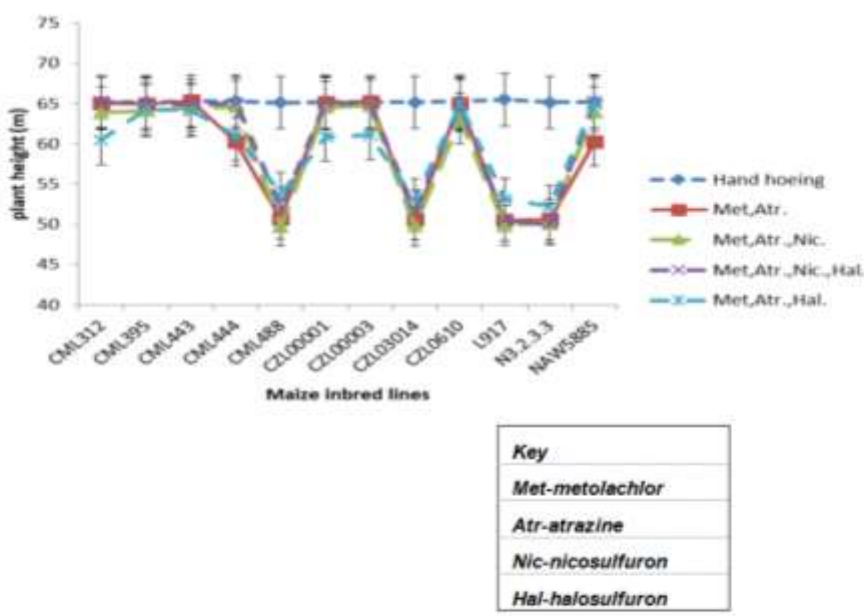

Figure 3. Effect of herbicide combinations on plant height of maize inbred lines, Week 4.

recorded the highest plant height of 187.65 cm as shown by the Table 3 below, metolachlor + atrazine + nic osulfuron herbicide combination recorded the lowest plant height but it was not significantly ($p<0.05$) different from metolachlor + atrazine + halosulfuron herbicide combination. Variety significantly ($p<0.05$) had an effect

Table 3. Effect of herbicide combination on plant height.

Herbicide	Plant height (cm)
Hand hoeing	187.65[c]
Met.Atr	177.21[b]
Met.Atr.,Nic	170.22[a]
Met,Atr.,Hal	171.61[a]
Met,Atr.,Nic.,Hal	177.53[b]
Grand mean	176.84
LSD	3.038
C.V %	3.7
$Fprob_{0.05}$	0.001

*Values followed by the same letter are not significantly different.

Table 4. Effect of maize variety on plant height.

Variety	Plant height (cm)
CML312	181.38[b]
CML395	181.27[b]
CML443	180.28[b]
CML444	180.21[b]
CML488	171.09[a]
CZL00001	182.04[b]
CZL00003	180.76[b]
CZL03014	168.44[a]
CZL0610	179.13[b]
L917	168.67[a]
N3.2.3.3	168.12[a]
NAW5885	180.73[b]
Grand mean	176.84
LSD	4.706
C.V %	3.7
$Fprop_{0.05}$	0.001

*Values followed by the same later are not significantly different.

on plant height. Inbred line CZL0610 recorded the highest plant height but was not significantly different from CML444, CML443, NAW5885, CZL00003, CML395 and CML312. N3.2.3.3 inbred line recorded the lowest plant height of 168.12 cm but it was not significantly ($p<0.05$) different from CZL03014, L917 and CML488 inbred lines as shown on Table 4.

Effect of herbicide combinations on phytotoxicity of maize inbred lines:

There was a significant interaction ($p<0.05$) between herbicide combination and maize inbred line on phytotoxicity. There was a significant difference ($p<0.05$) among herbicide control methods. No changes in plant form due to phytotoxicity were observed in hand hoeing. However, there was a significant difference ($p<0.05$) among maize inbred lines. CML312, CML444, CML443 and CML00003 were tolerant they recorded the lowest EWRC % score of phytotoxicity in metolachlor + atrazine + nicosulfuron and metolachlor + atrazine + nicosulfuron + halosulfuron herbicide combinations. Inbred lines CML488, CZL03014, L917 and N3.2.3.3 were susceptible; they had the highest phytotoxicity score in metolachlor + atrazine + nicosulfuron and metolachlor + atrazine + nicosulfuron +halosulfuron herbicide combinations (Figure 5).

Effect of herbicide combination on anthesis silking interval (ASI)

There was a significant interaction ($p<0.05$) between herbicide combination and maize inbred line on ASI. There was a significant difference ($p<0.05$) among the weed control methods. The shortest ASI was observed on hand hoeing. There was also a significant difference ($p<0.05$) among maize inbred lines. Inbred lines CML312, CML444, CML443 and CML00003 were tolerant; they recorded the shortest ASI number of days on metolachlor + atrazine + nicosulfuron and metolachlor + atrazine + nicosulfuron + halosulfuron herbicide combinations. CML488, CZL03014, L917 and N3.2.3.3 inbred lines were susceptible; they recorded the highest ASI number of days on metolachlor + atrazine + nicosulfuron and metolachlor + atrazine + nicosulfuron + halosulfuron (Figure 5).

Effect of herbicide combinations on ear height of maize inbred lines

There was a significant interaction ($p<0.05$) between herbicide combination and maize inbred line on ear height. There was a significant difference ($p<0.05$) among different weed control methods. The highest ear height was observed in hand hoeing on inbred line CZL0610 which recorded 135.23 cm. However, there was a significant difference ($p<0.05$) among the maize inbred lines. Inbred lines CML312, CML444, CML443 and CML00003 were tolerant; they recorded the least ear height on metolachlor + atrazine and metolachlor + atrazine + halosulfuron herbicide combinations. CML488, CZL03014, L917 and N3.2.3.3 were susceptible; they recorded the least ear height on metolachlor + atrazine + nicosulfuron and metolachlor + atrazine + nicosulfuron + halosulfuron herbicide combinations (Figure 6).

Effect of herbicide combination on grain yield of maize inbred lines

There was a significant interaction ($p<0.05$) between

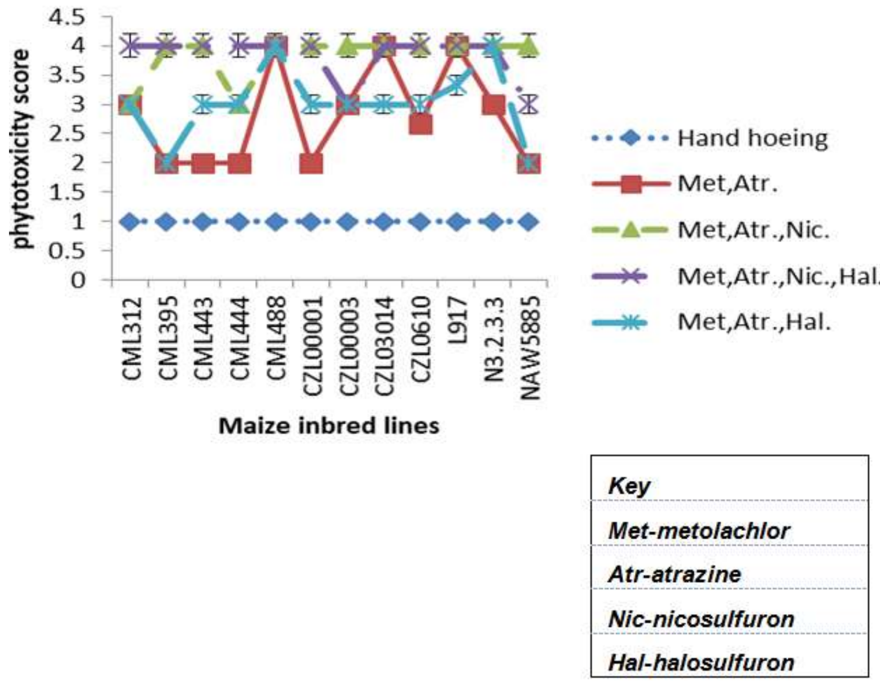

Figure 4. Effect of herbicide combinations on phytotoxicity of maize inbred lines.

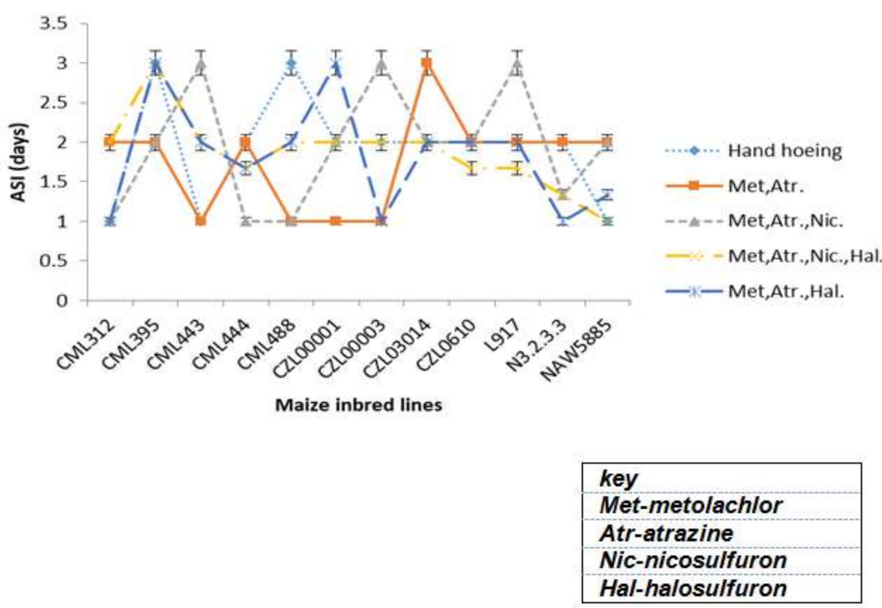

Figure 5. Effect of herbicide combinations on Anthesis Silking Interval of maize inbred lines.

herbicide combination and maize inbred line on grain yield. There was significant differences ($p<0.05$) among the weed control methods. The highest grain yield was observed in hand hoeing on inbred line CZL0610 which recorded 5.34t/ha. However, there was a significant difference ($p<0.05$) among maize inbred lines. CML312, CML444, CML443 and CML00003 were tolerant, they recorded the highest grain yield on metolachlor + atrazine and metolachlor + atrazine + nicosulfuron + halosulfuron herbicide combinations. Inbred lines CML488, CZL03014,

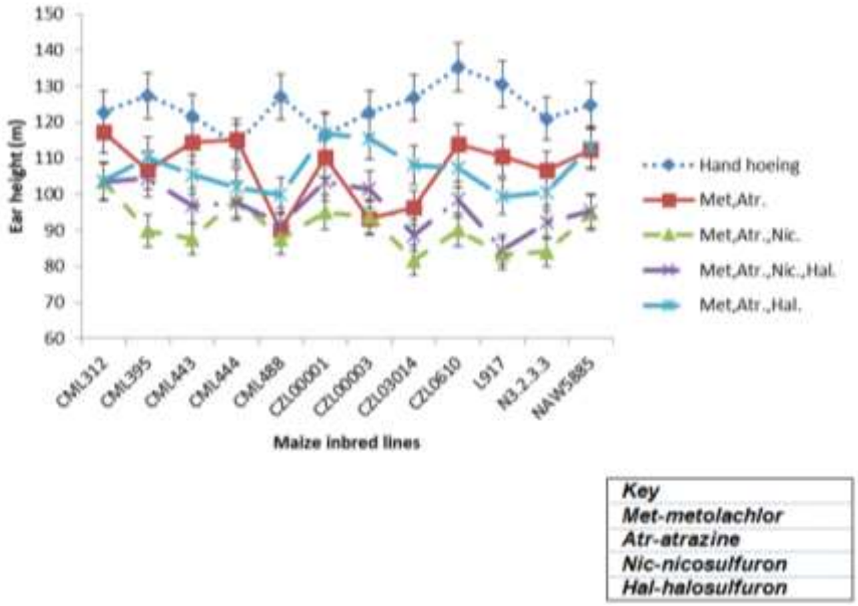

Figure 6. Effect of herbicide combinations on ear height of maize inbred lines.

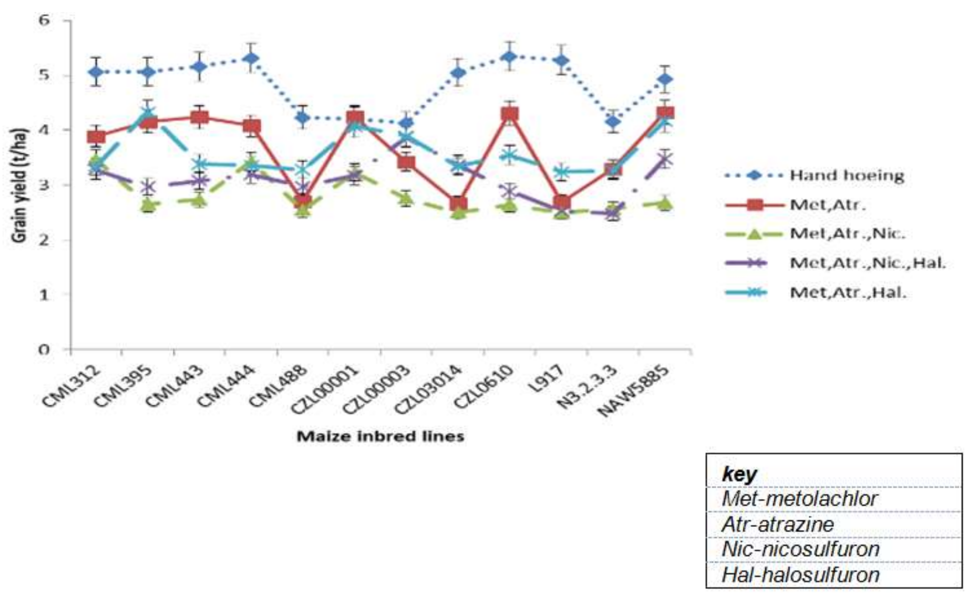

Figure 7. Effect of herbicide combinations on grain yield of maize inbred lines.

L917 and N3.2.3.3 were susceptible; they recorded the least grain yield on metolachlor +atrazine+ nicosulfuron herbicide combination (Figure 7).

DISCUSSION

Effect of herbicide combination on germination of maize inbred lines

The results indicated that there was an interaction between herbicide combination and maize inbred line on germination. Herbicides specifically metolachlor-96% might have inhibited growth in the germination phase. It was believed that this led to a reduction in the rate of shoot elongation, and so increased the time taken for the seedling to emerge from the soil. The different categories of these maize inbreds in response to different herbicide combination may be proof that tolerance to metolachlor in maize is genetically controlled. This may be attributed to the failure of the susceptible inbred lines (CML488, CZL03014, L917 and N3.2.3.3) enzymes to degrade the herbicides into less toxic form. Tolerant inbred lines CML312, CML444, CML443 and CML00003 metabolised (conjugation or degradation) the herbicide into less toxic form leading to poor uptake and translocation of the herbicide. Hand hoeing provided a true reflection that under free herbicide environment inbred lines had a maximum genetic performance due to absence of stress from herbicides. Results observed are in agreement with the findings by Bernards et al. (2006) that the variable response of hybrids to metolachlor was probably due to genetic inheritance. These results may be a true reflection of what may happen under field conditions, a result that was noted by Kanyomeka (2002) on his research on sensitivity of inbreds and hybrids to selected herbicides. Kanyomeka (2002) concluded that the susceptible inbreds may lose their germination capacity when they are exposed to different herbicide combinations.

Effect of herbicide combinations on plant height of maize inbred lines

Plant height was drastically reduced a week after pre-emergence herbicide application. These results are in line with those of Stefanovic et al (2010) who found that herbicides affect plant height of inbred lines. Mode of action of the herbicide and the genetic makeup might have contributed significantly to different inbred responses. Hand hoeing recorded significantly the highest plant height throughout the experiment. This might have been due to the ability of the inbred lines to perform and fully express their genetic potential in the absence of stress induced by herbicides. Previous studies indicated that sulfonylurea herbicides could seriously affect maize growth leading to yield loss (Stefanovic et al., 2010; Brankov et al., 2015).

At week two, metolachlor-96% might have inhibited growth on susceptible inbred lines since it is a shoot inhibitor of grass coleoptiles. It is believed that leaf curling and growth reduction experienced might have led to realisation of low plant height. A reduction in photosynthesis tissue at early stages is also believed to have contributed to these results. At week four significant differences in height were noted, this might have been a contribution of the mode of action of the herbicides; Nicosulfuron-75 % WG and Halosulfuron-75 % WG are protein amino acids inhibitors. They might have affected the biochemical pathway of the enzyme acetolactate synthase which triggers the manufacture of amino acids within the plant; this will have resulted in protein starvation and growth inhibition. The least plant height was observed on susceptible inbred lines CML488, CZL03014, L917 and N3.2.3.3 in metolachlor + atrazine + nicosulfuron and metolachlor + atrazine+ nicosulfuron + halosulfuron herbicide combinations.

Presence of the recessive gene which fails to degrade the herbicides into less toxic form might have contributed to herbicide susceptibility. These results were in accordance to those found by Green and Ulrich (1993) that, sensitivity of these inbred lines has been reported as being conditioned by single recessive genes which may affect inbred plant height. Different metabolic reactions and enzymes might have contributed so much in determining the rate of decomposition of the herbicide within the plant. An interaction of the environment, variety and herbicide might have speeded up the rate of absorption of the herbicide by susceptible inbred lines since higher temperatures and high humidity were experienced at the early stages of the season. Significant differences were observed among inbred lines and different herbicide conditions. At week 12, there was no interaction between herbicide combination and maize inbred line. These changes in height were noticeable at the beginning of the growing season and later on decrease significantly (Stefanovic et al., 2000) as exhibited on Table 4.

Effect of herbicide combinations on phytotoxicity of maize inbred lines:

At the beginning of the growing season higher temperatures and higher humidity were experienced, these conditions might have triggered a greater absorption and faster symptom development on susceptible inbred lines. No phytotoxicity symptoms were observed in hand hoeing since inbred lines expressed fully their genetic potential in the absence of herbicide. Tolerant inbred lines CML312, CML444, CZL00001 had the lowest phytotoxicity score; this might have been a contribution of good genetic makeup and the ability to degrade these herbicides into less toxic form (Sun et al., 2017).

Susceptible inbred lines CML488, CZL03014, L917 and N3.2.3.3 developed injury symptoms in response to metolachlor injury; they exhibited stunted shoots and leaf crinkling. It was believed that the genetic makeup has a major contribution on plant’s response to herbicides. Herbicide combinations metolachlor + atrazine + nicosulfuron and metolachlor + atrazine + nicosulfuron + halosulfuron scored the highest EWRC% score mostly on the susceptible inbred lines. Phytotoxicity symptoms of sulfonylurea herbicides were observed on the susceptible lines, roots exhibited bottle brush growth (unbranched, stubby), resulting in purple stems and leaves, along with overall plant stunting. Leaf tissue became light yellow from the outer edge of the leaf toward the veins, while veins turn light to dark purple.

In some cases, it is said that herbicides could decrease phytic and inorganic phosphorous content in maize leaves as in case of sulfonylurea herbicides (Brankov et al., 2015). These changes were noticeable at the beginning of the growing season, and later on decrease significantly (Stefanovic et al., 2000; 2007). It was believed that the active growing plant stage and thin stems absorbed herbicides at a faster rate. Obtained results were in line with those found by Zaric et al. (1998), Stefanovic et al. (1997, 2000) that under such conditions, very susceptible and moderately susceptible inbreds mainly were affected by unfavourable climatic conditions. Results are a supporting statement that environmental factors, such as high temperature and high humidity directly or indirectly affect absorption of herbicides and their effect on plants (Stefanovic et al., 2010).

Maize inbred lines were ranked by their response towards different herbicide combinations by the EWRC % scale into three categories, Tolerant; CML312, CML444, CML444 and CZL00001, Medium resistant; CML395, CZL0610, NAW5885 and CZL00003, Susceptible; CML488, CZL03014, L917 and N3.2.3.3. This was determined by looking at the EWRC scale (WSSA, 2002).

Effect of herbicide combination on ASI

The shortest ASI was observed in hand hoeing weed control method. This might have been a contribution of the maximum genetic potential of the inbred lines to perform well in the absence of herbicide stress. Tolerant inbred lines CML312, CML444, CML443 and CML00003 recorded the shortest ASI number of days on metolachlor + atrazine + nicosulfuron and metolachlor + atrazine + nicosulfuron + halosulfuron herbicide combinations. A combination of genetic inheritance, herbicide stress and moisture stress towards the reproductive phase might have affected the ASI. These results also point out that herbicides might have affected phases in the tassel and ear development. It is believed that a contribution of high temperatures experienced during the season promoted stunting and premature reproductive phase on susceptible inbred lines. This can be explained in such a way that if susceptible inbred lines are exposed to stress environments such as the presence of herbicides, there is a delay in DMS and a speeding up of DMP. This might have led to prolonged ASI thereby affecting pollen-silk synchronisation. These results were in line with those found by Stefanovic et al. (2010) and Zaric et al. (1998) who observed that these phases were shifted and normal ear fertilisation was not possible in three out of 15 inbred lines.

Effect of herbicide combination on ear height of maize inbred lines

Ear height is one of the most important yield attribute in seed production. It contributes significantly to the successes of good pollen-silk synchronisation. It determines the most effective position of the silk to receive maximum pollen for fertilisation. The highest ear height was observed in hand hoeing on inbred line CZL0610. Hand hoeing might have resulted in the eradication of potential weed competitors thereby allowing the inbred line to exhibit its genetic potential fully. The inbred line exhibited its maximum genetic potential in the absence of herbicides because it fully utilised its resources like nutrients, water and sunlight in the absence of stress. The least ear height was observed in metolachlor + atrazine + nicosulfuron herbicide combination on inbred line CZL03014. It is believed that an interaction of variety, herbicide and environment might have contributed significantly to the realisation of these results. This was observed on susceptible inbred lines CML488, L917 and N3.2.3.3. It is believed that any factor that affected plant height is believed to have affected ear height. Reduction in inbred plant height might have directly affected ear height. Most of the factors that were shortlisted to have affected plant height are believed to be the one that affected ear height. CML312, CML444, CML443 and CZL00001 recorded the highest ear height since they are late mature varieties with good genetic makeup and good seed quality standards. These findings were in accordance with those found by Stefanovic et al. (2010) that herbicides had an effect on ear height of maize inbred lines.

Effect of herbicide combination on grain yield of maize inbred lines

The highest grain yield was observed in inbred line CZL0610 in hand hoeing weed control method. The inbred line could fully utilise its resources in the absence of growth inhibitors such as herbicides. The least grain yield was observed in metolachlor + atrazine + nicosulfuron + halosulfuron herbicide combination on inbred line N3.2.3.3. This might have been an attribute of poor genetic potential in response to herbicides. Brankov (2016) observed that white and popcorn maize genotypes are more sensitive than standard maize genotypes. Yield is an attribute of many growth parameters which is believed to have an effect on the final grain yield. All the parameters measured in this experiment which were affected by herbicides might have contributed significantly to the final grain yield. Previous studies indicated that sulfonylurea herbicides could seriously affect maize growth leading to yield loss (Stefanovic et al., 2010; Brankov et al., 2015). These parameters are determined by the genetic potential of inbred lines to withstand stresses. A lag in development stages on inbred lines might have posed an effect on the final grain yield. Susceptible inbred lines CML488, CZL03014, L917 and N3.2.3.3 had the lowest final yield whilst CML395, CZL0610, CZL00003 and NAW5885 had the medium; CML312, CML444, CML443 and CZL00001 had the highest final grain yield. Herbicides had an effect on growth parameters which later affected the final yield (Stefanovic et al., 2010).

Conclusion and Recommendations

Metolachlor +atrazine +nicosulfuron and metolachlor +atrazine +nicosulfuron +halosulfuron herbicide combinations significantly affected germination, phytotoxicity, plant height, ASI, ear height and grain yield of maize inbred lines. Metolachlor + Atrazine and Metolachlor + Atrazine + Halosulfuron were the best effective weed control combinations to use across all maize inbred lines used in this experiment.

Variety significantly affected response of maize inbred lines to different herbicide combination. It was observed that parental components of hybrids of early maturity group (CML488, CZL03014, L917 and N3.2.3.3) expressed greater susceptibility to herbicides. Inbred lines were grouped into three categories in relation to EWRC score, efficacy and survival rate into; Tolerant (CML312, CML444, CML443 and CML00003), Medium resistant (CML395, CZL0610, NAW5885 and CZL00003; Susceptible (CML488, CZL03014, L917 and N3.2.3.3).

Based on findings of this study, farmers are advised not to use metolachlor +atrazine + nicosulfuron and metolachlor + atrazine + nicosulfuron + Halosulfuron herbicide combinations on susceptible inbred lines (CML488, CZL03014, L917 and N3.2.3.3) because these herbicide combinations had an effect on germination, phytotoxicity, plant height, ASI, ear height and grain yield of these inbred lines. Therefore, it is recommended to use hand hoeing, metolachlor + Atrazine and Metolachlor + Atrazine + Halosulfuron as weed control methods on maize inbred lines used in the experiment.

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CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Full Length Research Paper

Sustainable land management and ecological service assessment in Northwest of China: Case study of Yanchi, People's Republic of China

Kossi Fandjinou[1,2], Kebin Zhang[1*], Fousseni Folega[2] and Xiaohui Yang[3]

[1]College of Soil and Water Conservation, and Desertification Combating, Beijing Forestry University, 35 Qinghua East Rd 10083, Haidian District, Beijing-China.
[2]Laboratoire de Botanique et d'Ecologie Végétale, Université de Lome, BP 1515, Lome-Togo.
[3]Institute of Desertification Studies, Chinese Academy of Forestry, P.O. Box 35, Chinese Academy of Forestry, Yiheyuanhou, Haidian District, Beijing,100091, China.

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This research aims to assess the driving factors hindering the effectiveness of these protected areas implemented to counter land degradation and evaluate the services provided by these ecosystems in the North West of China. With Ningxia province, Yanchi County chosen as experimental research area, preferential sampling technique was used with 50 plots of 1 m^2 (quadrat) laid for plant community characteristics survey combined with species and biomass measures mainly in three different areas, along with unit price system of evaluating ecosystem services values based on Costanza's evaluation model also used to quantify the V_{ei} (Ecosystem Service Value). The results showed both up and down trends of vegetation characteristics in protected areas including E, E1 and E2 year-round enclosure, seasonal and un-enclosed area respectively where anthropogenic disturbance has been prohibited for natural restoration. Moreover, compared to 1999, the total ecosystem service values of the year 2004 increased by 6.75% and those for 2010, 2015 increased by 7.28 and 5.55% respectively, indicating some positive effects of the protected on the total value of the grassland ecosystem service. In addition, regulatory and support services occupied the largest proportions: 52.08 and 32.69% respectively, followed by supply and cultural services 8 and 7% respectively. These results prove that the protected areas are improving the grasslands by reducing the soil loss and increasing their ecosystem services provision. Thus, sustainability and guarantee of the ability of the arid ecosystem to continue to provide the ecological services is important in the management taking into account the limiting factors.

Key words: Land degradation, limiting factors, sustainable management, Ecosystem Service Value (V_{ei}).

INTRODUCTION

The Millennium Ecosystem Assessment (MEA) discovered that approximately 60% of the World's ecosystem services were degraded due to human being disturbance (MEA, 2005). In addition, after publication of the Economics and Ecosystems and Biodiversity (TEEB, 2010) coupled with MEA, the attention of the scientific

*Corresponding author. E-mail: ctccd@bjfu.edu.cn

community has been raised toward the urgency to combine ecological research to Economic Sciences in order to balance the development of the society (Costanza et al., 2004). Therefore, the need to undertake actions and plans both scientifically and socially remains obvious at each level and scale; local, national, regional and global. In China, the most populated country in world, the research on ecosystem service (ES) has become one of the growing areas in the last decades (Liu and Costanza, 2008). Nevertheless, those publications were in Chinese language making them not easily accessible to the global scholars (Wei Jiang, 2017). The first study on ES in China was conducted in 1999 by Ouyang et al. (1999), to estimate the economic values of Chinese terrestrial ES based on ecological models and economics valuation techniques. The ecosystem services represent then the process through which the natural ecosystem (grassland…) and the species that composed them, sustain and fulfill the human life (Ouyang et al., 1999). Those natural ecosystems were disturbed by human activities which hinders their ability to provide those natural services. Therefore, grassland ecosystems, as one of the world's most widespread terrestrial ecosystems, occupy approximately 13% of the earth's surface (Gong et al., 2009) and hold approximately 20% of global carbon storage (Scurlock and Hall, 1998). The degradation of grasslands can affect the carbon balance, biodiversity and food production (O'Mara, 2012) which are mainly ecosystem services provided by the global ecosystem for the welfare of humanity. Since the end of the twentieth century along with population growth and rapid economic development in China, strong pressure from human activities and global climate change was put on desert ecosystem structure and biological processes has changed dramatically. The stability of desert ecosystems and the overall level of ecosystem services have been reduced. Thus, the degradation of desert vegetation has resulted in reduction of plant biodiversity. In addition, the wind erosion process and sand storms are increasing, and the rapidly expanding desertification zone is highlighted. The degradation of the desert ecosystem has seriously constrained sustainable development so that the arid and semi-arid areas can be quoted among the regions whose economic and social developments are lagging behind in the World especially in China. Faced with this reality, China's national strategic objective was to build a harmonious society, maintain, improve and restore the structure, function and stability of the desert ecosystem (Zhang et al., 2000; Yan et al., 2011). Several protected areas (fencings or enclosures) have been set for reclamation in semi-arid and arid ecosystems everywhere in the country Therefore, grassland management has become one of the priorities of the Chinese government which recognizes that land degradation can be combated by herbaceous plant recovery for sustainable purposes due to increasing demands which were inconveniencing strongly the natural ecosystems and their service provision especially the terrestrial ecosystem. In fact, when the demands become too much, the soil becomes degraded. Soils are therefore the basis of all terrestrial ecosystems; meanwhile a degraded soil means lower fertility, reduced biodiversity, human poverty (Bridges and Oldeman, 2010) and explaining the direct link between ecosystem services and its limiting factors. Therefore, sustainability science raises questions about interactions between society and environment, and how these interactions affect both social and environment needs. Researches should then include more than just a single academic discipline's concern, and adopts a multidisciplinary focus that accounts for the complex interactions between people and their environment (Carpenter et al., 2009). In the literature review concerning this topic, none of the last research combined, the management methods and the ecosystem services provide their limiting factors. In fact, when focusing on the countries that are experiencing the consequences of desertification, China can be quoted as desertified lands in China are distributed in 471 counties, 18 provinces and regions, including Xinjiang, Tibet, Qinghai, Gansu, Hebei, Ningxia, Shaanxi and Shanxi. Thus, desertification means indirectly the loss or reduction of the ecosystem services. Therefore, one of the causes of desertification includes natural climatic factors and human factors which represent the most dominant causes. Human factors include: overgrazing, which is the main cause of rangeland degradation, over collection of fuel wood and Chinese medicinal herbs, over exploitation of mineral resources, and over cultivation of dry-land. Among the ecological issues confronted by China, land degradation in arid zones, especially in Western China, is one of the most serious challenges (Fandjinou et al., 2016). To overcome these challenges, several projects are being set up by the Chinese Government, among which can be quoted: the Grain for Green project through farmland converted to grassland and artificial fencing. These programs are based on the principle of offering compensation to farmers: grain, cash, and free seedlings (Cao et al., 2008) to the land users taking part in the program. Nevertheless, many articles related to grassland degradation omitted the crucial impact of the limiting factors of the projects implemented on land degradation in arid zones and the quantification of the services provided by these threatened ecosystems to make decisions and policy makers aware of the need to speed up sustainably the management plans and integrated strategies. This paper aims at analyzing the factors which limit enclosure or artificial fencing implemented for soil management in China especially in the Northern part of the country and provide a numerical value (Qian et al., 2014) of the services provided by the ecosystems in order to draw the attention of the policymakers to continue and reinforce what is being done to overcome the challenges of arid zones degradation which result in the decreasing of those ecosystem services.

MATERIALS AND METHODS

Research area

The study zone lies between 37° 10'04''N and 106° 30' 41''E (Figure 1). It is located in East of Ningxia Hui Autonomous Region. The total area of Yanchi is 8661.3 $\mathrm{km}^2$with a North-South distance of 110 km and east-West of 66 km. Yanchi is located at the junction of four provinces (regions), Shaanxi, Ningxia, Gansu and Inner Mongolia. The Southern part is Loess hilly landscape while the middle is occupied by hilly land with an altitude ranging from 1295 m to 1951 m (above sea level). The mean annual temperature is 8.1°C. The annual highest and lowest average temperatures are 34.9 and -24.2°C, respectively whereas the annual average frost-free and average precipitations are 165 days and 250 to 350 mm/yr respectively. This confirms the dry, windy and sandy weather that prevails in this county. The natural landscape mainly consists of prairie (sand wilderness). From a pedological perspective, Yanchi County is mainly denuded peneplain with a typical serosem, dark humus soil, sandy soil loess and a little salty clay, mainly white bentonite.

Data collection method

The field work was carried out every July during the vegetation growing season (VGS), species richness (number of species), height (relative biomass) and abundance (relative recovery) were collected. The sample plots were surveyed as recommended for phytosociological releves in grassland (Figure 1, Photo 1) (Dierschke, 1994; Chytrý and Otýpková, 2003). Sampling plot coupled with linear transect method were used for vegetation species frequency and abundance survey (Photo 1). Mechanical method was used with a metal tube containing a spring to measure the degree of land compactness by the depth of the whole it made in the soil in a surveyed plot and soil biological crust were measured (Belnap et al., 2003).

Data processing

The vegetation height field survey, coverage, biomass and other basic data processing was computed in EXCEL, SPSS software's worksheets to analyze the plant community structure according to the abundance, height, coverage, biomass, frequency and importance value. The plant community structure shows the plant density and relative importance of plant species in grassland vegetation (EC, 2013). Most scientists use the following three indices, such as coverage and height (Zhang et al., 2000) but in this study, plant height, abundance, coverage, biomass and frequency were used as follows:

Relative abundance (R_a= (a_i/a) × 100 (1)

Where a_i is abundance of a given plant *i* and *a* is abundance of all plants species.

Relative height (R_h) = (h_i/h) × 100 (2)

h_i = height of a given plant; *h* = height of all plants species surveyed.

Relative coverage R_c= (c_i/ c) × 100 (3)

Where:

Photo 1. 1 m^2 sample plot for plant species abundance, height, frequency survey (taken in 2014).

c_i represents the coverage of a given plant *i* and c the coverage of all plants.

Relative biomass R_b= (b_i/b) × 100 (4)

b_i is biomass of a given plant *i* and *b* refers to the biomass of all plants species surveyed.

Relative frequency R_f= (f_i/f) (5)

where f_i represents the frequency of a given plant *i* and *f* is the sum of the frequency of all plants species surveyed.

Frequency (f_i) = (Ni/N) × 100 (6)

Where Ni is quadrate number in which a given plant appeared and N is the number of quadrat surveyed.

Plants importance value: It involves the number of species, their relative biomass, relative height, relative coverage and relative frequency.

The equation used to calculate plant importance value is:

Plant Importance value (*Piv): Piv* =$\frac{\mathrm{Ra+Rc+Rf+Rh+Rb}}{5}$ (7)

Where *Piv*, R_a ,R_h, R_c, R_f and $R_b$represents respectively the plant importance value in a given area, relative abundance, relative height, relative coverage, relative frequency and relative biomass. The importance value is used because it takes into account the main characteristic of the plant species in order to calculate the community structure index that will show the state of the community there. The importance value then combines the five parameters above to form a synthetic index where the plant with the highest importance value is the most important; however, in that importance, another index can show the real structure of that community. This means that the synthetic index is insufficient itself, and explains the reason why the index of diversity of Shannon-Weiner and the ecological dominance of Simpson and the Evenness indexes are combined with the synthetic index to illustrate the whole aspect of the community.

Indices of community structure: The Shannon's diversity index (SW) is commonly used to characterize species diversity in a plant community and it helps to determine the spatial distribution of each plant gender. Moreover, the ability to quantify diversity in this way is an important tool to understand a plant community structure. In this study, Importance Value has been used to calculate the indexes of plant community structure.

(a) Shannon's diversity index formula is as follows:

$$SW= -\sum P_{piv} \ln P_{piv} \quad (8)$$

Where, SW= Shannon index of diversity; ln is the natural logarithm, P_{piv} is the proportion of importance value of the i^{th} species, (P_{piv} =ni/∑ *N) is the importance value of* i^{th} *species and N is the importance value of all the species*)

(b) Simpson Index of Dominance:

The equation used to calculate Simpson's index was

$$SP = 1/\sum_{i=1}^{n} {P_{piv}}^2 \quad (9)$$

Where, SP= Simpson index of Dominance; P_{piv} is the proportion of importance value of the i^{th} species (P_{piv}=ni/∑ *N, is the importance value of* i^{th} *species and N is the importance value of all species*).

(c) The species evenness was calculated by the equation

$$EV= (Sw -1)/ (PS-1) \quad (10)$$

Where, EV= Species Evenness index; PS is the number of plant species in the transect and SW= Shannon index of diversity.

Evaluation of Ecosystem Service (V_{ei})

Evaluation of V_{ei} has been widely used as a research method in academic fields (Wang et al., 2003). The value of ecosystem services can be estimated in various ways. In general, the framework is composed of three main parts: (1) measuring the provision of ecosystem services (Table 1); (2) determining the V_{ei}; and (3) designing policy tools for managing ecosystem services (Poplasky, 2008) On the basis of Cotanzas's Evaluation Model, a unit price system of evaluation suitable for China was developed (Xie et al., 2008). According to the area correction coefficient of V_{ei} in each province of China and with a consideration of the special study area, a junction of four provinces (Ningxia, Inner Mongolia, Shaanxi and Gansu) (Dierschke, 1994), the correction coefficient of Yanchi county is 0.66 by weighted average. Equivalent factors of V_{ei} of Yanchi County are shown as follows:

$$V_{eik}= \sum_f (A_K \times VC_{kf}) \quad (11)$$

$$V_{eif}= \sum_k (A_K \times VC_{kf}) \quad (12)$$

$$V_{eik}= \sum_k \sum_f (A_K \times VC_{kf}) \quad (13)$$

Where, V_{ei} stands for the total value of ecological service, *VC* is ecological service value per area, *A* is the land area, *k* is one type of the first services, and *f* is one type of the second service (Table 1).

Also, eco-compensation standard has been calculated using this equation:

$$E_o = \frac{1}{n} \sum_{i=1}^{n} \text{Vei} \times L_i \quad (14)$$

where, E_o is the eco-compensation and represents each district considering location (RMB/ha/a), Vei is the ecosystem services value of the ith sample plot (RMB/ha/a), Li is the adjusting indicator value of the ith sample plot, and n is the number of the sample plots in each area (Sheng et al., 2017).

Table 1. Ecosystem services (Sources: Harper et al, 1988; Malinga et al, 2013; MEA, 2005).

The first services	The second services
Supply services	Food production Raw material production
Regulating services	Air regulation Climate regulation Water conservation Waste disposal
Support services	Soil conservation Biodiversity conservation
Cultural services	Landscape regulation

Sources: Harper et al. (1988), Malinga et al. (2013) and MEA (2005).

RESULTS AND ANALYSIS

Table 2 shows E, E1, E2 which are year-round enclosure, seasonal and non-enclosure areas respectively. It displays also *Ra*, SW, SP and EV which represents Relative abundance, Species Shannon Diversity and Ecological dominance and Evenness Index respectively. The plant community structure characteristic displays the land cover of the plant community as the relative abundance itself can be an insufficient indicator of soil coverage. Therefore, comparing the values of Abundance for the three types of enclosures, it can be seen that seasonal enclosure E1 (Figure 2) is more abundant than E and E2. The diversity index is the highest in the year round enclosure until 2009 when it decreases resulting in E being the highest from 2009 to 2011. From 2011, E2 increases until 2012 with a little decrease between 2012 and 2014. The ecological dominance index increases from 2003 to 2009, 2009 to 2012 and from 2012 to 2014 in E, E1 and E2 respectively (Figure 2). These variations explain the fact that according to the enclosure type, the grass land restoration behaves concomitantly. Moreover, the Evenness index shows the uniformity of plant community distribution on the soil. According to Table 1 and Figure 2, it can be seen that the three enclosure types have approximately the same plant spatial coverage variation although the highest values appears in E2. Figure 2 shows that the variation of the number of species is highest in 2007 and 2011 for the seasonal enclosure area. The trend of abundance in the year-round oscillates with a minimum in 2006 and 2012 respectively.

Evolution of the plant community indexes shows that the species diversity is more stable in the seasonal enclosure area with slights oscillations. This evolution is not significant in the annual or year-round enclosure areas but very remarkable in the external area (E2).

Table 2. Species diversity indices under different grasslands enclosure.

Index		2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
	E	16	13	13	11	17	12	12	17	18	13	16	22
Ra	E_1	17	10	8	15	20	19	16	16	22	19	21	19
	E_2	9	4	6	10	10	8	10	15	15	19	17	16
	E	2.4	2	1.7	2.2	2.2	2.3	2	2	2.4	2.3	2.4	2.1
SW	E_1	2.2	2.1	2	1.7	2.2	2	2	2.3	2.2	2.	2.1	2.3
	E_2	1.4	0.7	1	1.6	1.5	1.3	1.5	2.1	2	2.5	2.4	2.3
	E	8.2	5	4	6	6.7	8.1	7.7	3.8	3.6	8.4	6.8	5.6
SP	E_1	5.7	5.6	5.2	4.5	6.1	5.8	5.8	5.6	8.1	6.3	9.6	7.8
	E_2	2.6	1.6	2.1	3.2	3.2	2.6	2.6	3.5	4.9	5.2	10.2	8.2
	E	1	0.8	0.8	0.8	0.8	0.8	0.7	0.7	0.8	0.8	0.8	0.8
EV	E_1	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.9	0.8	0.8
	E_2	0.6	0.5	0.6	0.7	0.7	0.7	0.6	0.7	0.7	0.9	0.9	0.9

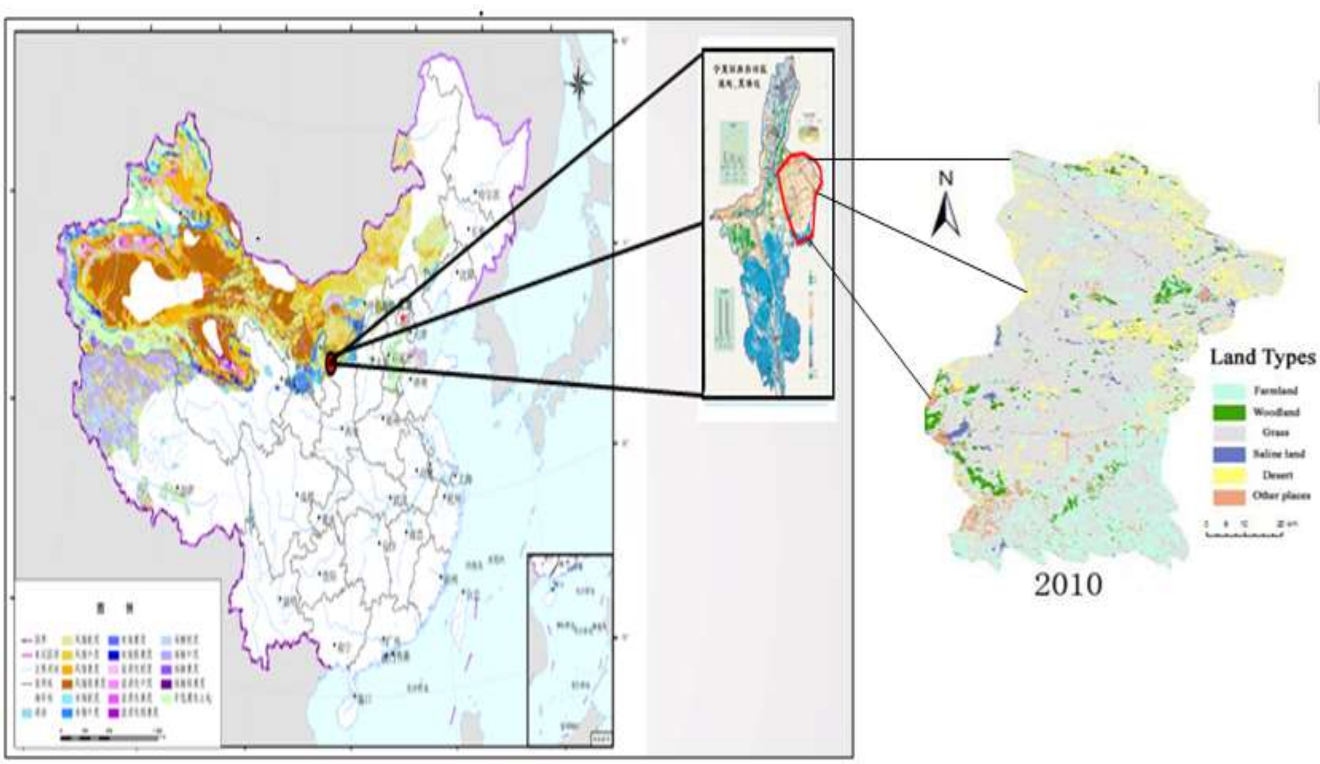

Figure 1. Research area.

These remarkable differences can be explained by the human activities and disturbance because of the open access due to an absence of enclosure or man-made fences around this area. In fact, animal grazing is the main form of human disturbance influencing the grassland of the research area. When the soil is bare, the erosion agents can easily degrade it. Hence, vegetation recovery becomes imperative for soil conservation by sustainable management.

In addition, the changes that occurred in ecological dominance index in the three land use types express the structure of the plant community on the soil. Moreover,

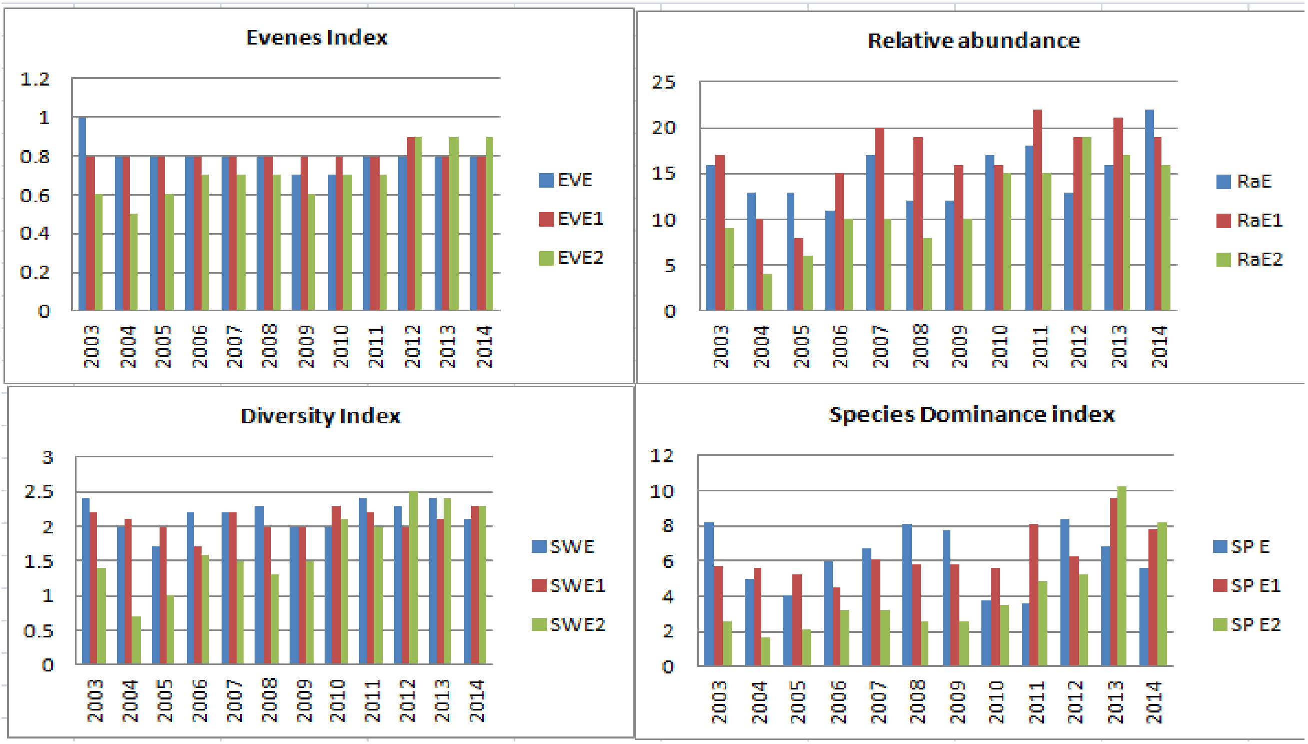

Figure 2. Plant community structure indexes.

Figure 2 shows also that plant recovery varies according to the land management technique. In fact, when analyzing this Figure 2, it was seen that the most even area is the seasonal enclosure area followed by the year round area and the unfenced area. The greatest values of Evenness occur in this seasonal area which has a good soil recovery and can resist erosion. This means that when implementing enclosure method, the purpose of the implementation and the length of fences period need to be taken into account. This characteristic shows that the artificial fencing can restore the soil ecosystem for vegetation recovery and indirectly the support services reinforcement. Therefore, any factor disturbing the fulfillment of this function hinders indirectly the support services of the natural ecosystem restoration. All the ecosystem services are provided in different proportions, the highest peaks are reached for biodiversity conservation and soil conservation (Table 3, Figure 3) during 1999, 2004, 2010 and 2015.

Table 5, Figure 5 indicates the plant characteristics under different soil use type and management. Between these five types of soil, from the diversity index part, it appears that the quick sand (moved dunes) area is the most diverse followed by the natural grassland and the farm land converted to grassland and finally the less diverse is the artificial fencing. This shows that each use or monitoring technique impacts the ability of the soil ecosystem to provide its service (Table 5).

Table 3. 1999 to2015 V_{ei} per unit area of Yanchi County (Yuan.hm^{-2}.a^{-})

	1999	2004	2010	2015
Food production	0.98	1	0.95	0.94
Raw material production	0.998	0.78	0.82	0.78
Air regulation	2.68	2.43	2.64	2.58
Climate regulation	3.118	2.85	3.16	3.1
Water conservation	2.98	2.73	3.04	2.98
Waste disposal	2.78	2.73	2.91	2.89
Soil conservation	3.84	3.7	3.9	3.84
Biodiversity conservation	3.4	3.22	3.4	3.36

The Biological Soil Crust (BSC) stabilizes the sand by its filament and protects against erosion (Anderson et al., 1982). This biological soil crust did not appear in (A) which is like an indication of the efficiency of that enclosure technique (Photo 2).

The most important biological soil (BSC) crust is very thick and abundant in the artificial fencing than in the ancient farmland and in wetland. In fact, the soil crust is very important for soil sand fixation and desertification combating. The farmland converted to grassland contains a crust more than a wet land. This observation shows also that this method impacts positively the soil and increases its capacity to produce support services. (Table 6, Figure 6).

The Ordinary Square analysis has been used to show

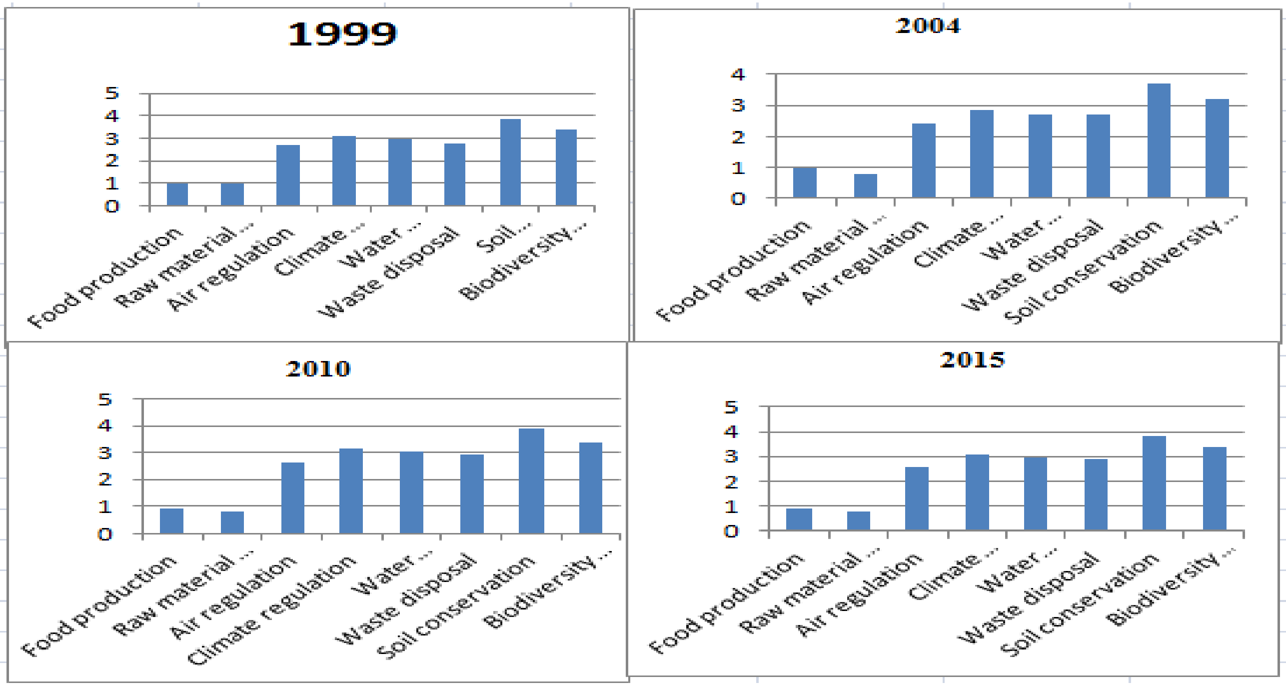

Figure 3. V_{ei} from 1999 to 2015.

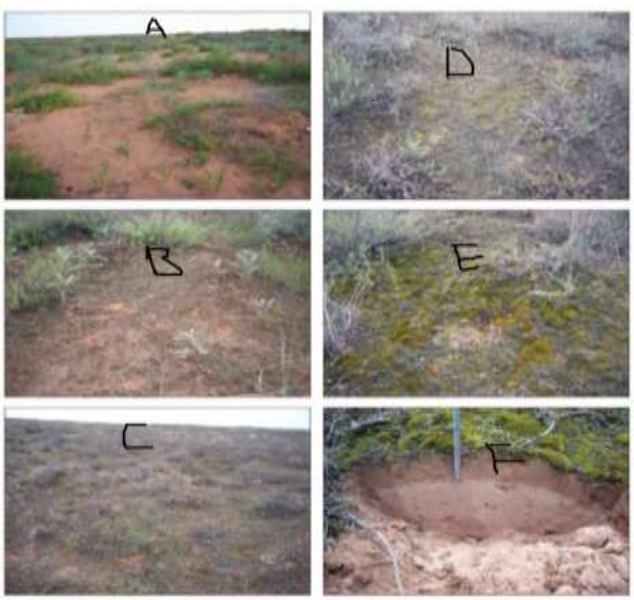

Photo 2. Appearance stage of soil crust in the different fencing period. **A & B:** Yanchi (taken in 2004), **C & D:** Yanchi (taken in 2015), **E & F:** Yanchi (taken in 2010).
Source: Belnap et al. (2003) and Anderson et al. (1982).

the relationship between the crust recovery and precipitation. The correlation linear equation describes a link between climatic factors and biological factors for land degradation restoration. In fact, the biological soil crust generated stabilizes the soil sand to resist air or water erosion. But the limit of this stabilization is on the economic income that is missed making it unsustainable. Although this correlation coefficient was feeble stating that there is less link between these two factors, it has been shown in practice (on field investigation) that the precipitation amount influences the biological crust production (Table 7 and Figure 7) so that the more wet a soil is, the more capable it is to generate biological soil crust.

From Figure 7 it can be seen that the correlation between the precipitation and the biological crust is slightly obvious and remarkable. This statement is shown by the correlation coefficient being very feeble less than 80% and the trend line of the crust variation. This graph which represents the precipitation and biological crust generated annually from 2003 to 2013 intended to portray graphically the variation of the land status on stabilization basis. It emphasizes the relationship between the amount of rain received every year and it influences on the capacity of that land to bear biological activity. In fact, the crust generated bound the sands and make the soil able to resist erosion, showing on one hand the good influence of fences establishment as well as the lack of an economic income for the local population implementing this policy.

DISCUSSION

The need to restore degraded environments especially

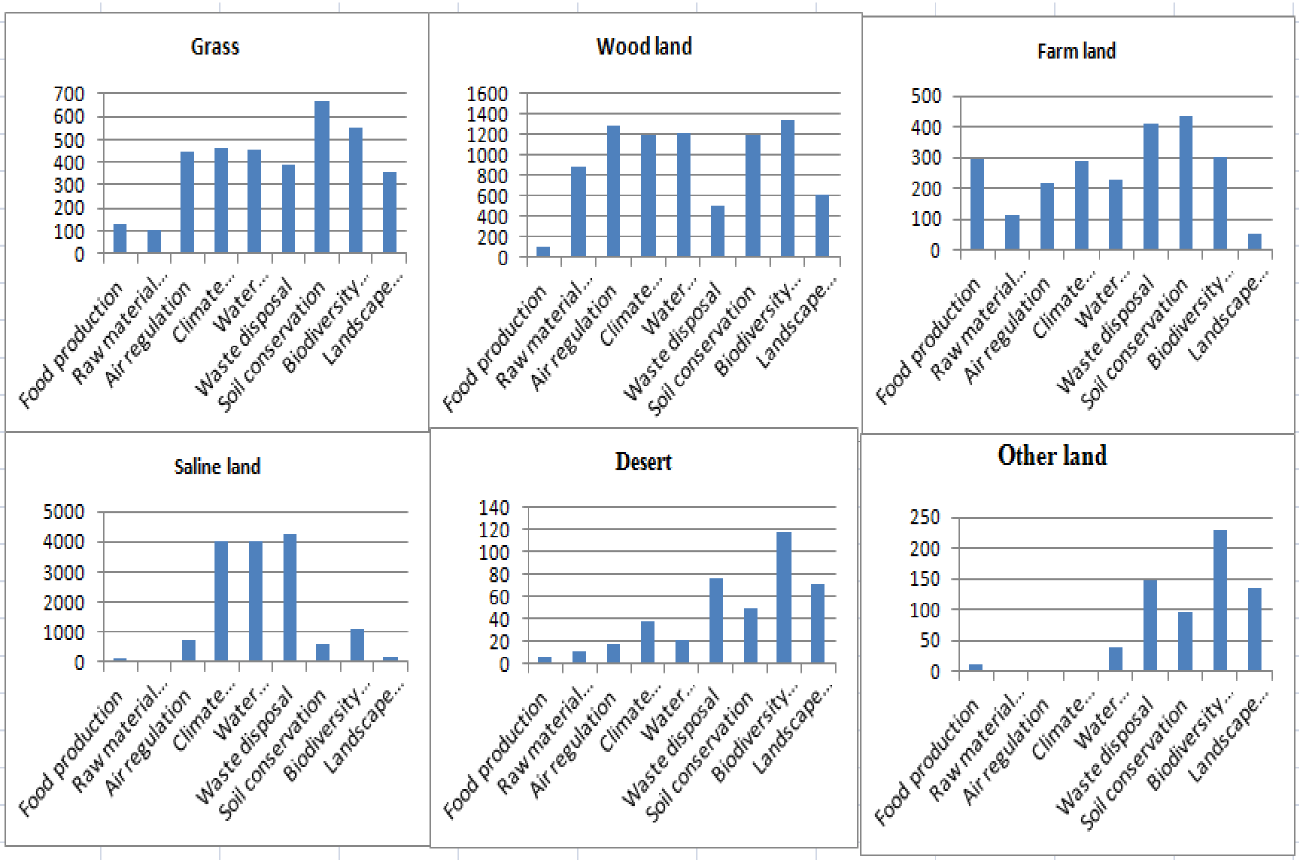

Figure 4. V_{ei} per unit area.

soil degradation has led the Chinese government to implement several projects which are influencing the grassland variation. These ecological projects are important and vital method to help ecosystem adaptation and restoration in response to environmental change and human interference and disturbance (Han et al., 2010) and for biological restoration. On the other hand, these techniques increase indirectly the capacity of the soil ecosystem to provide efficiently the ecosystem services for human welfare.

In order to analyze the influencing factors for both monitoring techniques such as enclosure method and ecosystem service provision in Yanchi, data has been collected from 1999 to 2015 by preferential sampling technique used as a sampling design and 50 plots measuring 1 m × 1 m (quadrat) were laid up for plant community characteristics assessment in different land use types and the ecosystem service values (V_{ei}) have been quantified in other hand.

Following the hypothesis that vegetation characteristics were able to portray effectively by their behaviors the quality of the soil, the analyses of the results showed that likewise it is shown in the Figure 2 that the vegetation characteristics are insufficient to explore the land cover effectively. For this reason, other indexes including vegetation evenness, biodiversity and dominance indexes were calculated. The calculation of these indexes enables analyzing the structure of the vegetation on the soil, and vegetation shows that an abundant area can be "uneven" and an even area can be less diverse. In addition, the comparison between the different diversity indexes of all kinds of land use indicates that grassland diversity is the highest outside (E) of the fences than in the enclosure (Figure 2). In the enclosure, the growth of the dominant species competes with the other species; a fact that decreases the biodiversity inside the enclosure than outside. In addition, the outside is influenced by the animal grazing effects because the growth of the dominant species meets the animal passage, making the conditions fair for the other species, enriching the biological diversity in the unclosed area. Moreover, Figure 2, Figure 4, Table 4 and 5, shows that plant recovery varies according to the land management techniques and land type. In fact, when analyzing Figure 2, it was seen that the most even area is the seasonal enclosure area followed by the year round area and the unfenced area. The greatest values of evenness occur in this seasonal area. The seasonal area has a good soil recovery and can resist against erosion. This means that when implementing enclosure method, the purpose of the

Table 4. V_{ei} per Unit Area

	Farm land	Wood land	Grass	Saline land	desert	Other land
Food production	296.41	97.81	127.45	106.71	5.93	11.4
Raw material production	115.6	883.29	106.71	71.13	11.85	0
Air regulation	213.41	1280.47	444.61	714.34	17.79	0
Climate regulation	287.52	1206.37	462.4	4016.3	38.53	0
Water conservation	228.23	1212.3	450.54	3983.69	20.75	39.91
Waste disposal	412.01	509.82	391.25	4268.25	77.07	148.24
Soil conservation	435.72	1191.55	663.95	589.85	50.39	96.93
Biodiversity conservation	302.33	1336.79	554.28	1093.74	118.56	228.06
Landscape regulation	50.39	616.53	357.88	139.14	71.13	136.84

Table 5. Vegetation indexes per land use type

Land type	Diversity index Sw	Ecological dominance Sp	Evenness index E
Natural grass land	2.64	10.32	0.51
quick sand or moved dunes	2.78	13.21	0.64
Artificial fencing	2.16	8.17	0.71
farmland convert to grass land	2.54	9.90	0.60
Abandoned land	2,44	10.35	0.49

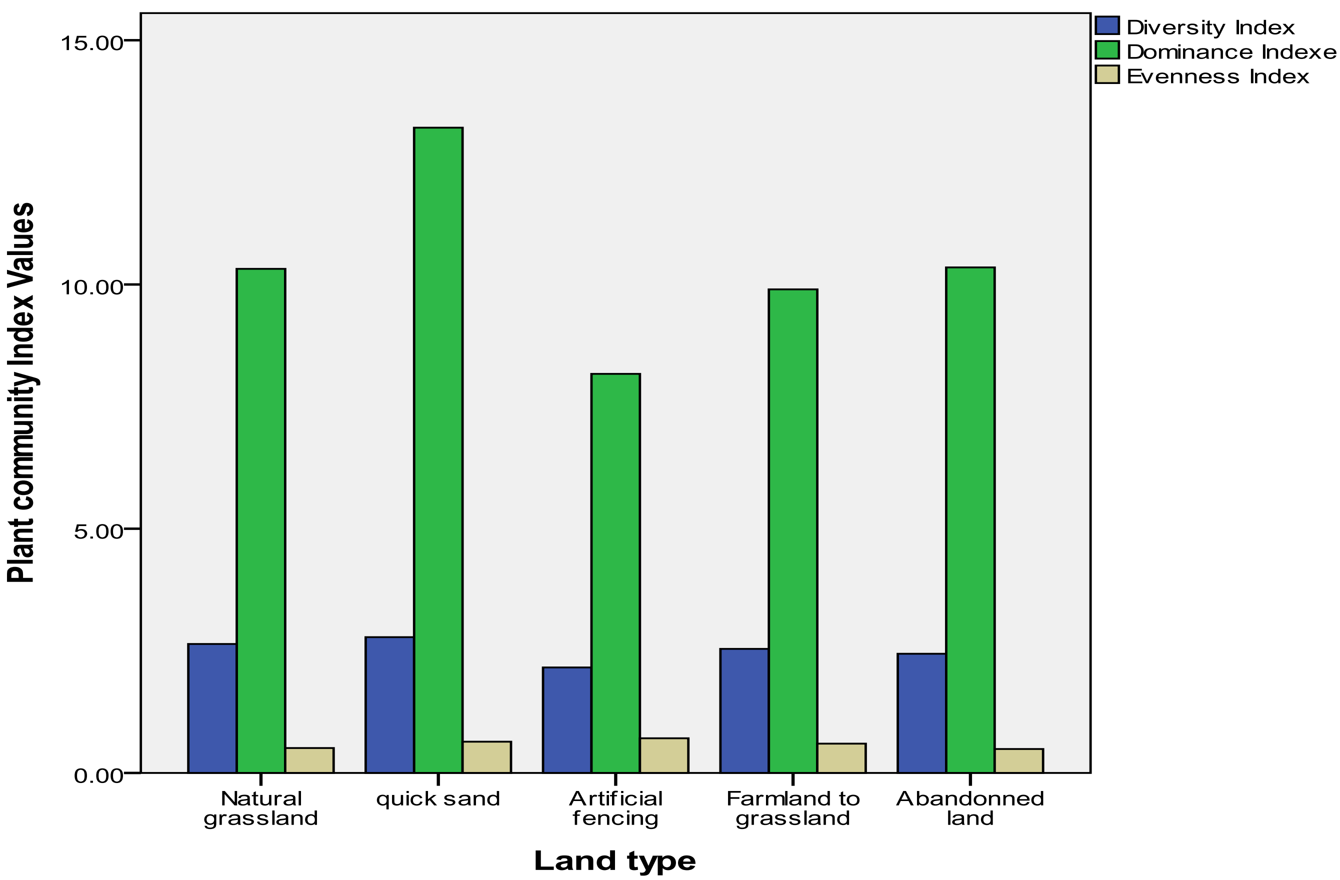

Figure 5. Plant indexes and land types.

Table 6. Land type and crust

Land type	Crust thickness
Farm land to Grass land	0.5
Wet land	0.37
Artificial fencing	0.56

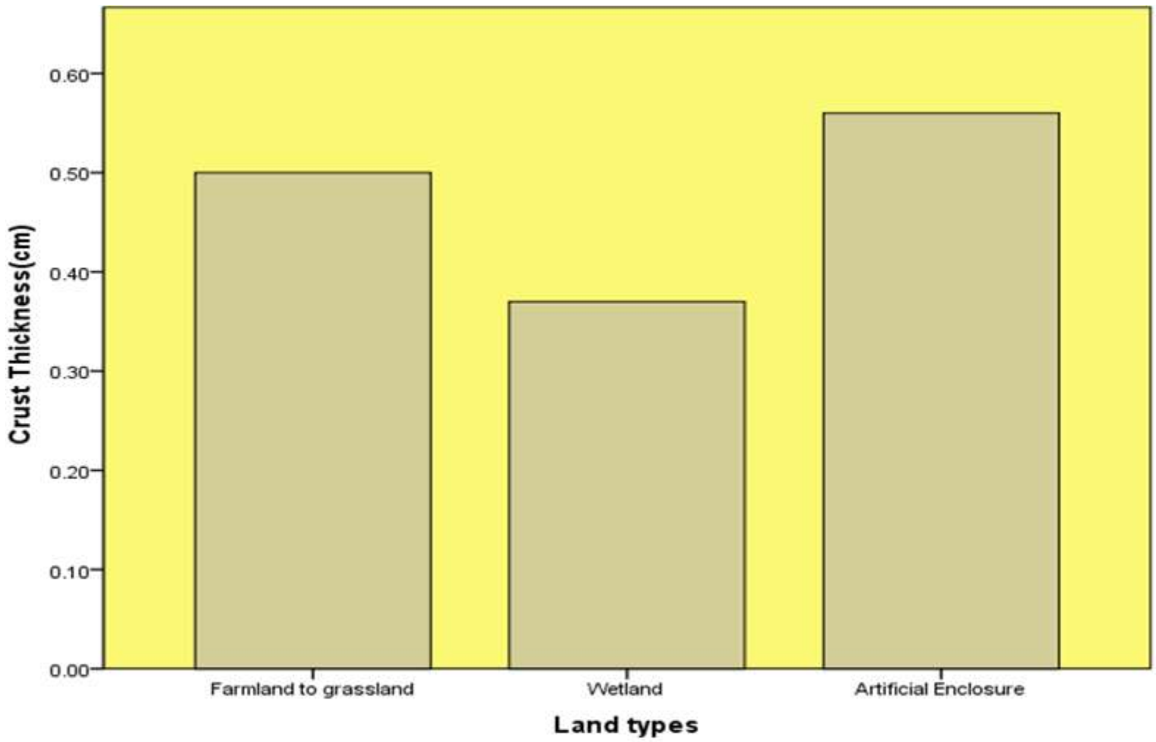

Figure 6. Biological crust and land types.

Table 7. Rain and Biological Crust correlation assessment in the fencing area (E1)

years	X= Rain(mm)	Y=Biological Crust $\times 10^{-2}$cm
2003	293.9	80
2004	262	60
2005	180	40
2006	212.1	30
2007	284.1	20
2008	266.7	50
2009	280.7	40
2010	248.4	20
2011	352.6	70
2012	308.4	80
2013	320	70

implementation and the length of fences period need to be taken into account. In fact, the biological life cycle of the species living in this area depends on these factors including temporal and spatial factors.

In addition, the fencing areas are influenced by some climatic factors such as amount of precipitation during the

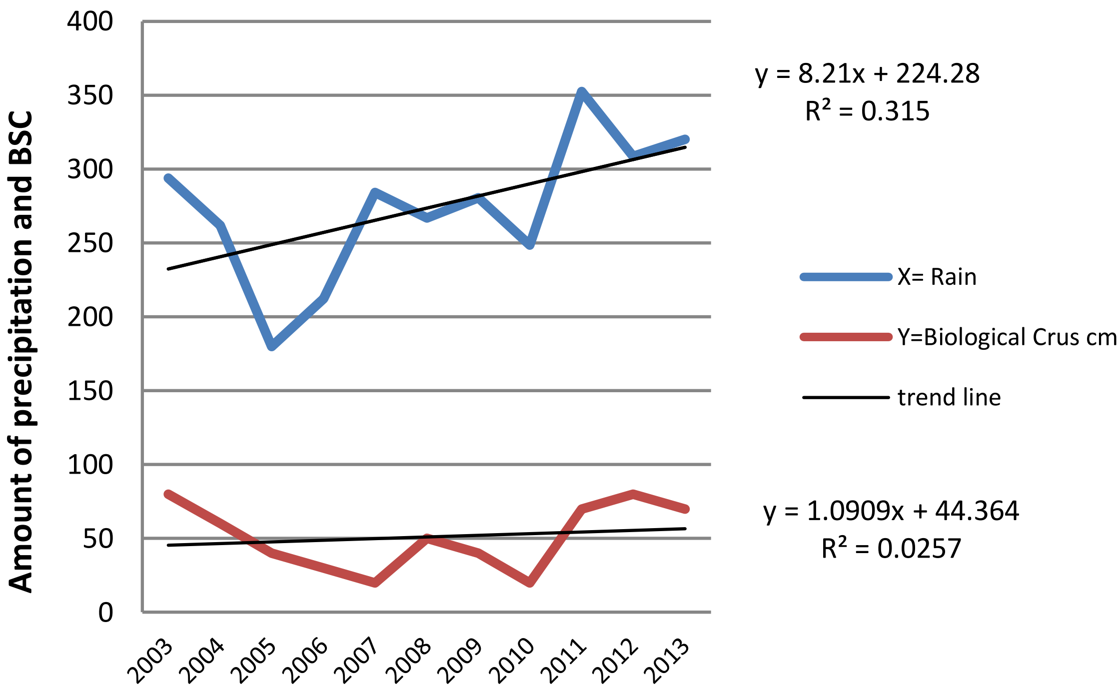

Figure 7. Precipitation and biological crust correlation graph.

year especially in the growing season. In fact, the link between soil activity and available water is shown by the biological crust measured during the field investigation. The most important biological soil crust is very thick and abundant in the artificial fencing than in the ancient farmland and in wetland. In fact, the soil crust is very important for soil sand fixation and desertification combating (Schwartzman and Volk, 1989). Referring to it as cryptogrammic, crypto biotic or micro biotic, biological soil crust are mainly dominated by cyanobacteria, lichens and or mosses and increases the soil pH, retains the moisture longer, can trap dust as well as increase the soil fertility and water holding capacity (Matthies et al., 2015). In addition, the farmland converted to grassland contains a crust more than a wet land. This observation shows also that this method impacts positively the soil even though the link between the biological crust and precipitation is not very obvious.

Moreover, the quantification of the services provided by the environments and using the Chinese Land Classification System, the land use was classified into six types: farmland, woodland, grass, saline land, desert, and other type of land use. Therefore, measures have been done and it has been seen that from 1999 to 2015 there was first a decrease and then an increase of the ecological services values. From 1999, 2010 and 2015 an increase of 6.75, 7.28 and 5.55%, respectively has been noticed. The V_{ei} was the highest for the grass zones, which represents 68.47% of the total amount, followed by agricultural land which is 13.25%, wooded area 9.03%, salt land 7.25%, other land 1.05% and desert 0.94%. This increase of the ecosystem services can probably be the result of the projects implemented to manage the grass land especially the protected areas.

Conversely, for primarily services, average annual rate control services, support services, supply services and cultural services were 52, 33 and 8%, respectively. Among secondary services, climate regulation, water conservation, waste disposal and air regulation were included in the regulatory services, with an average annual rate of 27 and 26%, respectively. In support services, the average annual soil conservation rate was 53%, which was higher than biodiversity conservation (47%). In ecological services, the average ratio of food production to raw material production was 54.79%, respectively. In the cultural services, the regulation of the landscape has changed slightly from one year to another. The average annual value of soil conservation, biodiversity conservation and climate regulation accounted for the largest proportions of all secondary services: 3.82 × 10^8 Yuan, 3.35 × 10^8 Yuan and 3.06 × 10^8 Yuan, respectively. These results indicated the positives impacts of the enclosure technique for arid and semi-arid areas restoration in the study area especially the fencing techniques. In fact, the capacity of the soil ecosystem to provide primary or secondary services such as biodiversity conservation and soil conservation has been improved by the artificial fencing which generated biological soil crust for erosion avoidance and soil fertility for food production (Schwartzman et al., 1989).

Conclusion

The economic estimation of the ecosystem services is effective in drawing the attention of the policy makers to addressing the challenge of land degradation in the World and especially in China. Therefore, analysis of this research shows that the Chinese Government has set the environmental protection and restoration as main priorities for sustainable development by actions and national plans implemented. Thus in the Northwest, several methods were implemented among which fencing method can be quoted as an effective method for vegetation restoration and ecosystem services provision in the arid and semi-arid areas especially in Yanchi County. These good incomes of the artificial fencing are also hindered by (1) the natural or climatic factors (precipitation rhythm and mount and soil crust) and (2) artificial factors especially human disturbance by animal grazing or soil cultivation. As a result, the enclosure technique should be periodically managed for a complete efficiency; and by the numerical knowledge of the services provided by a specific ecosystem and according to the contribution of each land use type to ecosystem services, the following rank order can be found (3); woodland, grass land, farmland, saline land, desert and other lands.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Technology transfer and anthropotechnology: An analysis of the sugarcane harvesting in Australia and Brazil

Lidiane Regina Narimoto* and João Alberto Camarotto

Production Engineering Department, Federal University of São Carlos, city of São Carlos, São Paulo State, Brazil.

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The present paper conducts a comparative analysis of the operation of sugarcane harvesting machines in their original place of design (Australia) and in a recipient country of this technology (Brazil). The method comprised Ergonomic Work Analysis (EWA) and the assumptions of anthropotechnology proposed by Wisner. The results achieved depict the similarities and differences between the two countries regarding: (a) the work organization and harvesting practices, (b) the harvesting strategies of the teams, and (c) the design modifications performed in the harvesting machines. The differences of how the machines were operated in both countries were identified, such as sloping grounds and amount of working hours, which lead to structural modifications in Brazilian machines. Thus, the design-in-use to adapt a technology to local conditions is crucial when there is inadequate technology transfer. The anthropotechnological approach proved to be relevant to understand all the broader factors causing difficulties in a technology transfer process.

Key words: Sugar cane harvester, harvesting machine, design-in-use, work organization, ergonomics.

INTRODUCTION

Brazil is the world's largest sugarcane producer and since 2007 the country has advanced towards fully mechanized harvesting. The harvesting machines currently used in the sugarcane fields worldwide were originally designed in Australia (Keer and Blyth, 1993) and were transferred to Brazil in the 1970s.

Technology transfer is defined by Shahnavaz (2000), as the diffusion of new technical equipment, practices and know-how from one region to another. It can provide opportunities for developing improvements in safety, operations, products and services.

The role of technology transfer is a relevant theme for ergonomics. When a technology is produced, its characteristics take into account the needs and resources of the country, its user population and its operating environment. When this technology is transferred to another country, some adaptation is needed to fit the transferred technology to the recipient country, which may have different requirements and characteristics (Shahnavaz, 2000). If these adaptation changes are not performed, the recipient country may have problems such as high rates of accident and injuries, low productivity

*Corresponding author. E-mail: lnarimoto@hotmail.com. Tel: 5519996166178.

and low work quality (Shahnavaz, 2000).

As pointed out by Wisner (1992), every machine is a culture-based machine. This means that every person or group that conceives a technical system will take into account the predicted use, under specific conditions and the people they imagine or believe to know. Thus, the essence of the difficulties encountered by technology transfer is the difference among populations (Wisner, 1992).

However, difficulties in technology transfer involve more than mismatches between users due to anthropometric dimensions, stereotyped stimulus-response, and misinterpretation of linguistic instructions; there are also more complex factors such as cultural factors (Moray, 2004).

Some authors, such as Hendrick (1997) refer this topic as macro ergonomics. Wisner (1995), on the other hand, proposes a clearly different term: anthropotechnology. According to the author, the term emphasizes that when addressing the difficult issues of technology transfer, knowledge belongs to a higher level than those of ergonomics. While ergonomics studies the operators in the workplace, anthropotechnology goes beyond these boundaries. Therefore, anthropotechnology is the adaptation of technology to the people, the ergonomics of technology transfer.

This increasingly used method allows discovering the multiple causes of difficulties encountered through a meticulous analysis of behavior and activity of the groups (Wisner, 1995). In other words, it offers the interpretation of operational defects in technical systems that were transferred and allows the creation of multi-level spaces in order to solve the difficulties identified.

Through anthropotechnology, Garrigou et al. (2012) studied French vineyards and identified the limitations of technology transfer regarding the use of pesticides. The referred approach brought to light limitations concerning the marketing authorization process, the equipment design processes, the ineffectiveness of protective clothing. The results obtained allow stating the different priorities related to technology transfer. These priorities elucidate real situations of use (in the toxicological models and in the agricultural machinery design) and the development of training processes that could empower farmers.

According to the authors, anthropotechnology has shown that cultural and anthropological dimensions have hardly been considered in the design stages, as well as the real situations of use in viticulture in France (Garrigou et al., 2012).

The literature about anthropotechnology is scarce and we understand it still needs further contributions, since it is a comprehensive approach (Nathanael and Marmaras, 2008) to address technology transfer between different countries and different contexts.

In view of the fact that sugarcane harvesting machines have undergone technology transfer processes, one of the main objectives of this study was to compare how these machines are operated in both countries.

In addition to anthropotechnology, the second paradigm adopted in the study was the development of artifacts through their use (Rabardel and Béguin, 2005). As emphasized by ergonomics, when users utilize an innovation, they put in practice their creativity and inventiveness, necessary conditions for work efficiency and the continuity of design in use.

Thereby, this study also considered the similarities and differences between the referred countries with regard to the design modifications of the machines performed by the harvesting teams. It allows us to verify whether the modifications made in the field are the result of an inappropriate technology transfer.

METHODOLOGY

The qualitative research methodological approach was used, based on Ergonomic Work Analysis (EWA) (Wisner, 1995). EWA consists of a methodological approach of intervention in order to understand the complex relationship between workers and their work, putting their real activity at the center of the analysis (Wisner, 1994).

To Wisner (1995), the use of EWA in situations of technology transfer is even more convincing than that of its general use in ergonomics. According to the author, there are many factors that influence work and the origin of the difficulties encountered can be searched through anthropotechnology. It allows constructing a tree of causes which is not only limited to the technical and organizational aspects that are closer to the workstation, but also to economic, social and anthropological factors.

In order to understand the operation of sugarcane harvesting machines in both countries, we divided the study into different phases: the first in Brazil (May/2013 to February/2014) and the second in Australia (July/2014 to November/2014).

In Brazil, the study was conducted in three situations, in the city of Piracicaba – São Paulo State: a sugar mill (situation A), a company that offers harvesting services (situation B) and a sugarcane grower (situation C). In Australia, the research was undertaken from July/2014 to November/2014 in cooperation with the Minerals Industry Safety and Health Centre (MISHC) of the Sustainable Minerals Institute (SMI) of the University of Queensland. In Australia, the sugar cane growers are responsible for the harvesting, therefore, the research was conducted in two properties, one in Tweed Heads, New South Wales (situation D) and the other in Tully, North Queensland (situation E).

A total of 19 harvesting machine operators participated in the study, as well as 4 Brazilian mechanical technicians, as this line of work does not exist in Australia.

In both countries, the following methods were used: open and systematic observations, individual and group interviews, photographs and video footage and questionnaires.

Observations were conducted inside the cabins of the harvesters and tractors and also in the field within a safe distance from the machines.

The study included open and semi-structured interviews. Individual interviews were conducted during the operation of the machines and the collective ones whenever the team was available, such as during pauses for refueling, maintenance, etc., and also during the off-season period, which was the case of the Brazilian research phase.

Video footage was conducted during machine operation, varying between 30 and 40 min for each operator participating in the study. The design modifications of the harvesting machines were

Table 1. Studied situations in Brazil and in Australia.

Situation	Brazil			Australia	
	A	**B**	**C**	**D**	**E**
Machine	13 (1 Case 7700 and 12 Case 8800)	3 John Deere 3522	2 John Deere 3520	1 John Deere 3510	1 Cameco CH2500
Average productivity (machine/day)	600 ton	900 ton	800 ton	800 ton	800 ton
Burning practices	No	No	No	Yes	Occasionally
Shift length	3 shifts of 8 h	2 shifts of 12 h	2 shifts of 12 h	1 shift of 12 h	1 shift (duration varies according to the daily quote)
Time off pattern	5×1	9×1	10×1	N.A. Mondays to Fridays	5×1 and 6×1
Pay system	Worked hours + bonus according to productivity	Worked hours	Worked hours	Worked hours	Worked hours + bonus according to productivity
Harvesting team	Team leaders, operators, tractor drivers, mechanical technicians	Team leaders, operators, tractor drivers, mechanical technicians	Team leaders, operators, tractor drivers, mechanical technicians	Operators and tractor drivers	Operators and tractor drivers
Number of tractors/harvester	2:1	2:1	2:1	2:1	3:1

registered through photographs.

The application of the questionnaires included all operators and four Brazilian mechanical technicians. These questionnaires were administered at different time intervals: (a) during the first visit, to collect the workers' general data and their experience and (b) during the study, in order to detail their personal evaluation regarding the characteristics of the machines.

After the analysis and description, the data were validated with all the teams. The study adhered to the guidelines of the ethical review process of both universities: University of Queensland and Federal University of São Carlos. All workers participating in the study were informed about the research goals and signed a consent form.

RESULTS

The results achieved were divided into three sessions for didactic purposes. First, the five studied situations were described, focusing on the work organization and harvesting practices in each country. Then, the operation of the harvesters and the harvesting strategies were presented. And last, the design modifications performed by the teams were considered.

Studied situations

Table 1 summarizes the main characteristics of the studied situations, such as the model of the harvesting machines, average daily productivity per machine and burning prior to harvesting. Table 1 also shows the differences in work organization practices: length of work shifts, time off pattern, type of pay system, the composition of the harvesting teams and number of tractors per harvesting machine.

According to the table, some issues draw attention when comparing both countries. The first issue is the difference in productivity. As observed, the average productivity of Brazilian situations ranges from 600 to 800 ton per day for one-row machines and 900 ton per day for two-row machines. Additionally, the harvesting runs 24 h a day and workers are arranged in a rotating shift system. In Australia, on the other hand, there is only one 12-h work shift and the average productivity is of 800 ton per day.

The second difference is related to the production practices and work organization of the harvesting workforce.

In Australia, sugarcane growers are responsible for the harvesting; the mills are only responsible for providing transportation. In situation D, all fields were burned before harvesting and in situation E, the burning occurs only in cases when the cane is difficult to harvest (very big or tangled):

"If it is difficult to harvest, if there are big canes or all tangled, too hard to pick up with trash on it, then we burn. Not even 5% of the crop. We burn only when we need to".

In Brazil, the harvesting teams send the sugarcane to the mill on a continuous basis. In Australia, on the other hand, there are daily production targets that have to be met. Before the season starts, the mill estimates the amount of sugarcane of each grower and based on this prediction and its processing conditions, the mill informs the harvesting team the daily production target to be delivered (number of bins). The bins are supplied throughout the day and 10 tons of sugarcane fit in each one. In situation E, for example, during three days of observation, the daily target varied from 68 to 87 bins.

The Brazilian harvesting teams composed of: team leaders, harvester operators, tractor drivers and mechanical technicians (and their assistants). In Australia, there are only harvester operators and tractor drivers, and the operator can also be the owner of the machine, as in situation E. Moreover, there are no mechanical technicians in the Australian teams, since the operators are the ones responsible for basic maintenance and more complex problems are directed to a specialized assistance service.

Generally, two tractors were assigned to one harvester: while one is loaded the other is unloading the harvested material onto the transport units. However, in situation E it was observed that three tractors were assigned to one harvester.

During the off-season period in Brazil, the operators help the mechanical technicians in the maintenance of all machines. In Australia, besides maintenance, other tasks can be assigned to the operators.

Harvesting strategies

A harvesting machine is a complex machine with several functions, which have to the adjusted by the operators according to the characteristics of the sugarcane, plot and soil.

All the operations and activities related to performing the complete harvesting of a row of sugarcane were identified (beginning, during and end of a row), as well as all the strategies applied to the harvest in various situations.

Due to scope limitations, the complete description of the operation and all its variabilities were not presented (Narimoto et al., 2015), but three important questions that differentiate the use of harvesting machines in both countries were highlighted: night harvesting cycle, sloping grounds and harvesting strategies.

As mentioned earlier, during the season period in Brazil, harvesting occurs 24 h a day uninterruptedly, which means harvesting at night. The main problem of harvesting at night regards the limited visibility: it is more difficult for the operators to identify the sugarcane rows and to align the machine on the rows. As pointed out by one operator:

"your visibility decreases, you can't see much, only what the light allows you to see, so it's a lot harder. And when there's bad cane, tangled, lying on the ground, you get lost in the plot".

Sloping grounds is the second most important factor affecting the operation of harvesting machines. The currently commercialized models have a restriction regarding the slope where they can operate, of up to 12%. In Australia, country of origin of the technology, the harvesting situations do not have sloping grounds.

On the other hand, in Brazil and especially in Piracicaba, there are worksites with slopes greater than 12%. In this case, it was observed that the harvesting teams use the machines and try to harvest as much as possible.

"There are lands that have really steep slopes. Most of them are more than 12%. 20% is easy to find too and once we even cut 30%" (operator of situation A).

"There are a lot of slopes. We harvest what we can, where there is no danger of the machine rolling over and then there is the manual cutting and then the harvesting is over. But we harvest most of the places. We rest the elevator on the transshipment and hold onto God's hand, right? (operator of situation B).

To harvest in sloping grounds, the operators develop strategies of balancing the machine with the elevator and of resting it on the transporter.

"What makes the machine stand in position in a slope like this is the elevator. If you don't spin the elevator to the opposite side, the machine rolls over. When I maneuver the machine, I automatically spin the elevator too… You can't forget that… And in very steep slopes you have to use the terminal as support".

One of the operators of situation E recognized the sloping grounds in Brazil as one of the main harvesting problems:

"We went to Brazil three years ago and the main problem we saw over there for mechanical harvesting is the geography, the hills and the contour banks, that's the biggest problem. Here it is flat, everything is flat, long, we can just go on… We were averaged for the whole season at around 85-90 tonnes per hour. Here we do 800 to 900 tonnes per day with one shift and over there; they take 24 hours to do that".

The third important aspect to be highlighted is the

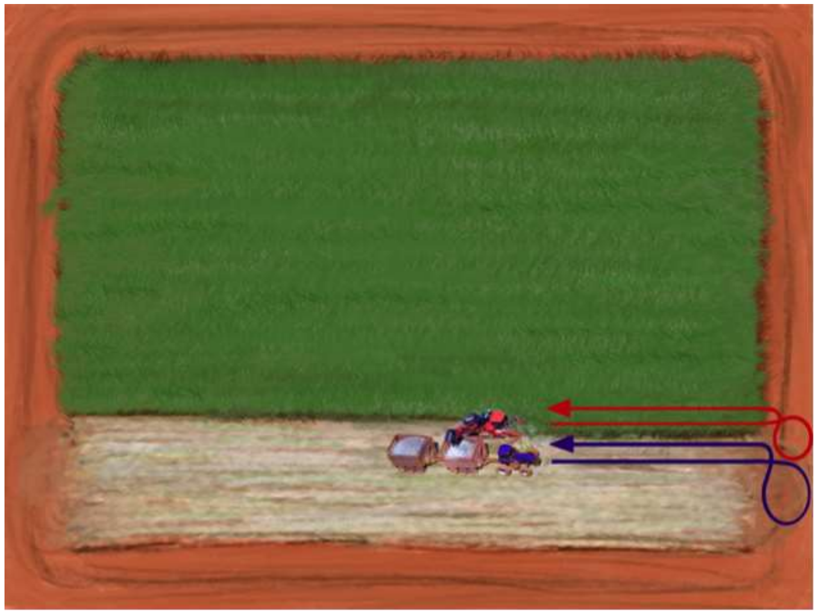

Figure 1. Harvesting strategy "row after row" (Narimoto, 2015).

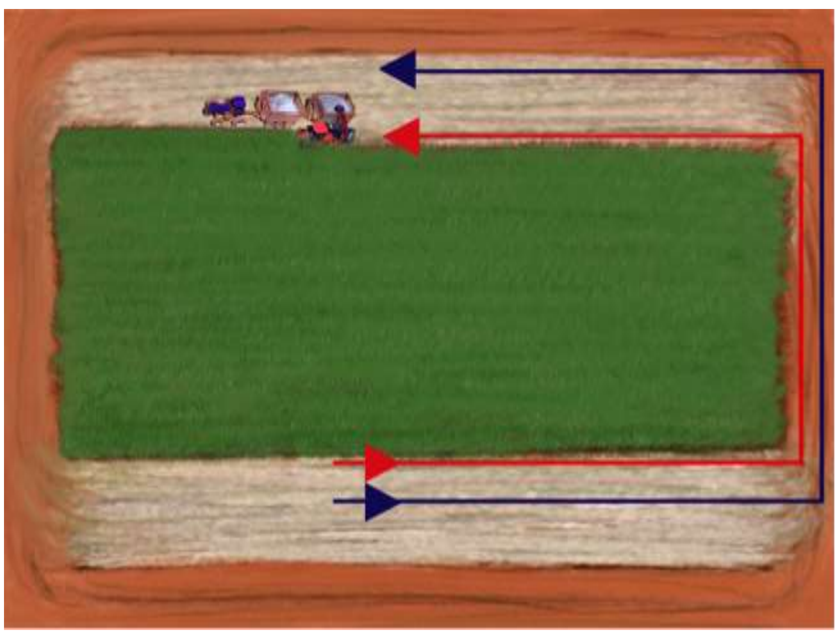

Figure 2. Harvesting strategy of "going around" (Narimoto, 2015).

difference regarding the harvesting strategies used by the teams of the studied situations.

In Brazil, the most commonly used harvesting strategy is "row after row", where at the end of each sugarcane row, both harvester and tractor maneuver and begin harvesting the following row, as shown in Figure 1.

In Australia, it was observed that the harvesting could be performed using two main strategies: going around the plot or with the tractor alternating forwards and backwards.

The strategy of going around, observed in situation D, consists of going around the plot (Figure 2) at the end of a row, instead of maneuvering the machines to harvest the following row. Depending on the size of the plot, the operators divide it into blocks so the machines do not have to drive long distances between one row and

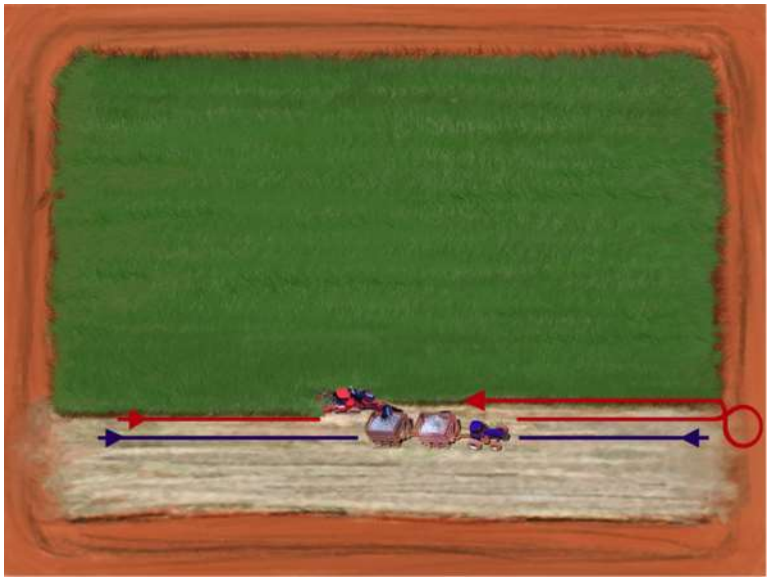

Figure 3. Harvesting strategy with tractor alternating forwards and backwards (Narimoto, 2015).

Figure 4. Tractors without the front wheels in Queensland (Narimoto, 2015).

another.

"We think it is better going round and round, although the other groups don't do it as much as we do. The main reason is because we think it is quicker. Also when you go round and round you don't need to turn around, you save the tracks… It is a lot easier for the machine. If it's a big paddy, you don't have to go from end to end. You go to the middle, go round and round and then to the middle to the end, and round and round again".

The strategy of alternating the tractor forwards and backwards, observed in situation E, consists of harvesting one row after another but without maneuvering the tractors. Then, as illustrated in Figure 3, only the harvesting machines maneuver at the end of a row and the tractor alternates one row forwards and the other backwards.

"We always cut backwards and forwards because it takes less time, the tractor doesn't have to turn around" (Operator).

"You spend a lot of time turning around every row. This way it is a lot quicker" (Tractor driver).

In order to facilitate reversing the harvester, the front wheels of the tractors are removed (Figure 4).

Figure 5. Extra welding- hard facing.

"It is easier to reverse with no front wheels. When you have a tractor and a trailer with the front wheels on, it is very hard to reverse the harvester. So when you take the wheels off, it is a lot easier to go backwards".

As mentioned, in situation E there are three tractors assigned to one harvester, a needed proportion, especially when the harvesting area is far from the drop-off point so the harvester does not have to stop and wait for a free tractor. It was observed that the number of tractors also allows the team not stopping the harvester to change the tractor: at the end of the row, the next tractor takes place even if the current one does not have its bin completely full.

"I could probably get more but then I would be full in the middle of the row and then we would have to stop the harvester for the next bin to come in, so takes a bit more time. This makes it easier, I get out and the other tractor comes in without having to stop" (Tractor driver).

Design modifications

One of the modification categories observed in the machine design was the structural modifications, which include structural improvements in the machines, with reinforcements or even substitutions of some parts.
Some of these modifications are performed as soon as the machine is purchased and others after the warranty period. As explained by a Brazilian mechanical technician:

"When the machine comes in its original state, it doesn't go straight into the field, we have to prepare it first. We can't change a new machine because of the warranty, right? But there are a few things that the factory allows us to do".

The structural modifications performed in the machines after being purchased by the mill/grower are welding the parts to increase their thickness, process called hard facing. Figure 5 shows the extra welding in specific parts of the machine.

These modifications were observed in all studied situations, both in Brazil and in Australia and are repeated before the beginning of every season. The parts that undergo hard facing are: crop dividers, base cutter, feeding rollers and chopper rollers.
One of the operators explained:

"We put hard facing because if we don't, it wears out, makes holes and you have to replace the part. With hard facing, it lasts a whole season. Then, during off-season, we repeat the hard facing all over again".

Besides preventing wear, these reinforcements are also done to improve the harvesting quality, such as a specific part of the base cutter (Figure 7), which can either be covered with welding or completely remade by the teams, using a thicker material. One of the mechanical technicians of situation B explained:

"This part is used to pull the sugarcane. The original one is thinner so we put hard facing to prevent wear or we cut new ones from a thicker iron plate. The harvester swallows more cane… It's like eating spaghetti with a spoon, right? You try to spin it around and you can't… If this part is flat, the harvester can't grab hold of the cane".

In Brazil, it was observed that besides the reinforcements using welding, parts and components are replaced by more resistant ones. These structural modifications are performed according to the needs, type and model of machine and conditions of use. The main structural reinforcements in Brazilian machines comprise parts such as: primary extractor, chassis and elevator (Figure 6).

Primary extractor

In the three different machine models studied in Brazil (Case 8800 and John Deere 3520 and 3522), it was observed that the maintenance teams made reinforcements and/or replacements of the primary ring of the extractor, as seen in Figure 8.

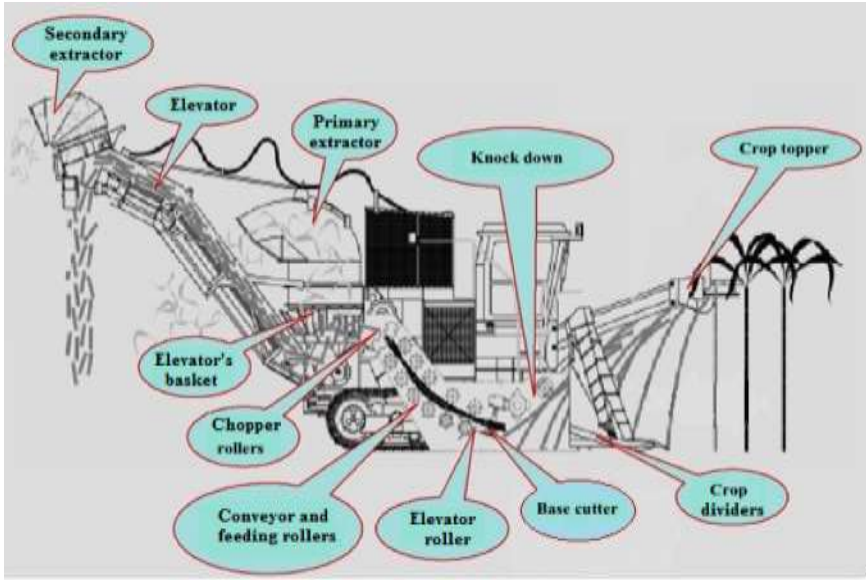

Figure 6. Main functions of the harvester machine (Narimoto, 2015).

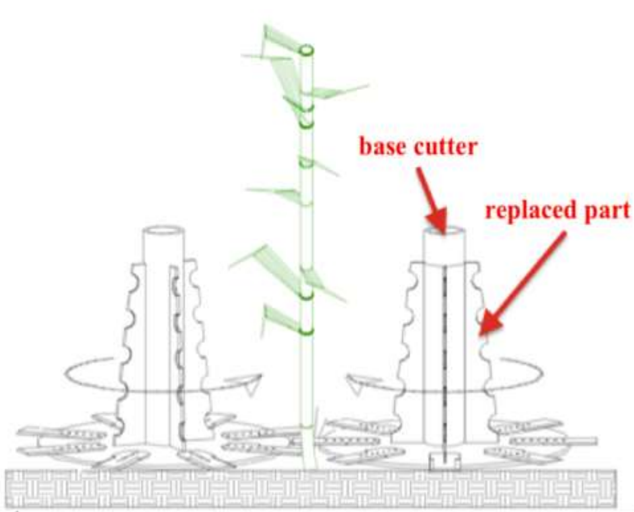

Figure 7. Base cutter (Braunbeck and Magalhães, 2002).

"Every single machine has problems with this ring because it's too thin, it wears out and it breaks. You have to either place another ring on the original one or make a new one thicker".

Chassis

The reinforcements on the chassis are made according to the cracks and breaks the teams detect in specific spots. As identified in the machines and described by the teams, there are several reinforcements placed in the structure of the machines:

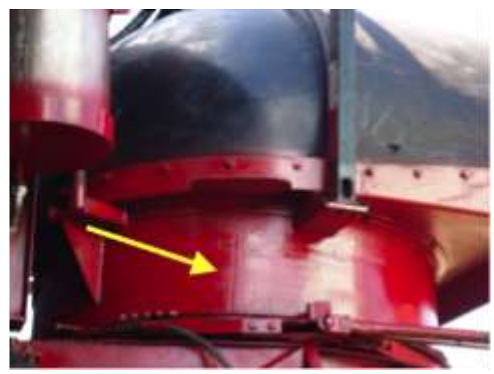

Figure 8. Primary extractor's ring.

"We have a lot of problems with structure. If you operate on a sloping ground, with erosion, and all those things, it cracks the entire chassis".

Figure 9 shows some specific locations for cracks on the chassis of a John Deere 3520 and a Case 8800, as explained by the technicians in charge:

"These parts over here (Figure 9A) *where the junctions are, break and you have to reinforce everything later. All these parts are reinforcements made after cracking because the machine didn't withstand the work situation… We work in very complicated uneven grounds with slopes with hard soil, so you have to continue making reinforcements".*

"Case's chassis cracks even more because they use a 3/16 sheet and John Deere, 5/16. Then, there's no way, it

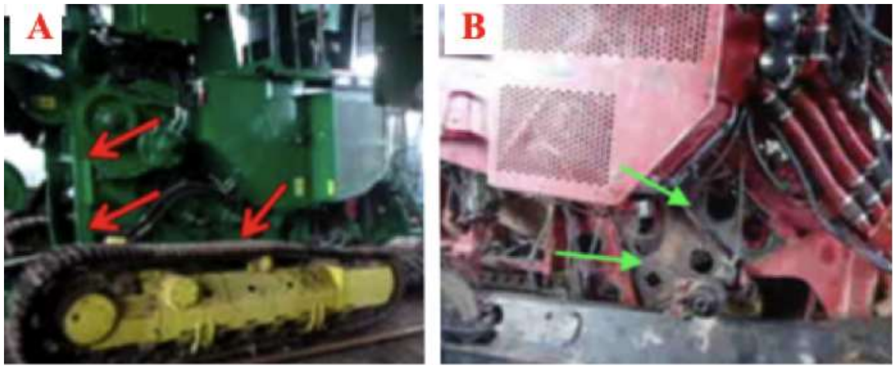

Figure 9. Fragile chassis' spots of John Deere 3520 (A) and Case 8800 (B).

breaks and then it looks like that (Figure 9B) *all mended. Everything that is not red is a mend. We measure, cut and weld the same size, shape and sometimes we have to replace the entire side".*

Figure 10 shows the structure of a machine at location C with a new reinforcement in addition to the original reinforcement:

"There are reinforcements here at the back and at the front of the machine as well. Here is an original reinforcement and we add a new one down here, otherwise it cracks".

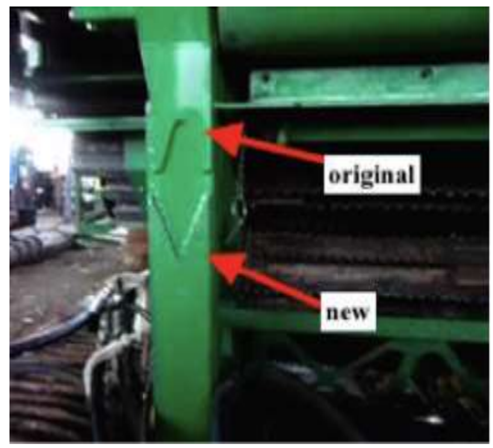

Figure 10. Original and additional reinforcements of a John Deere 3520.

Elevator

Several structural reinforcements are also applied to the elevator. Figure 11 shows some of the structural reinforcements applied to elevators by the Brazilian teams. One of the technicians explained the modifications to a John Deere 3520 (Figure 11A):

"I think the elevator is too weak. Its structure cracks because it's too thin, just 1/8. We removed all the original sheets and put on 3/16. You can see that it's thicker and it withstands more. The original lasts one year. Some parts have to be replaced in the middle of the season because they start cracking and breaking. It breaks, and the elevator doesn't move any-more, billets fall on the ground, a lot of cane is thrown on the ground."

The modification applied to the elevator of the Case 8800 (Figure 11B) was explained by the technician at location A:

"We put that X made of a 1/4 to prevent the elevator from opening because if you don't do that, the elevator opens. That's the reinforcement we perform because the factory puts only the lower X down there."

When questioned about overall structural reinforcements, considering the entire machine, the teams unanimously affirm the need to do this so the machines can operate for an entire season:

"Structure is really a problem. The engineers come here sometimes and say that the reinforcements will increase the machine's weight, but there is no way out, you have to reinforce!" (technician at location A).

"The weight of the elevator, for example, really increases with all the reinforcements, but there's nothing we can do! If we don't make the changes, we don't work. You know, you have to harvest to be productive, and having to stop for welding the elevator means that the machine is not harvesting cane" (technician at location C).

"Each of these harvesters was increased by 1600 kg considering the overall reinforcements. Our boss gave us the freedom to do anything, and we did what we thought would be better. Some people said 'you are going to have trouble,' but it didn't interfere at all, even when there is more cane passing through, because it's a two-row

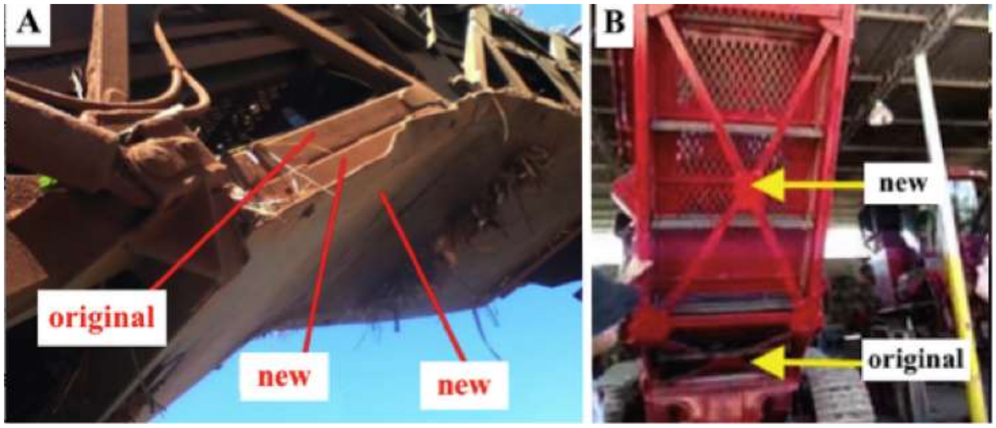

Figure 11. Original and additional reinforcements of a John Deere 3520.

machine. The elevator, for instance, the engineer designs it, but I don't think he can actually calculate the amount of cane and weight passing through it. The factories have their numbers, and they think they have to follow them, but it's not like that. We are in the field every day, and we have the notion of what is really needed." (technician at location B).

An important factor to be highlighted is how the modification process is conducted at the Brazilian locations. The operators and mechanical technicians discuss the problem and then they design, build, and test the solution together.

DISCUSSION

According to the results, there are three main differences between the two studied countries: design modifications, work organization and harvesting strategies.

Design modifications

The structural modifications clearly show the differences between Brazil and Australia regarding the operating conditions of the harvesters. The modifications made to prepare the harvesters after purchase (which are repeated during the off-season) are essentially the same in both countries, i.e., using extra welding to prevent wear of the crop dividers, base cutter, feeding rollers, and chopper rollers. These modifications are meant to improve reliability and improve the harvest quality, such as the modifications to the base cutter.

However, except for these modifications, no other structural modifications were made to the Australian machines. In Brazil, several modifications were observed, ranging from structural reinforcements to replacement of parts. As observed, various modifications were performed on the primary extractor, chassis, and elevator.

The structural reinforcements of the machines, especially the chassis, are related to the terrain in which the Brazilian machines operate, i.e., uneven and sloping ground. According to a report by the Brazilian Agricultural Economy Institute (IEA, 2015), the 2013-2014 sugarcane season had a mechanization index of 84.8% in the state of São Paulo, with some regions surpassing this statewide average. However, the region of Piracicaba was below the average (72.7%). According to the report, this was due to the sloping ground in the region.

As observed earlier, harvesting in slopes is very rare in Australia, home country of the harvesting machine, but very common in Brazil, especially in Piracicaba. As stated by the operators,

"*there are a lot of sloping plots", "the machine doesn't withstand the job… We work in really bad grounds".*

This is corroborated by one of the Australian operators who had the opportunity to check the Brazilian harvesting:

"we went to Brazil three years ago and the main thing we saw over there for mechanical harvesting is the geography, the hills and the contour banks, that's the biggest problem. Here it is flat, everything is flat".

Even the John Deere machines, considered more robust by the teams, are not sufficiently reliable to harvest the referred region. As observed, the structural reinforcements are necessary as they assure harvesting with no maintenance stops, as reported:

"there is no way out, you have to reinforce!", *"if we don't make the changes, we don't work"*, *"having to stop for welding means that the machine is not harvesting".*

Therefore, it can be stated that the structural modifications are the result of an inadequate technology transfer to the Brazilian conditions of use and operation.

According to Wisner (1995), an acquired technology cannot be used unless it is under-stood in depth, taking into account the specific realities of the country of use. In another study, Wisner (2004) stated that the success of technology transfer requires an under-standing of the geographic, demographic, sociological, anthropological, technical, and economic conditions of each country involved in the transfer.

In addition to the sloping ground, another possible reason for many of the Brazilian structural modifications is the long working hours of the machines. In Australia, there was only one 12-hour work shift, and the season lasted up to five months (July to November). At one of the Australian locations, harvesting was performed from Monday to Friday. At the other location, the work shift could end early if the production target was achieved. In Brazil, the same machines work 24 hours a day for seasons that last eight or nine months (April to December). This means that there are greater demands on the Brazilian machines. In addition, harvesting 24 hours a day implies harvesting at night, which requires additional modifications for lighting, as discussed by Narimoto and Camarotto (2017).

Wisner (1992) highlights that technology transfer is a difficult process and requires considerable transformation of the machine. Considering the sugarcane harvesting machines, the differences between the two countries regarding the ground and working hours require modifying the artifacts. This transformation is achieved through design in use, which depends on the operators and mechanical technicians, as discussed earlier.

The interviews with the mechanical technicians showed that equipment designers are aware of the modifications made in the field: "*Engineers come here sometimes*." In fact, some modifications are allowed by manufacturers, even within the warranty period. This topic raises other questions, including: Why are these particular modifications not made by the manufacturers? What processes are used by manufacturers to incorporate modifications? Future research can provide answers.

Work organization

The difference between Brazil and Australia regarding working hours raises another important question: Why is productivity so different between the two countries? At the Australian locations, the machines harvested about 800 tons in 12 hours. At Brazilian locations A and C, the machines had a productivity of 600 tons in 24 hours. At location B, with two-row machines, the productivity was about 900 tons. How is it possible to harvest more in half of the time? In addition to difference in the ground conditions, the answer appears to be found in the work organization.

Work organization is the second main difference between the two countries. In Australia, the responsibility for sugarcane harvesting falls on the growers rather than on the mills. Therefore, growers either buy harvesting machines (individual or collectively) or hire a harvesting service. As observed at location E, the owners of the machines are commonly the machine operators. Furthermore, Australian harvesting teams have daily production targets to achieve, regardless of the pay system, i.e., per hour (as at location D) or per ton of harvested material (as at location E).

The idle time of the harvesters is a constant concern at the Australian locations. As observed, when longer distances have to be traveled by the tractors to reach the drop-off point, an additional tractor is allocated, as at location E. Working with three tractors eliminates possible delays in harvesting due to lack of an available tractor to receive the load. Even the time required to change tractors is taken into account; the change occurs at the end of a row even if the bin is not completely full.

Additionally, burning the crop before harvesting is a practice that can be always used (as at location D) or at least used sporadically (as at location E) when the sugarcane has characteristics that make it difficult to harvest. In Brazil, mechanized harvesting only occurs in green crops.

Therefore, in addition to the more suitable ground and the fact that the technology was created and developed for Australian locations, all the aforementioned conditions also contribute to Australia's higher productivity when compared to Brazil.

Harvesting strategies

The third main difference observed between the two countries is in the harvesting strategies adopted by the work teams. These harvesting strategies can be another explanation for the difference in productivity. Instead of harvesting row after row and maneuvering both machines at the end of the row, as in Brazil, the Australian teams used two strategies that were thought to be faster and more efficient. Both of these strategies are related to the operators' experience and to the characteristics of Australian sugarcane plots:

(1) Going around the plot, as in situation D, saves maneuvers of both machines;
(2) Alternating the tractor forwards and backwards, as in situation E, saves maneuvers of this machine.

Professional experience allows the advancement of new modes of organization and operation (Weill-Fassina and Pastré, 2007). Australia is a leader in mechanized harvesting. Since 1979, all Australian crops have been fully mechanized (Kerr and Blyth, 1993). Because of this, the harvesting machines studied here were older models. Australia has many years of experience with mechanized harvesting. As a result, the workers have developed and improved harvesting strategies that may be more efficient.

Obviously, the ground on which the machines operate must allow implementation of these harvesting strategies. In other words, suitable ground conditions (i.e., flat, long, and without erosion) offer more possibilities to practice different strategies.

In both countries, the sugarcane harvesting operation is the same, and both countries have harvesting variabilities related to crop age, position, and soil composition. However, in Australia, there are no slopes nor harvesting at night. In addition to the differences in productivity, there were differences regarding the safety and health of the work teams. According to Cherubin (2017), the most common accidents reported in Brazilian sugar-cane harvesting are due to collisions that occur mainly at night and rollovers caused by soil conditions.

Harvesting at night is more difficult (“Your visibility decreases, you can’t see much”), and harvesting on sloping ground requires strategies for balancing the machine and even resting the elevator on the transporter (“We rest the elevator on the transporter and hold onto God’s hand, right?”). These findings are aligned with Béguin et al. (2012), who pointed out that not considering the cognitive conditions and social dynamics of the recipient countries during technology transfer can lead to work situations that are not only costly to individuals but are also dangerous.

Agriculture is one of the most hazardous of all industrial sectors, and many agricultural workers suffer occupational accidents each year (ILO, 2011). Nonetheless, official data on the incidence of occupational accidents are imprecise and notoriously underestimated due to insufficient national labors law and/or poor application of existing laws. The prevalence of seasonal, migratory, and casual labor in agriculture (along with limited knowledge of workers’ rights) increases the challenge (ILO, 2011).

Considering the data related to accidents and injuries in sugarcane harvesting, the pat-tern is no different: available data are scarce and imprecise for both Brazil and Australia. A report on work-related accidents in Brazil by Fundacentro (2013) showed differences in the data according to the source, which indicated nationwide underreporting of work-related injuries and low rates of formal employment across the country. With regard to sugarcane harvesting machines, Rodrigues (2014) [Not listed in the References] reported that 64 accidents (fatal and non-fatal accidents were not distinguished) were recorded by the Brazilian Government from 2001 to 2013. This number reflects only the state of São Paulo, and the author noted that the reporting system was under adaptation from 2001 to 2007, so the real number is likely higher.

In Australia, according to the Australian Centre for Agricultural Health and Safety (AgHealth, 2017), from2011 to 2016, only twelve injuries (three of which were fatal) involving harvesting machines in general were reported for the whole country. However, it cannot be determined how many of these injuries were related to sugarcane harvesting.

The lack of precise data makes conclusions more difficult, but it also reinforces the need for future research to improve occupational safety and health in agriculture. Considering sugarcane harvesting, is the high number of reported accidents in Brazil related to the inadequate technology transfer observed in the field? How many accidents might occur in crops that are not reported? How does ergonomics contribute?

Through consideration and comparison of all the factors that comprise the use of technology in the country of origin and its transfer to another country, anthropotechnology, according to Wisner (1997), is capable of achieving favorable results in the recipient country, considering its conditions. As in ergonomics, by using EWA, anthropotechnology prevents a simplistic interpretation of the defects of imported technical systems and enables creating spaces at various levels to solve the observed difficulties (Wisner, 1995).

As shown in this study, the application of EWA in both countries was useful for understanding the conditions of use of sugarcane harvesting machines in each country, as well as the difficulties and the differences between them. It was also possible to identify machine modifications that were made to adapt the technology to Brazilian conditions.

Manufacturers of agricultural machines comply with ISO 4254-1:2013, which specifies the safety requirements for the design and construction of agricultural machinery. Part 7 of the standard (ISO 4254-7:2017), reviewed in 2017, specifically applies to sugar-cane harvesters. By considering the modifications made by the Brazilian work teams, it is possible to improve the ISO standard as well as adapt the national standards for sugar-cane harvesters to meet safety requirements more realistically.

Conclusions

This study showed that there are three main differences between Australia and Brazil regarding sugarcane harvesting practices: work organization, harvesting strategies, and design modifications performed by the work teams.

Based on the structural modifications applied to the Brazilian machines, it can be concluded that design-in-use is crucial for adapting a technology to local conditions. There is no such thing as a “universal” machine, and multinational equipment manufacturers need to consider this when they offer products to different countries, such as the countries considered in this study. Design-in-use practices have an essential role in minimizing the problems that originate from inadequate technology transfer, and they lead to a more reliable and efficient operation.

This study also showed the importance of EWA for understanding questions involving technology transfer between different locations and how the anthropotechnological approach, which still lacks studies in the literature, is relevant for this purpose. Anthropotechnology allows tracing the causes of difficulties both inside and outside the location where the imported devices are used, considering broader aspects than those addressed by ergonomics.

LIMITATIONS

Due to the limits of this study, it was not possible to explore the relationships between inadequate technology transfer and accidents, worker injuries, or work-related fatalities. A complete analysis of the relevant accident reports is necessary to answer the following questions: How many accidents and injuries are related to collisions or rollovers? Do design modifications have a positive impact on the accident statistics? Further research can consider these questions.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Full Length Research Paper

Rainfall variability and its implications for agricultural production in Gedarif State, Eastern Sudan

Lotfie A. Yousif[1], Abdelrahman A. Khatir[2], Faisal M. El-Hag[3], Ahmed M. Abdelkarim[4], Hussain S. Adam[5], Abdelhadi A. Wahab[6], Yasunori Kurosaki[7] and Imad-eldin A. Ali-Babiker[3,7*]

[1]Gedarif Research Station, Agricultural Research Corporation (ARC), Gedarif, Sudan.
[2]El Obied Research Station, Agricultural Research Corporation (ARC), El Obied, Sudan.
[3]Dry Lands Research Center (DLRC), Agricultural Research Corporation (ARC), Soba, Khartoum, Sudan.
[4]Sudan Meteorological Authority (SMA), Khartoum, Sudan.
[5]Water Management and Irrigation Institute, University of Gezira, Wad-Medani, Sudan.
[6]College of Graduate Studies, Desert and Arid Zones Sciences Program, Arabian Gulf University, Manama, Bahrain.
[7]Arid Land Research Center (ALRC), Tottori University, Tottori, Japan.

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Rainfed agriculture is practiced in the central clay plains of Sudan and is affected by the high rainfall variability in time and space within and between seasons. This study focused on analyzing rainfall variability and trend using a 30-year record (1985-2014) of seven meteorological stations at the major agricultural production areas in Gedarif state in eastern Sudan. Yearly rainfall has relatively low variability compared to monthly variability. According to annual rainfall totals, it was possible to classify stations into two groups; one with annual rainfall more than 600 mm and the second with rainfall ranging between 500 to 600 mm. In both groups, the majority of rainfall (60%) occurred during July and August. Trends of rainfall were inconsistent and the cropping season extended from June to September. Farmers in areas having high rainfall and extended growing season (group I) could grow suitable crops and varieties and their appropriate management practices should be implemented. In areas of low rainfall and short growing seasons (group II), farmers could grow crops of short maturing varieties and water harvesting techniques. There is a need for research activities that examine rainfall trends and how agricultural practices might adapt accordingly.

Key words: Rainfall, variability, trend, sorghum yield, Gedarif, Sudan.

INTRODUCTION

The rainfall as the most important hydrological variable significantly affects agriculture in dry land areas. Agricultural production is one of the main pillars of the Sudanese economy as it provides food for most of the country's citizens and raw materials for local industries besides its contribution to the export market. The contribution of agricultural sector to gross domestic product (GDP) is about 30.6% (Central Bank of Sudan, 2013). In Sudan, agriculture is divided into irrigated and rainfed sectors. The latter represents about 92% of the total cultivated area in the Sudan (18.7 million ha) (Federal Ministry of Agriculture and Irrigation, 2015). Rainfed agriculture is practiced in the central clay plains of Sudan in three climatic zones; dry, semi-dry and semi-humid zones (Adam, 2008). It is mainly practiced in Gedarif, Blue Nile, White Nile and Southern Kordofan states. Although these areas differ in the amount and distribution of rainfall, the crops grown and their associated management practices are more or less similar. Sorghum (*Sorghum bicolor* L.), the main staple food crop in Sudan, is mainly produced under rainfed conditions. Farah et al. (1996) studied the effect of climate and cultural practices on rainfed agricultural production in Sudan. Their results showed sorghum yields declined over the years. They also presented a strong association between rainfall distribution over time and crop yields.

Rainfed agriculture in Gedarif state is one of the most important Sudan areas; comprising of both traditional and mechanized farming practices. Mechanized rainfed farming in Gedarif state started in the mid-1940s. Since that time, it has witnessed a substantial expansion in area and by early sixties constituted around 30% of total sorghum area in Sudan (Ahmed, 1994). However, average Sorghum yields have declined from 0.7 t/ha during the period 1970-1979 to 0.36 t/ha in recent ten years (Ministry of Agriculture, 2011). The expansion in sorghum cultivated area is considered as compensation for the declining yields over years (Farah et al., 1996).

Several studies worldwide have shown that productivity of rainfed agriculture is a function of climate and cultural practices, with more emphasis on climatic variables. Mertz et al. (2009) suggested that high vulnerability of rain fed sector coupled with limited adaptation options have direct effects on production. Frequency and dry spells length are the major factors affecting yield (Rockström et al., 2002). On other hand, changes within season lead to changes in growing and maturation periods of crops (Dong et al., 2009). Rawhani et al. (2011) studied the climate variability and crop production in Tanzania. They found that climate variability reduced yields by 4.2, 7.2 and 7.6% for maize, sorghum and rice, respectively.

Generally, climatic factors, especially rainfall plays an essential role in the success of agricultural production in rainfed areas for the following reasons:

1) Rain is the main source of water for crops; hence it determines types of grown crops and their yields.
2) Rain determines the start and the end of the season (growing season length); consequently, it affects selection of varieties and scheduling of field operations.
3) Rain determines the available working days for machinery; through its effect on soil moisture content, thus, it affects the type and size of machinery to be used.
4) Variability of rainfall from season to season and during the season affects the whole farm planning and management.

Therefore, it is imperative to maximize the efficiency of rainwater use. Although it is difficult to predict rainfall in advance, because it varies in place and time of occurrence, analysis of rainfall records can help to understand rainfall patterns and trends; hence better rainwater management. Rainfall data analysis, such as; rain variability and trends will help to furnish information for policy and decision makers as well as farmers to develop and implement their plans. Moreover, it helps researchers to orient their research activities toward more suitable adaptation technologies to achieve sustainable agricultural productivity under the changing climate.

The main objective of this research was to analyze rainfall records from seven stations in Gedarif state over the 30-year period from 1985 to 2014. The specific objectives are to assess the monthly and annual rainfall variability, and to study trends of rainfall over this 30-year period.

MATERIALS AND METHODS

Description of study area

Gedarif State lies in the Eastern part of Sudan between latitudes 12.67º and 15.75º N and longitudes 33.57º and 37.0º E, covering 71,000 km^2 (Figure 1). The State stretches from North to South through three climatic zones; dry, semi- dry and semi-humid zones (Adam, 2008). The soil is heavy cracking clay (Vertisols), characterized by shrinking when dry and swelling when moistened. The daily mean temperature reaches 33.4°C in May and drops to 26.3°C in January. The relative humidity varies from 22% in March to 71% in August (Sudan Meteorological Authority, 2010). Rainfall is always in the summer and most rainfall events occur within the period June to October; resulting in a short-single growing season. About three million hectares are cultivated annually in Gedarif State. About 85% of this area is cropped by sorghum, the staple food crop. Seven stations were selected which are located and scattered in the major rainfed agricultural production areas of Gedarif State as shown in Figure 1. These stations are Gadambalia, Gedarif, Alhoory, Douka, Alhawaata, Umseenat and Samsam. The elevation of these stations is 505, 600, 540, 443,637, 467 and 480 m above sea level, respectively. All the stations are located in very flat extended areas with no significant topographic or forests lactated between them.

Data collection

To achieve the objectives of this study, rainfall data were obtained from Mechanized Farming Corporation (MFC) records. Monthly (April to October) rainfall data were obtained from the seven stations over a 30-year period (1985 to 2014). Moreover, data on sorghum cropped and harvested area (ha), total production (ton) and grain yield (kg/ha) were obtained from the records of Ministry of

*Corresponding author. E-mail: imadaa@gmail.com.

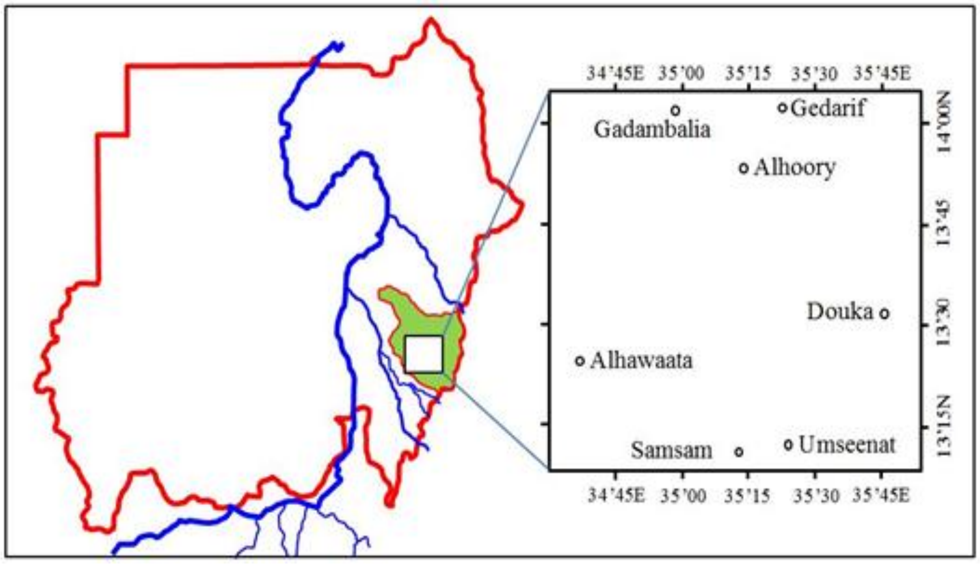


Figure 1. Sudan map showing Gedarif State (Green) and the studied area with the 7 Stations.

Agriculture and Irrigation in Gedarif State for the period from 1985 to 2013.

Data analyses

In order to summarize data set and check its quality, a box and whisker plot was constructed from median, lower and upper quartiles, lower and upper extremes, and the mean is marked in it for each month for all stations. The changes in rainfall distribution were analyzed using statistic indicators such as average, percentage and coefficient of variation were used to analyze the monthly and total rainfall data for each station. In addition, anomalies for the total annual rainfall calculated as its departure from the long-term average values for the period 1985 to 2014 at each station. The monthly rainfall anomalies were also calculated for each month (June, July, August and September) separately and its departure from each month long-term average values for the same period (1985-2014).

Changes in rainfall distribution

Deviations of the total annual rainfall from average values at each station was obtained and plotted with their corresponding years to show changes in annual rainfall distribution. Point maps were created for these stations in *ArcGIS* software (ESRI, 2008) using their coordinates and annual rainfall data. Rainfall data in stations were interpolated to cover the entire study area; the results were continuous maps. The maps are based on the inverse distance weighted (IDW) interpolation which determines cell values using a linearly weighted combination of a set of sample points (stations). This method assumes that the variable being mapped decreases in influence with distance from its sampled location. To better visualize these rainfall data, the continuous maps were categorized into 50 mm isohyets.

Rainfall trends

To determine rainfall trends, the annual rainfall totals of each station for the 30 years were divided into three groups: (1985 - 1994), (1995 - 2004) and (2005 - 2014). The average of each ten years was calculated. The same procedure was used for monthly rainfall data. To analyze trends in rainfall data, regression coefficients were produced in image format. Simple linear regression modelling was applied to extract the regression parameters. Following Fuller (1998), time (in years) was defined as the independent variable and the rainfall data values as the dependent variable. The resulting individual linear regressions consisting of correlation coefficients and regression slope values indicate the strength and magnitude of the calculated trends (Eckert et al., 2015). The regression slopes of all pixel locations were thus categorized into negative trend", "positive trend" and "no trend" categories and then mapped accordingly.

RESULTS AND DISCUSSION

The box and whisker plots (Figure 2) indicated that there are generally viewer outliers. However, most of the months showed slightly positively skewed. In all stations, July and August showed large dispersion (IQR), while June and September was much less in dispersion. Some stations showed small dispersion in May. All stations showed no dispersions in April and October.

The analysis of rainfall data showed that the majority of rainfall (60%) occurred during July and August throughout all stations. The high amounts of rains during July and August adversely affect the necessary cultural practices such as plowing, sowing and weeding operations. This is because of the inherent limitations of Vertisols which are largely related to soil moisture. Generally, these soils have a narrow range of soil moisture within which mechanical operations can be conducted. A recent study indicated that a soil moisture content between 28.3 and 33.1% results in poor tillage (Yousif et al., 2012). The same study showed that more than 39.4% soil moisture

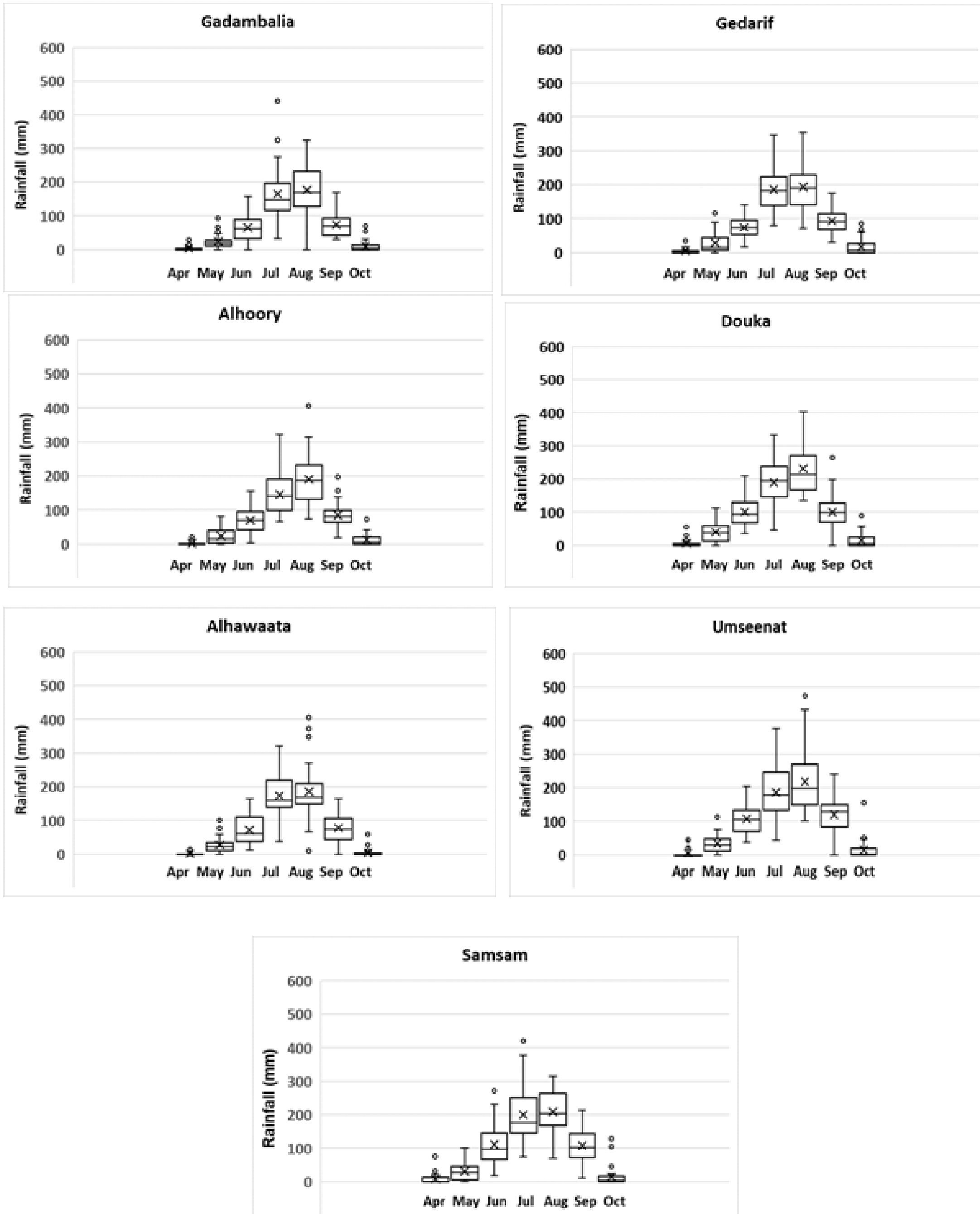


Figure 2. Monthly rainfall box and whisker plot for seven stations in Gedarif State for period from 1985 to 2014.

makes the soil unworkable. Due to the very low hydraulic conductivity of the soil, when high rainfall happens continuously during July and August, flooding occurs which may lead to severe crop damage.

Both June and September received half of the amount of rainfall that fell in July and August. Less rainfall (10%) occurred in April, May and October. Monthly rainfall distribution analysis can help in selecting and scheduling farm operations; for example to avoid water logging during seedling stage and water shortage during flowering stage of certain crops.

There are differences in the average total rainfall over the 30 years amongst the stations (Figure 3). Umseenat, Samsam and Douka stations hadthe highest and same average rainfall (683-684 mm); however, Alhawaata, Alhoory and Gadambalia stations had the lowest one

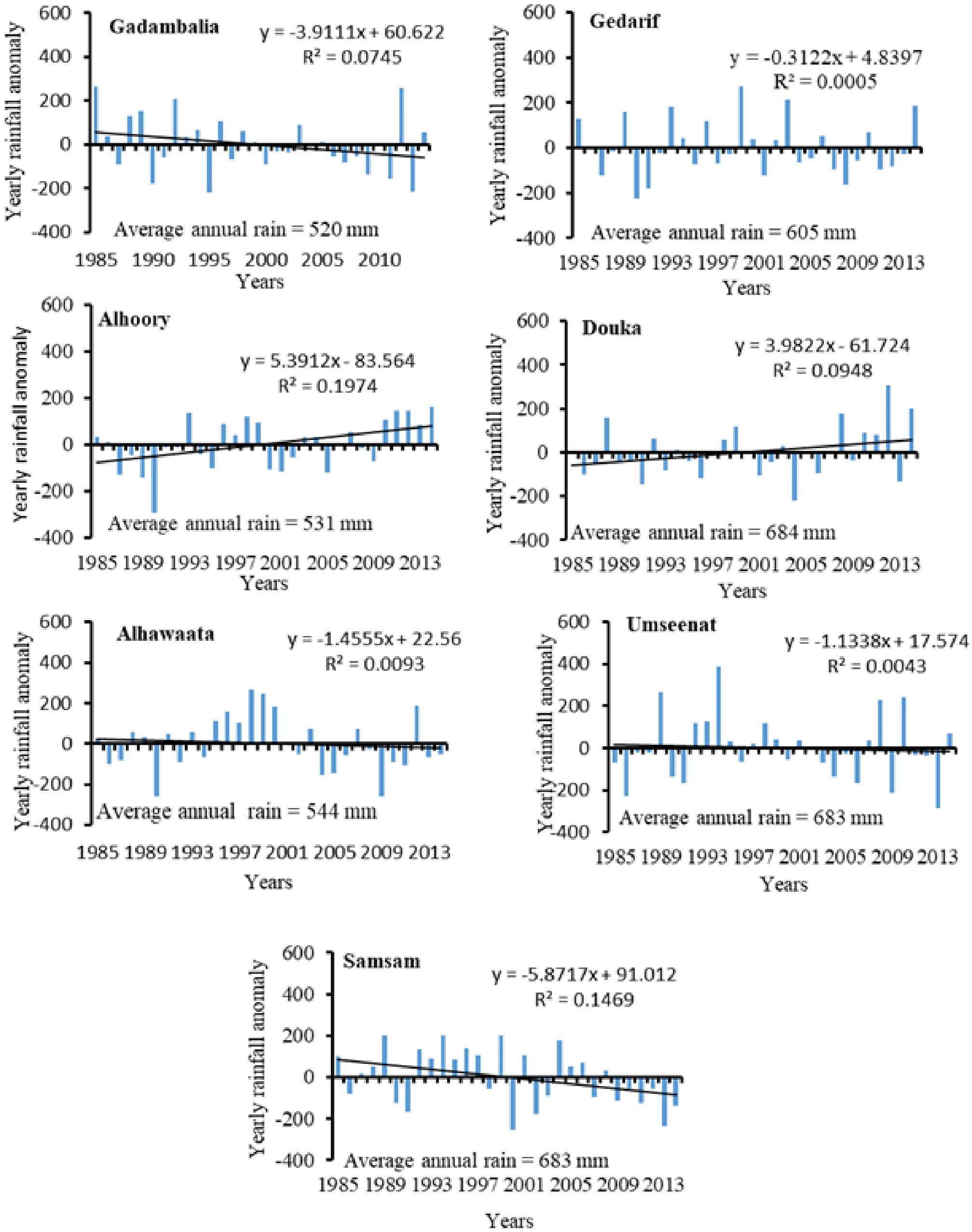


Figure 3. Yearly total rainfall anomalies at seven stations in Gedarif State for period from 1985 to 2014.

(520-544 mm), while Gedarif station had about 600 mm. There is a relationship between longitude and rainfall (that is more rain in the south than north). Figure 3 also shows the variability in annual rainfall in Gedarif State. The deviation of annual rainfall from the overall average rainfall at each station.

The coefficient of variation (C.V.) for yearly total rain fall at all stations was not high and was ranging between 17 and 24%. In contrast, C.V. for monthly rainfall varied; in July and August, it ranged between 29 and 49% and in April and October it is very high ranging between 137 and 260%. C.V. use allows for the comparison of the variability of rainfall between locations which have different average annual rainfall.

Generally, the monthly C.V. increases when the rainfall decreases. However, it is worth noting that similar monthly C.V. was found for stations recording different rainfall totals. For example, the C.V. at Umseenat and Gedarif in June was the same (41%) but the same stations had different rainfall; 107 mm and 74 mm respectively. These results are in concur with the findings of Tilahun (2006) who found that rainfall was a highly variable factor in comparison with other meteorological parameters in arid and semi-arid regions of Ethiopia.

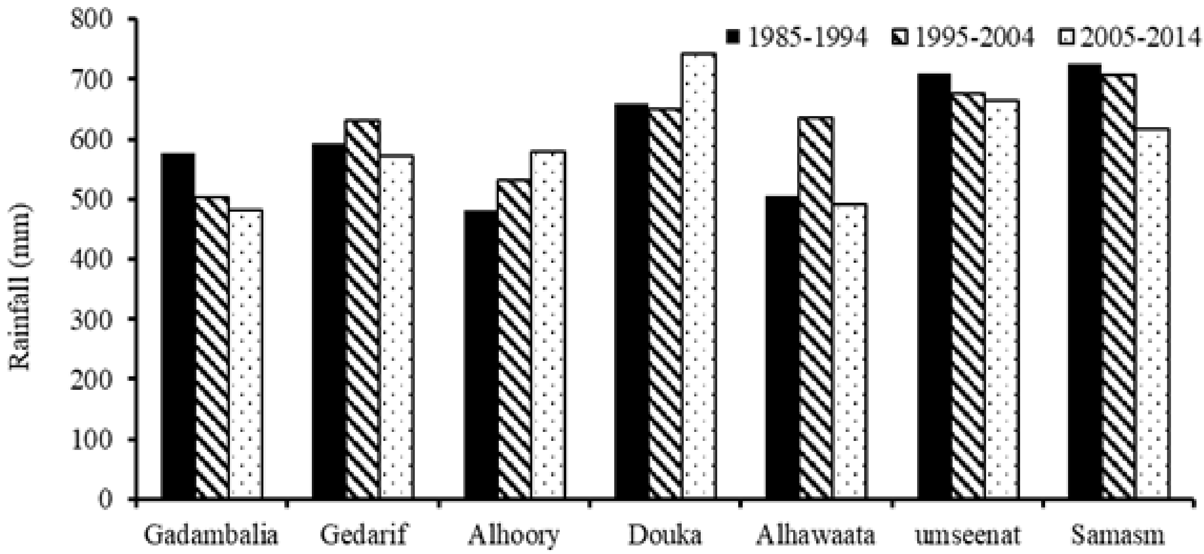


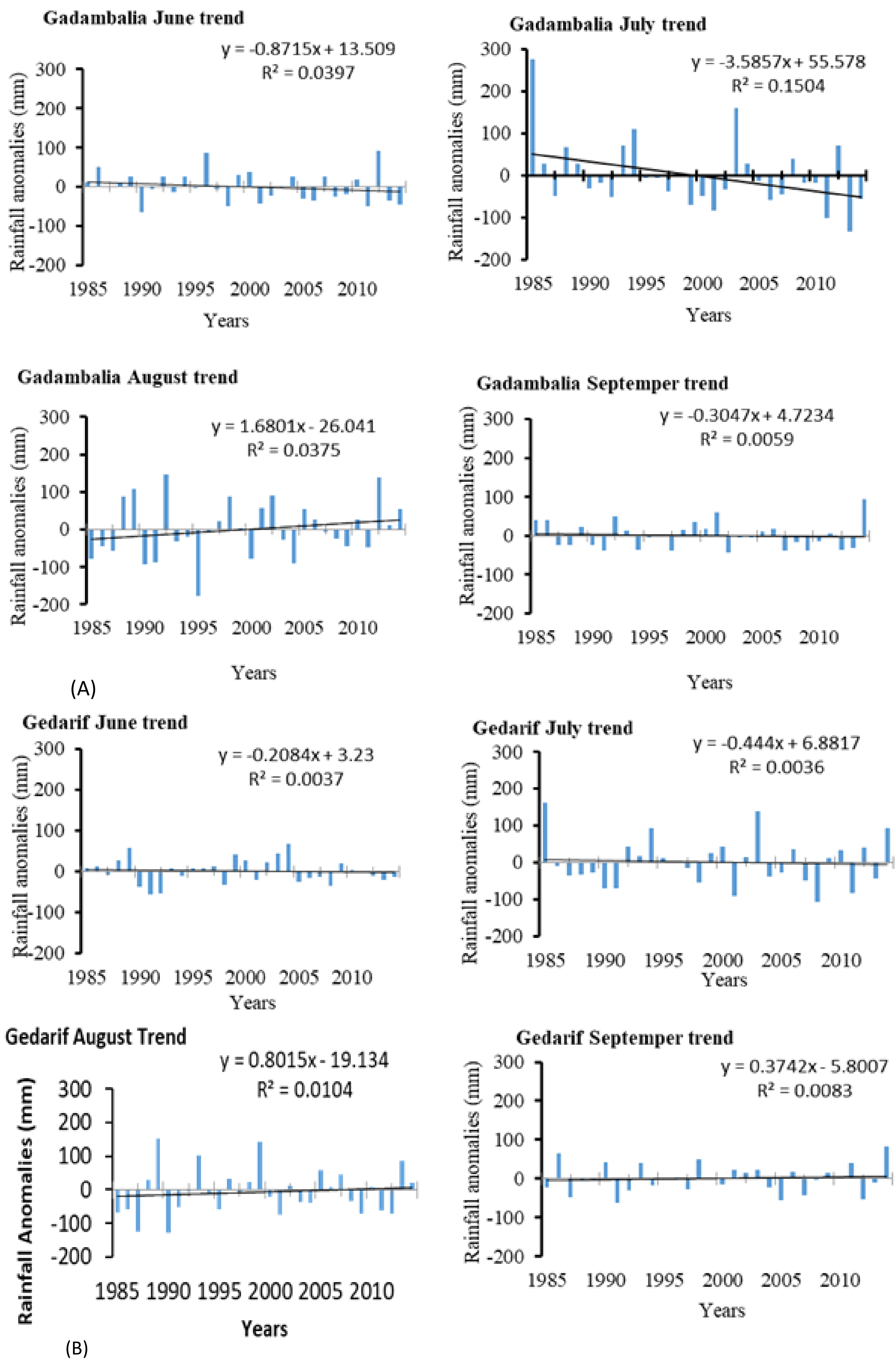
Figure 4. Total annual rainfall (mm) each ten years (1985 to 2014) at seven stations in Gedarif State.

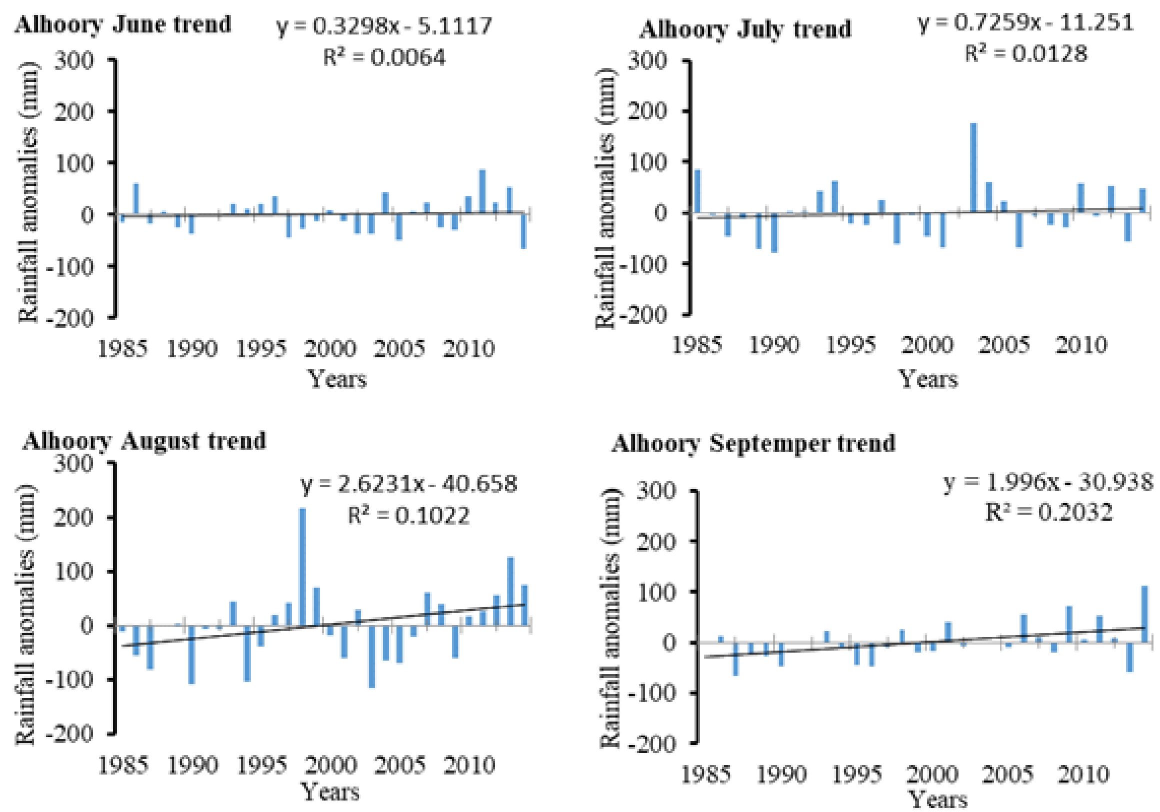
Similarly, Adam (2008) mentions that the ecology of any region is not only dependent on how much rainfall falls but also on how it is distributed in time and space within and between seasons. This agrees with the fact that drier conditions mean even greater rainfall variability (Batisani and Yarnal, 2010). Total rainfall trends at Umseenat, Samsam and Gadambalia stations reflected a decrease in average rainfall in 10-year periods from 1985 to 2014 (Figure 4), whereas at Alhoory and Douka there was an increase trend. At Alhawaata and Gedarif stations, no steady trend between the three periods was similarly observed.

The monthly rainfall anomalies (June, July, August and September) at the seven stations during the period 1985-2014 are shown in Figure 5a to g. Four stations (Gadambalia, Gedarif, Alhoory, and Douka) showed no changes in the rainfall trend in June. On the other hand, three stations (Alhawaata, Umseenat and Samsam) those located more to south expiated slight rainfall decrease trend in June. For July, all the stations, except Alhoory and Douka, showed varied decreasing trend in rainfall. In contrast, for August, all the stations, except Samsam, showed perceptible increases in the rainfall whereas for September all the stations exhibited slight to noticeable increases in the rainfall. Although the rainfall variability during the same month among different years was very high, but there is the general trend that rainfall decreases at the beginning of the season (June-July) and increase towards the end of the season (September). Increasing trends in monthly rainfall were observed in July in Alhoory, August in Gedarif, and September in Douka as well as Alhoory (Figure 6). However, a decreasing trend of rainfall was seen in June in Gadambalia and July in Umseenat, Samsam and Gadambalia stations, August in Samsam, and October in Gedarif and Gadambalia. On the other side, some months showed unstable trends in rainfall such as June in Umseenat, Douka and Alhoory as well as July in Douka. Farah et al. (1996) suggest that good distribution of rainfall during the growing season is a stronger determinant of crop yield than the total annual rainfall.

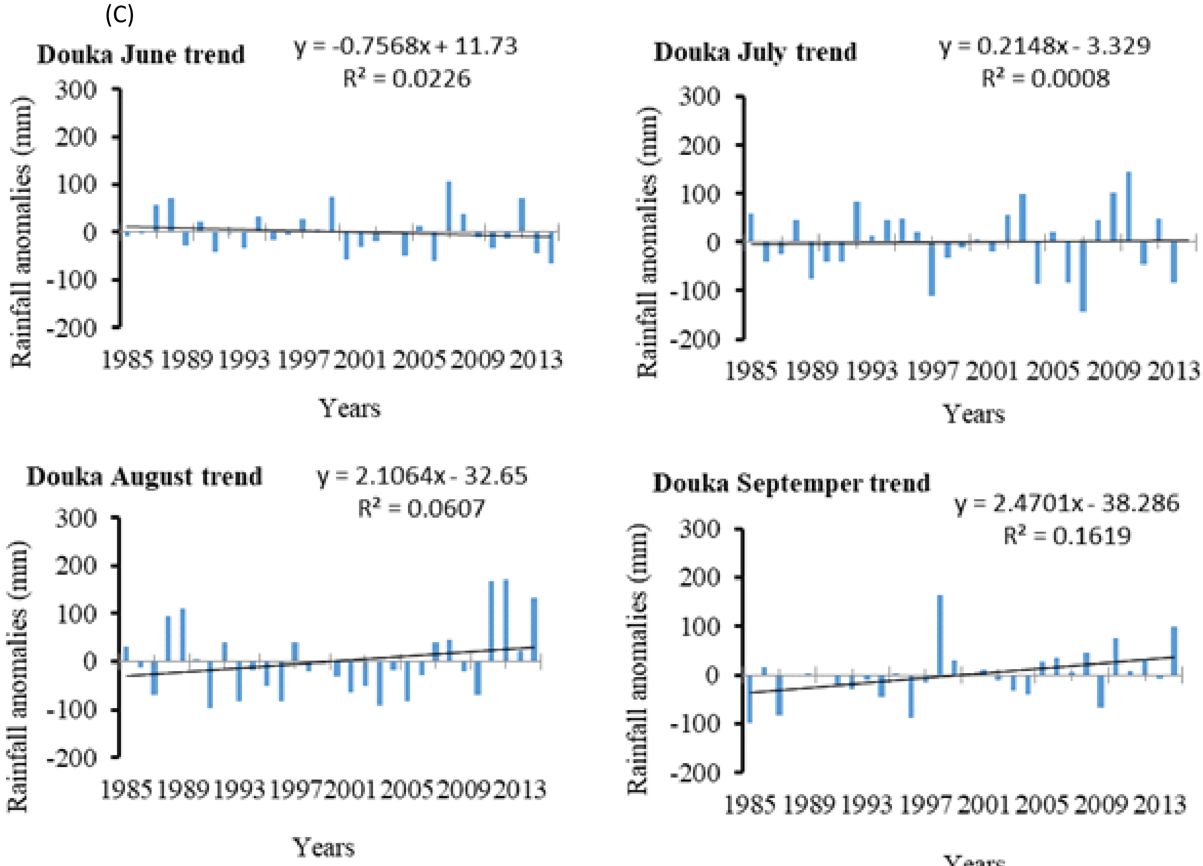
These results have implications on timing of land preparation and planting crops. Huho (2011) reported similar trends in the March-April-May rainfall season in Kenya, as the beginning of the season showed gradual decline in rainfall amounts while towards the end of the season showed increased monthly rainfall totals. Under such situations, farmers commence sowing later when rainfall was certain. This cautiousness by farmers favor the shifts in planting dates from late June and early July to late July and early August due to the changing rainfall patterns in order to avoid the cost repeated sowing in occasions when July rainfall delayed. These results imply that short to medium maturing varieties of field crops, which have lower crop water requirements, and their associated management practices are required for the near future.

The result of mapping trends in rainfall distribution across the study area over the whole study period is shown in Figure 7. The areas of Alhoory and Douka showed a positive trend in rainfall distribution, whereas Gadambalia, Samsam and to some extent Umseenat showed a negative trend. On the other hand, in Gedarif and Alhawaata rainfall distribution was unstable and reflects no trend. A previous study showed a declining trend in mean annual rainfall throughout Sudan during the period 1952 to 1992 except for Gedarif where it remained unchanged (Mohamed, 1998). A recent study in Butana region, part of which lies in northern Gedarif State, showed that rainfall isohyets have moved

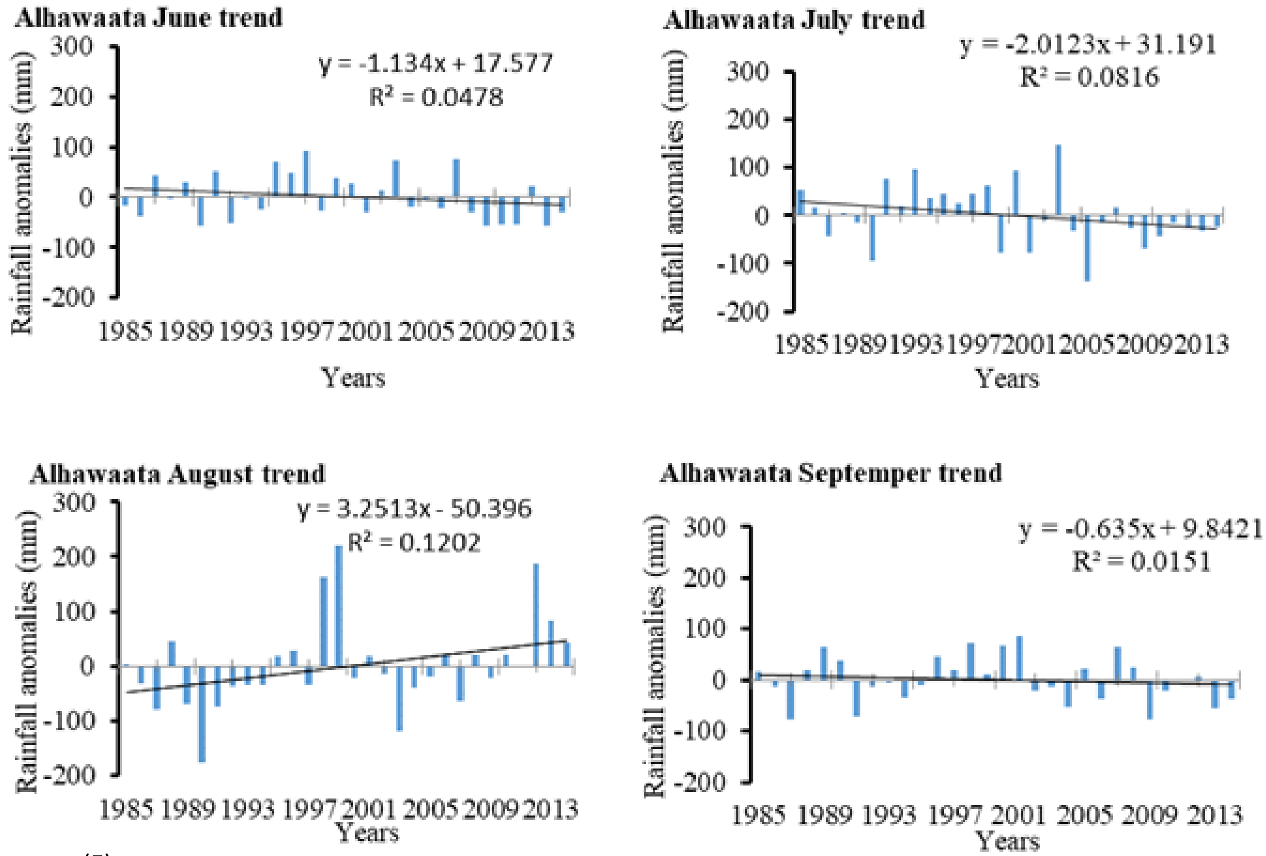

Gadambalia June trend
y = -0.8715x + 13.509
R² = 0.0397
Rainfall anomalies (mm)
300
200
100
0
-100
-200
1985 1990 1995 2000 2005 2010
Years
Gadambalia July trend
y = -3.5857x + 55.578
R² = 0.1504
Rainfall anomalies (mm)
300
200
100
0
-100
-200
1985 1990 1995 2000 2005 2010
Years
Gadambalia August trend
y = 1.6801x - 26.041
R² = 0.0375
Rainfall anomalies (mm)
300
200
100
0
-100
-200
1985 1990 1995 2000 2005 2010
Years
Gadambalia Septemper trend
y = -0.3047x + 4.7234
R² = 0.0059
Rainfall anomalies (mm)
300
200
100
0
-100
-200
1985 1990 1995 2000 2005 2010
Years
(A)
Gedarif June trend
y = -0.2084x + 3.23
R² = 0.0037
Rainfall anomalies (mm)
300
200
100
0
-100
-200
1985 1990 1995 2000 2005 2010
Years
Gedarif July trend
y = -0.444x + 6.8817
R² = 0.0036
Rainfall anomalies (mm)
300
200
100
0
-100
-200
1985 1990 1995 2000 2005 2010
Years
Gedarif August Trend
y = 0.8015x - 19.134
R² = 0.0104
Rainfall Anomalies (mm)
300
200
100
0
-100
-200
1985 1990 1995 2000 2005 2010
Years
Gedarif Septemper trend
y = 0.3742x - 5.8007
R² = 0.0083
Rainfall anomalies (mm)
300
200
100
0
-100
-200
1985 1990 1995 2000 2005 2010
Years
(B)


Alhoory June trend
y = 0.3298x - 5.1117
R² = 0.0064
Alhoory July trend
y = 0.7259x - 11.251
R² = 0.0128
Alhoory August trend
y = 2.6231x - 40.658
R² = 0.1022
Alhoory Septemper trend
y = 1.996x - 30.938
R² = 0.2032
Rainfall anomalies (mm)
300
200
100
0
-100
-200
1985 1990 1995 2000 2005 2010
Years

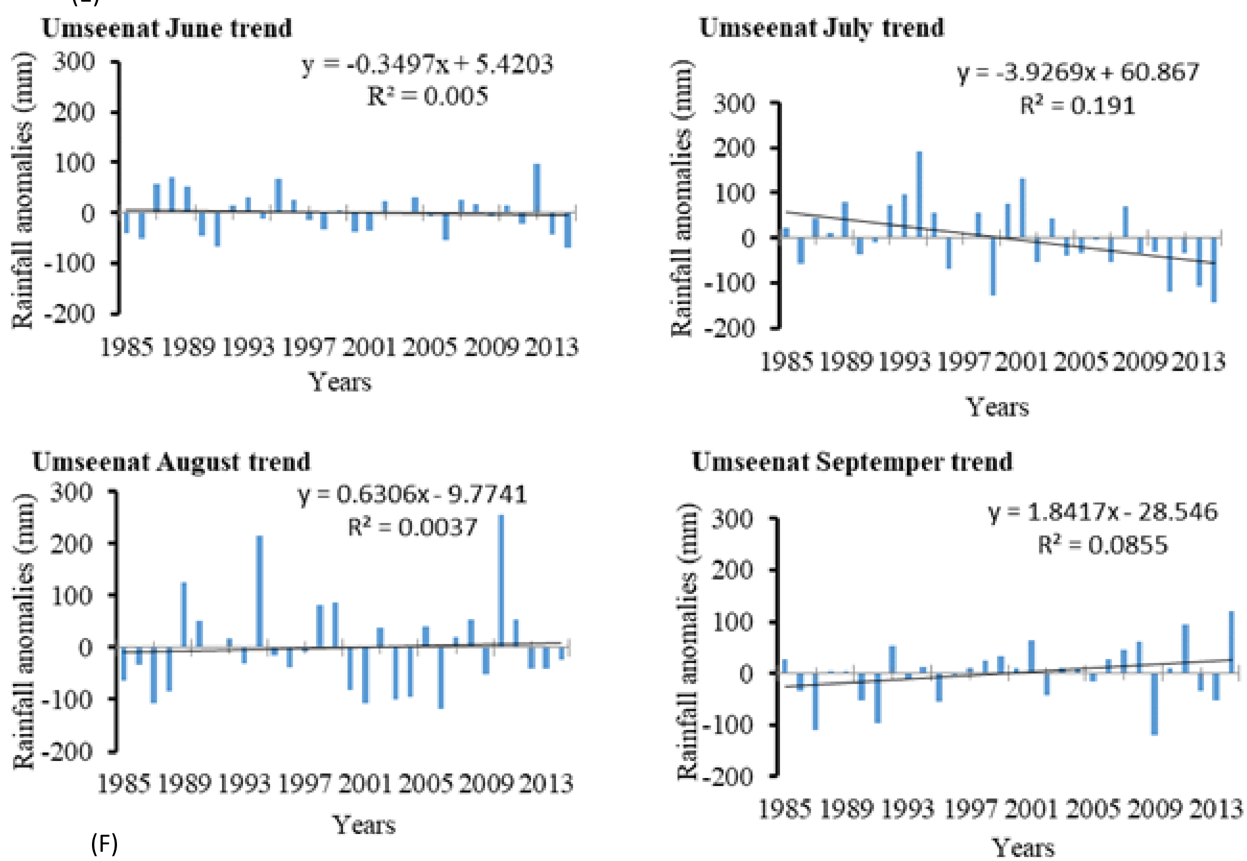
(C)


Douka June trend
y = -0.7568x + 11.73
R² = 0.0226
Douka July trend
y = 0.2148x - 3.329
R² = 0.0008
Douka August trend
y = 2.1064x - 32.65
R² = 0.0607
Douka Septemper trend
y = 2.4701x - 38.286
R² = 0.1619
Rainfall anomalies (mm)
300
200
100
0
-100
-200
1985 1989 1993 1997 2001 2005 2009 2013
Years

(D)


Alhawaata June trend
y = -1.134x + 17.577
R² = 0.0478
Rainfall anomalies (mm)
Years
Alhawaata July trend
y = -2.0123x + 31.191
R² = 0.0816
Rainfall anomalies (mm)
Years
Alhawaata August trend
y = 3.2513x - 50.396
R² = 0.1202
Rainfall anomalies (mm)
Years
Alhawaata Septemper trend
y = -0.635x + 9.8421
R² = 0.0151
Rainfall anomalies (mm)
Years

(E)


Umseenat June trend
y = -0.3497x + 5.4203
R² = 0.005
Rainfall anomalies (mm)
Years
Umseenat July trend
y = -3.9269x + 60.867
R² = 0.191
Rainfall anomalies (mm)
Years
Umseenat August trend
y = 0.6306x - 9.7741
R² = 0.0037
Rainfall anomalies (mm)
Years
Umseenat Septemper trend
y = 1.8417x - 28.546
R² = 0.0855
Rainfall anomalies (mm)
Years

(F)

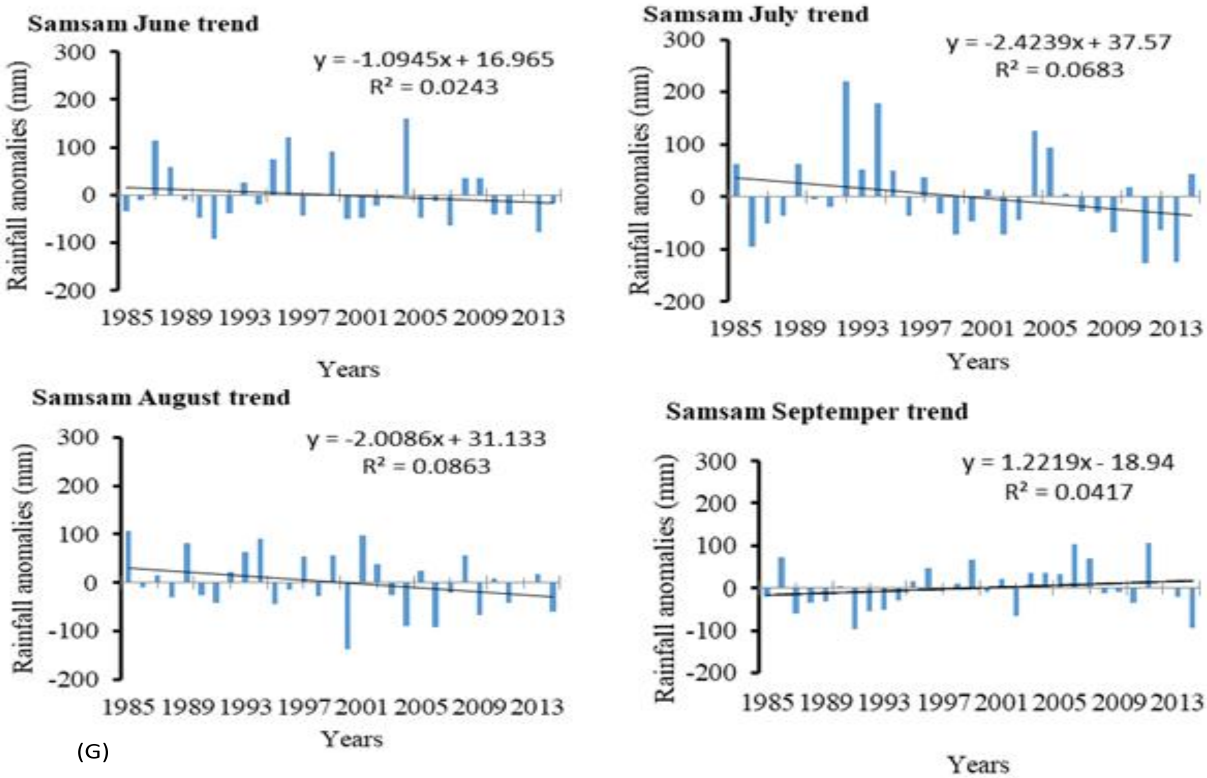


Figure 5. (a) Monthly rainfall anomalies (June to September) for Gadamballia station for period from 1985 to 2014, (b) Monthly rainfall anomalies (June to September) for Gedarif station for period from 1985 to 2014, (c) Monthly rainfall anomalies (June to September) for Alhoory station for period from 1985 to 2014, (d) Monthly rainfall anomalies (June to September) for Douka station for period from 1985 to 2014, (e) Monthly rainfall anomalies (June to September) for Allhawaata station for period from 1985 to 2014, (f) Monthly rainfall anomalies (June to September) for Umseenat station for period from 1985 to 2014, (g) Monthly rainfall anomalies (June to September) for Samsam station for period from 1985 to 2014.

northward in recent years (Magboul et al., 2015).

Rainfall distribution linear regression slope values for trends derived from the 7 stations rainfall data every 10 years is shown in Figure 8. For the first period (1985 - 1994), the 600 mm Isohyets almost divide the area into two equal halves (Figure 8a); one half to the south-east including Douka, Samsam and Umseenat, was favored with higher rainfall (650-700 mm). The other half was around Alhoory and Alhawaata with lower rainfall (550 mm). Rainfall distribution during the second period (1995 - 2004) shows a decrease in total rainfall amounts; the 700 mm isohyet was no longer seen on the image (Figure 8b). It was also noted that areas receiving rainfall below 550 mm were larger in the second period. The third period (2005 - 2014) witnessed greater variation in rainfall distribution. In the southeastern part (around Douka), rainfall was higher than 700 mm, whereas in the western part, more areas were received rainfall below550 mm (Figure 8c).

Rainfall variability in Gedarif State may increase the risk and uncertainty in crop production; because climate change is one of the main drivers of the inter-annual variation in vegetation activity (Zhou et al., 2001; Schimel et al., 2001). Recent studies (IFPRI, 2009) indicated that by 2050 in sub-Saharan Africa, yields of food crops will decline by up to 22% as a result of climate change. The results can serve to help researchers to tailor their research plans to cope with the anticipated rainfall amounts in each area. It is clear from the results that there is higher rainfall in southern areas than in northern areas. As rainfall amounts and distribution determine the selection of the crops grown, the crop varieties in northern areas must therefore be more drought tolerant than those grown in southern areas.

Table 1 shows that there is an increasing trend in total cropped area in Gedarif State during the periods 1985-1994, to 1995-2004 and 2005-2014. One reason for this expansion in cropped area is due to the fact that farmers cultivate sorghum in multiple locations in an effort to cope with the uncertinity of the rainfall in time and space. Another reason for the expansion in the total cropped area is that it is a response-measure to compensate for the declining yields which in turn are due to decreased rainfall as well as an increase in degraded lands (Farah et al., 1996). The results also show that crop yield is very low (Table 1) and declining over the 30 year period due

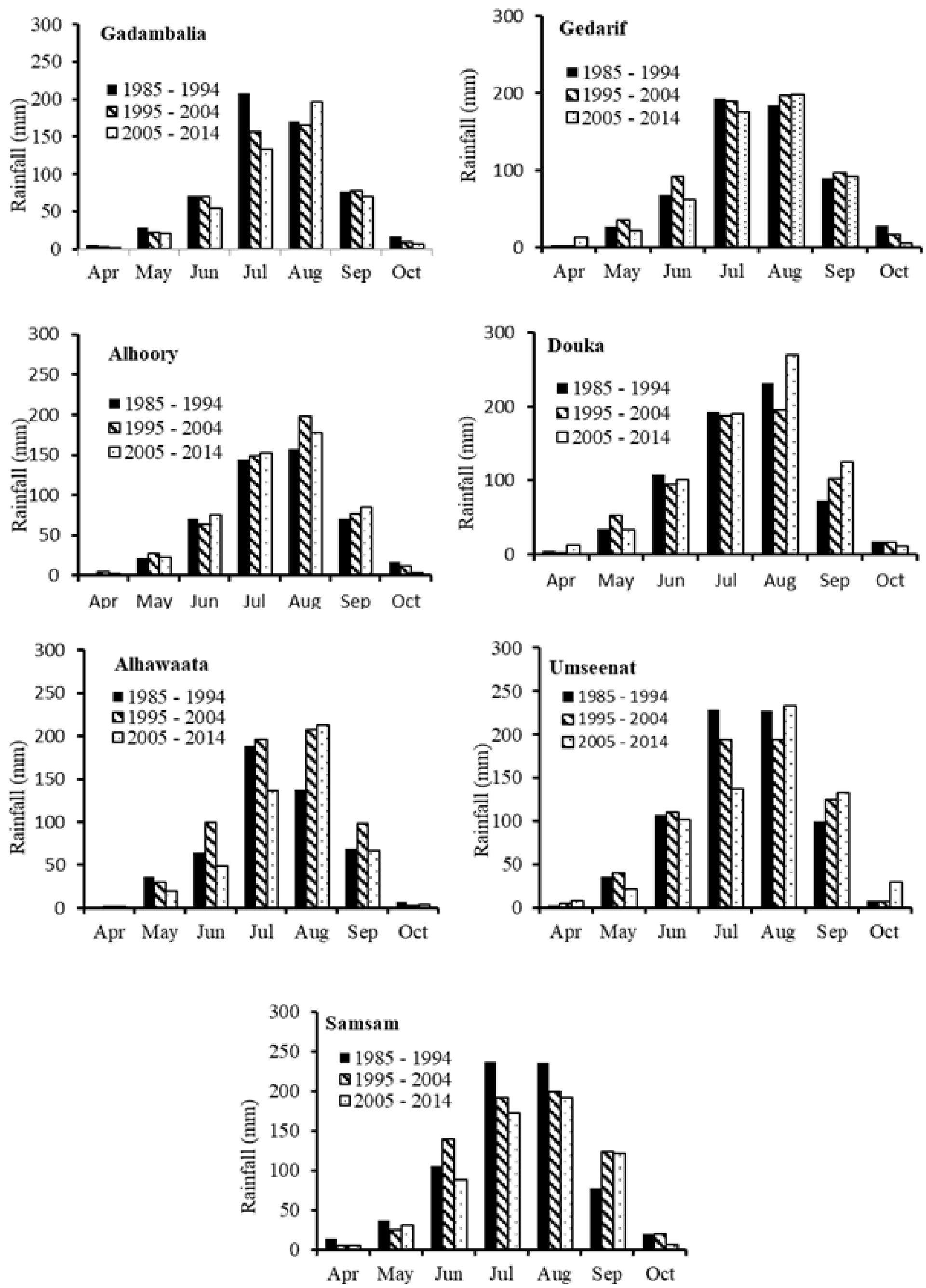


Figure 6. Average monthly rainfall each ten years at seven stations in Gedarif State during the years from 1985 to 2014.

to the delayed rains and therefore delayed sowing date coupled with lower rainfall amounts during the critical growing period (the grain filling and maturity stages during September and October).

Sorghum grain yield (kg/ha) in Gedarif State during the period from 1985 to 2014 fluctuated with years (Figure 9). Generally, this variability reflects the variability in annual rainfall for the seven studied stations. Figure 8 also shows a noticable declining trend in sorghum grain yield during the period. Ali Babiker et al. (2015), reported a similar declining trend in sorghum yield in Gedarif State during the period from 1979 to 2009. This may be due to negative (declining) trend in rainfall in Gadambalia, Samsam and Umseenat, which represent large production areas in Gedarif State. Ahmed (2011) studied climate change impacts on rainfed sorghum production and the length of growing season trends during the last 20 years (1991- 2010) in Gedarif area. His results also show a

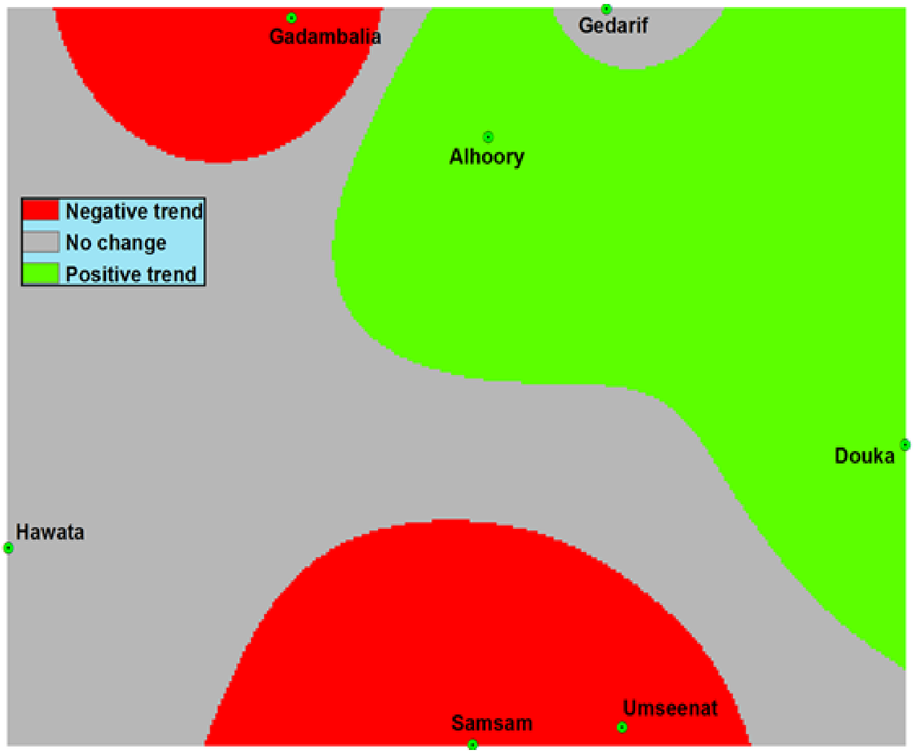


Figure 7. Linear regression slope values for trends derived from the 7 stations rainfall data (1985-2014).

decreasing trend in sorghum productivity, as well.

Conclusion

The results of this study and the above reviewed literature can shows that annual rainfall in the studied stations has relatively low variability compared to monthly variability. According to annual rainfall totals and for agricultural purposes it is possible to classify the stations into two groups; for example Umseenat, Samsam and Douka stations should be considered as one group (I) which have high annual rainfall more than 600 mm; while Alhawaata, Alhoory and Gadambalia stations could be considered as group (II) with annual rainfall ranging between 500 to 600 mm. The majority of rainfall at all the studied stations occurred during July and August supporting the adoption of suitable management practices to avoid water logging during seedling stage for example in areas of group I; and water shortage during flowering and maturity stages of crops for example in areas of group II. Trends of rainfall revealed that some areas, like Alhoory and Douka, showed positive trends in rainfall, whereas Gadambalia, Samsam and to some extent Umseenat showed negative rainfall trends. In Gedarif and Alhawaata, there was no definite rainfall trend. The different trends in rainfall across Gedarif State, might suggest that according to geographical area, different varieties of field crops (for example short to medium maturing varieties) and their associated management practices might be more appropriately applied. Crops of short maturing or drought resistant varieties and early sowing dates coupled with water harvesting techniques should be used in areas of short growing seasons for example areas under group II, to avoid the risk of crop failure whereas in areas of extended growing season for example areas under group I, suitable crops and varieties and their appropriate management practices should be implemented.

Further analysis of rainfall coupled with crop water requirements will be useful to predict crops yield. Also, studies on the effect of dry spells early in and during the growing season on crops yield are of great importance.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENTS

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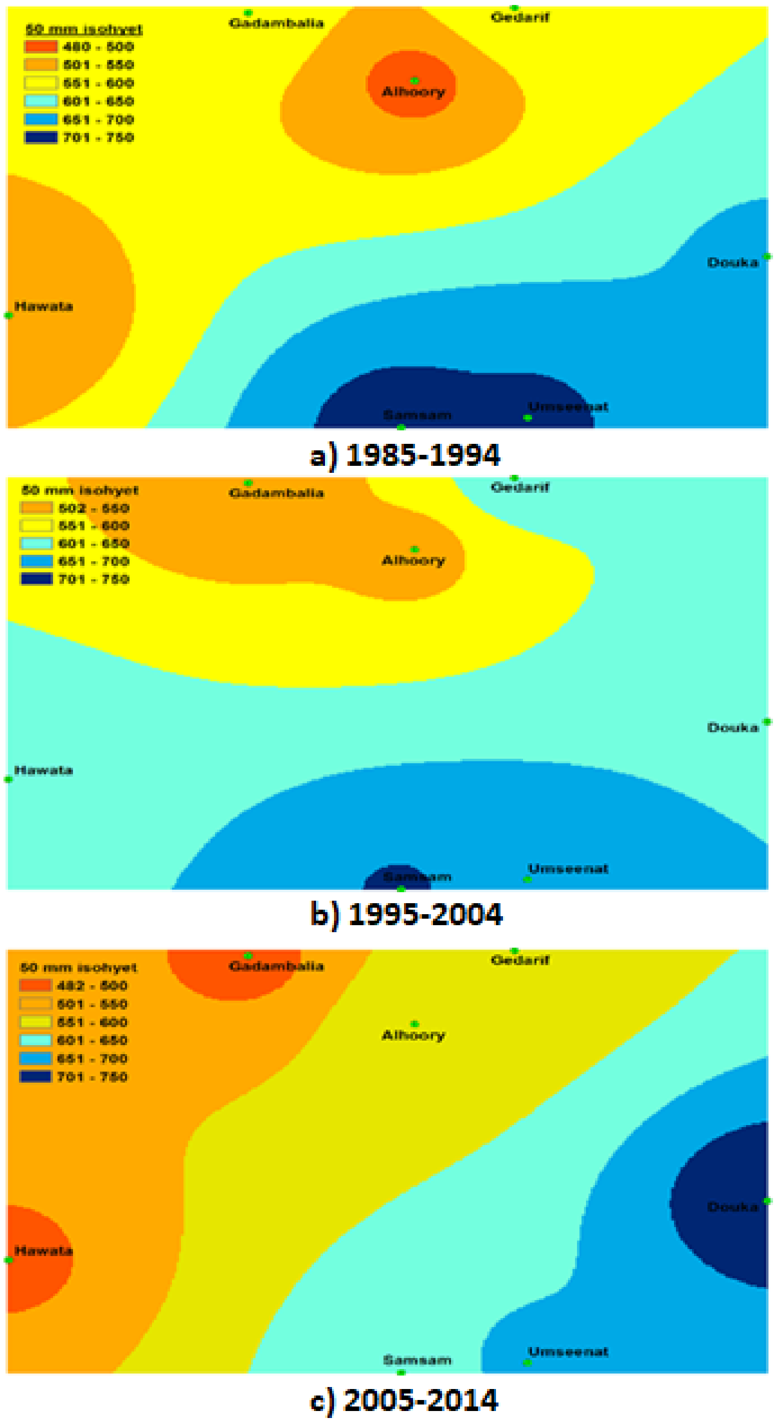

Figure 8. Linear regression slope values for trends derived from the 7 stations rainfall data every 10 years.

Table 1. Average sorghum cropped and harvested area, total production and grain yield in Gedarif State from 1985 to 2014.

Period	Cropped area millon (ha)	Harvested area million ha	Production million (ton)	Yield (ton/ha)
1985 - 1994	1.5	1.3	0.76	0.55
1995 - 2004	1.8	1.5	0.63	0.41
2005 - 2014	2.2	1.4	0.55	0.39

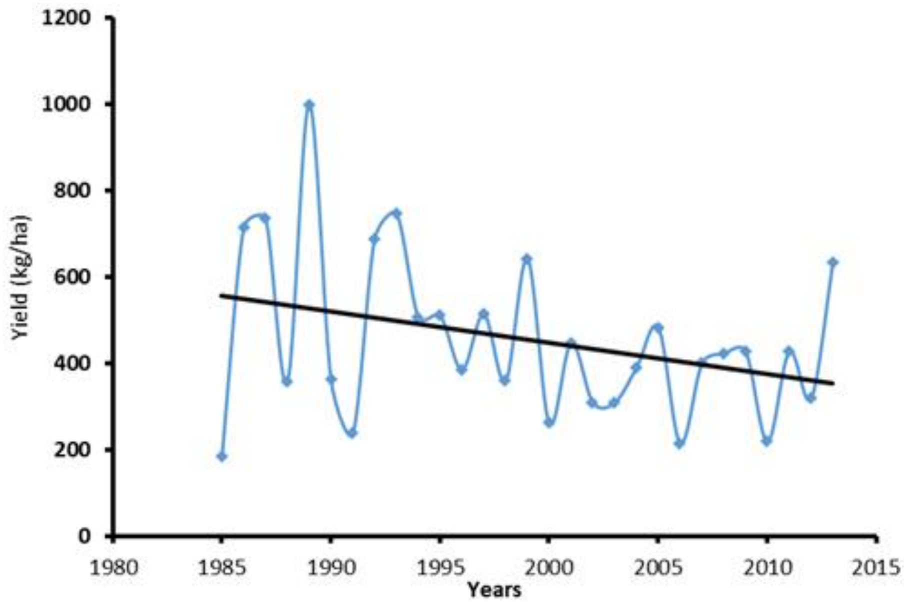

Figure 9. Sorghum yield (kg/ha) in Gedarif State during the period 1985 t0 2014.

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Full Length Research Paper

Effect of cutting height on nutritional characteristics of three agroforestry tree legume species and their feed supplement value on *Chloris gayana* Kunth.

Marguerite Mukangango[1, 2*], Ewa Wredle[3], Mupenzi Mutimura[4] and A. Sigrun Dahlin[1]

[1]Department of Soil and Environment, Swedish University of Agricultural Sciences, P.O. Box 7024, SE-75007 Uppsala, Sweden.
[2]University of Rwanda, College of Agriculture, Animal Sciences and Veterinary Medicine, Butare Rwanda.
[3]Department of Animal Nutrition and Management, Swedish University of Agricultural Sciences, P.O. Box 7014, SE-75007 Uppsala, Sweden.
[4]Department of Animal Production, Rwanda Agricultural Board, P.O. Box 5016, Kigali, Rwanda.

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This study investigated the effect of cutting height (30 and 100 cm) on chemical composition and *in vitro* digestibility in field-grown *Acacia angustissima* (Mill.) Kuntze. (Prairie acacia), *Leucaena pallida* Britton & Rose (guaja) and *Mimosa scabrella* Bentham. (bracatinga) legumes and their value in supplementing a basal diet of *Chloris gayana* Kunth. (Rhodes grass). Cutting height did not affect major chemical composition. Crude protein (CP) was highest in *A. angustissima* and lowest in *M. scabrella*, while neutral detergent fibre (NDF) and acid detergent fibre (ADF) were highest in *M. scabrella*. Degradation parameters were greater at 100 cm cutting height. *L. pallida* showed high *in vitro* organic matter digestibility but *A. angustissima* had the highest metabolisable energy. Addition of *A. angustissima*, *L. pallida* and *M. scabrella* to the basal diet increased improved the nutritional value and increased the CP content from 8.4 to 19.8% and 18.1 and 16.1%, respectively. Cutting height of *A. angustissima*, *L. pallida* and *M. scabrella* had no effect on their nutritional value. Their other functions and benefits will determine choice of cutting height as management practice when used on farms.

Key words: Legume trees, cutting height, chemical composition, *in vitro* degradability.

INTRODUCTION

Livestock production is an important component to the livelihood of many smallholder farming systems throughout the tropics (Klapwijk et al., 2014). Demand for animal-based foods is increasing, providing good possibilities for livestock producers to improve their income. However, they will need to increase the productivity of the livestock, for example through improved nutrition and feeding. Population increases

*Corresponding author. E-mail: marguerite.mukangango@slu.se; mukangango2@gmail.com.

have decreased access to grazing lands in many countries, leading to adoption of zero grazing system based mainly on cut-and-carry grass forage. Tropical grasses mature rapidly, with productivity limited by soil infertility in particular and their lack of N leads to protein deficiency in livestock (Giller, 2001) , so they often need to be supplemented with protein feed resources. Use of commercial concentrates is not financially feasible for many smallholder farmers, who instead use forage from shrubs and tree legumes to correct dietary deficiencies in protein, energy and minerals (Al-Masri, 2007). Moreover, tree legumes are tolerant to drought, can fix nitrogen, stabilize the soil and be used in terracing, contour cultivation and strip-cropping to combat soil erosion and increase soil fertility (Dubeux et al., 2017). Tropical tree legumes have high concentrations of CP, ranging from 14 to 29% of dry matter (Simbaya, 2002). However, their use as feed supplements to ruminants can be limited by the presence of anti-nutritional factors, such as tannins and phenolic, which can limit feed intake, digestibility and reduce live weight gain, milk and other production parameters (Mlambo and Mapiye, 2015). Foliage from legume trees is reported to have both positive and negative effects on feed value parameters such as digestibility, energy, nitrogen content and voluntary intake of individual forages (Niderkorn and Baumont, 2009). According to Dal Pizzol et al. (2017), the positive effects of legumes in feed mixtures are governed by the fermentation rate of different components. This rate is dependent on the fermentability of their chemical constituents, especially proteins, sugars and cellulose (Mauricio, 1996). *Acacia angustissima*, *Leucaena pallida* and *Mimosa scabrella* are promising tree legumes that can provide protein-rich feed for ruminants, as well as fuelwood, nutrient-rich mulch, erosion control and land stabilisation (Niang et al., 1998; Gusha et al., 2013; Mutimura et al., 2015). However, information on their nutritional quality and productivity under different agro-ecological conditions and management strategies is limited (Mokoboki, 2011; Mutimura et al., 2013a). This study examined the effect of cutting height on nutritional characteristics of tree legumes grown on an acidic Ferralsols in Rwanda, and their nutritional effect when mixed with grass forage.

MATERIALS AND METHODS

Study area and plant material

Biomass of three tree legumes (*A. angustissima, M. scabrella* and *L. pallida*) and one grass species (*C. gayana*) was produced in a field experiment at Tonga research station (29°43'E; 2°35'S; 1700 m above sea level). The site has mean annual rainfall of 1200 mm and mean annual temperature of 20°C. The soil is a Ferralsols sandy clay loam, with average pH 4.5 and exchangeable Al^{3+} content 3-4 cmol kg^{-1}. *Eucalyptus* spp. and *Eragrostis curvula* dominated the site prior to establishment of the experiment. Soil preparation was done by hoe and machete.

The experiment (3x2 factorial arrangement) was laid out in a randomised complete block design with six replicates. Trees were established with fertiliser application of 15 tonnes ha^{-1} fresh weight cattle manure and 2 tonnes ha^{-1} burnt lime to boost the starting of the seedlings. Tree seedlings were planted in four rows, with 1 m between rows and 0.5 m between plants within rows, and rooted tillers of *C. gayana* were established at 0.25 m spacing between and within rows. The trees were cut to 30 or 100 cm height. Legume samples were collected in net plots comprising the two middle rows, excluding all plants less than 3 m from the borders of plots. Regrowth of the 5^{th} cut, collected 22 months after establishment and about 5 months after the previous cut, was used for analysis of chemical composition and feed value. Leaves, petioles and succulent stems (Ø <8 mm) were collected from all trees in net plots and pooled to one sample per plot. *Chloris gayana* samples were collected at the flowering stage.

Chemical analyses

Fresh samples were divided into two parts. One part was oven-dried at 105°C for 8 h to determine dry matter (DM) content and the other was oven-dried at 60°C for 72 h and milled to pass through a 1-mm sieve. Samples of the legumes, the grass and mixed legume-grass in proportions 30% legumes and 70% grass were analysed. Total ash and crude protein (CP) (AOAC, 1990; method 942.05), calculated as 6.25 times Kjeldahl nitrogen (N) measured by method 988.05. Calcium (Ca), magnesium (Mg) and phosphorus (P) concentrations were determined by dry ash (methods 927.08, 964.04). Organic matter (OM) was calculated as the difference between DM and ash. Total polyphenols (TP) content was determined according to Anderson and Ingram (1993). Cell wall constituents (neutral detergent fibre (NDF) and acid detergent fibre (ADF) were determined according to Van Soest (1991).

In vitro gas production

In vitro gas production (GP) was measured following Menke et al. (1997). Fermentation media consisted of micro-mineral solution (A), two buffer solutions B and C prepared according to Osuji (1993) and ruminal fluid to provide microbial inoculants. Rumen contents were obtained prior to the morning feed (8:00) from two fistulated steers grazed on *Panicum maximum* and fed with *C. gayana* in their stalls. Rumen contents were collected in sealed thermos flasks. To keep the thermos flask warm, it was filled with boiled water and caped tightly until the time for collecting the rumen contents. The water was quickly replaced with rumen contents, the cap screwed tightly and delivered to the laboratory within 10 min. The rumen contents were squeezed through three layers of cheesecloth into a beaker (250 ml) to remove particles. During the squeezing, the cheesecloth and contents were tightly fitted into the beaker also to ensure minimum exposure to oxygen.

Incubation and data recording

On the day of the incubation, the buffer solutions were prepared according to Osuji (1993) and preheated to 39°C. Samples (200 mg DM basis) were weighed into airtight gas syringes (100 ml). Aliquots of the combined buffer solutions (20 ml) and rumen fluid (10 ml) were dispensed into each gas syringe using a Veterinary Drenching Gun (ROUX-REVOLVER®; Henke-Sass, Wolf GmbH). Syringes containing samples with fermentation medium or blanks with only fermentation medium were incubated at 39°C in an oven

(Model 600 Memmert). Initial gas readings were recorded before the syringes were placed into the oven, and subsequent gas production was recorded at scheduled intervals up to 96 h: 2 hinterval during the first 24 h, 4 h interval between 24 and 48 h and 6 h' interval from 48 up to 96 h of incubation.

Data computation and statistical analysis

Cumulative gas volume in each syringe was calculated as the difference between the value at time (t_i) and the initial value (t_0), adjusted for control values (blanks) at the corresponding recording times. From the gas produced, organic matter digestibility (OMD) and metabolisable energy (ME) values were estimated according to Menke et al. (1979):

$$\text{OMD (g/kg DM)} = 148.8 + 8.89V_{24} + 4.5\ \text{CP} + 0.651\ \text{Ash} \quad (1)$$

$$\text{ME (MJ/kg DM)} = 2.20 + 0.136\ V_{24} + 0.057\ \text{CP} + 0.0029\ \text{CP}^2 \quad (2)$$

Where, V_{24} (mL) is the estimated gas at 24 h and CP is the crude protein.

The kinetics parameters of gas volume production were determined using combined models (Schofield et al., 1994):

$$GP = G/1+e\ [2+4c\ (lt-t)] \quad (3)$$

As described by Campos et al. (2004):

$$GP= a/1+e\ [2+4d(c-t)] +b/1 +e[2+4e(c-t)] \quad (4)$$

Where, GP is total gas volume (mL), a and b are gas volume from rapidly soluble and slowly soluble degradable fractions, respectively, d and e are degradation rate (h^{-1}) for rapidly and slowly degradable fractions, respectively, and c is bacteria colonization or lag time (h).

The time taken to produce half the gas volume ($T_{1/2}$) was estimated based on Sahoo et al. (2010):

$$T_{1/2}(h) = lt+1(2xc) \quad (5)$$

Models 3, 4 and 5 were run using PROC NLIN in SAS software 9.4 (SAS, 2012). Data on chemical composition, *in vitro* degradation, ME and kinetics parameters were subjected to two-way analysis of variance (ANOVA) using general linear model procedures in SAS software 9.4 (SAS, 2012):

$$Y_{ijk} = \mu + \alpha_i+\beta_j +\alpha\beta_{ij} +e_{ijk} \quad (6)$$

Where, Y_{ijk} is independent variable, μ is overall mean of observations, α_i is effect of species (i=1,2,3), β_j is effect of cutting height (j=1, 2), $\alpha\beta_{ij}$ is interactive effect between species and cutting height (i=1,2,3; j=1,2) and e_{ijk} is residual effect. Differences in means were statistically examined by Tukey's test at p<0.05.

RESULTS

Chemical composition

Most of the chemical constituents of the legumes species, *C. gayana* and mixtures of grass and legumes showed significant differences (Tables 1 and 2). The CP was highest in *A. angustissima.* The NDF and ADF were highest and TP lowest in *M. scabrella*. Mineral content was relatively similar across the legume species. *C. gayana* had the highest contents of ash, cellulose and K and the lowest CP (Tables 1 and 2). Protein level was not affected by cutting height but higher levels of NDF were found at 100 cm cutting height in *A. angustissima* and *M. scabrella* (Table 1).

In vitro gas production, fermentation kinetics and *in vitro* degradation

There were few consistent differences between the legume species. Higher gas production was observed in the legumes at 100 cm than at 30 cm cutting height, and also higher ME were observed in *A. angustissima*. Positive correlations (P<0.05) were observed between ME and CP (r=0.141), ash (r=0.259) and total polyphenols (r=0.040). Generally, mixing *C. gayana* with legumes increased dietary CP, P and Ca concentration compared to the pure grass (Table 2), and decreased gas production (Table 4). Increased rapidly soluble degradable fraction (a) and decreased slowly soluble degradable fraction (b) were also observed in the mixed feeds compared to the pure grass (Table 3).

DISCUSSION

The crude protein content was high in all legume species in the present study and it was not affected by cutting height. The CP content in *A. angustissima* and *L. pallida* was higher than reported by Adbulrazak et al. (2000) for different *Acacia* spp. and by Mutimura et al. (2013b) for *L. pallida.* The CP content in *M. scabrella* was lower than that reported by Niang et al. (1996), although they do not mention cutting height. According to Kazemi et al. (2012), legumes, grasses and legume-grass mixtures with CP concentration >19% (DM basis) are classified as prime quality and those with CP <8% as inferior quality. In all cases, the CP content of *A. angustissima, L. pallida* and *M. scabrella* at both cutting heights made them eligible as a protein source in poor-quality basal diets. The fibre content in the legumes was high compared with literature values, for example for NDF in *A. angustissima* (Abdulrazak et al., 2000; Hove et al., 2001; Rubanza et al., 2005). The NDF content in *L. pallida* was similar to that reported by Mutimura et al. (2013b), but lower than that reported by Diriba et al. (2013). The high NDF content in our findings was a result of mature leaves developed during the long (~5 months) and dry period (June-October) since the previous cut. Similarly, Elseed et al. (2002) observed increased NDF concentration in different *Acacia* spp. harvested late in the dry season, compared with early in the dry season, in Sudan. Buxton (1996) concluded that increased temperature lowers forage quality, irrespective of morphological stage. An increase in NDF and/or ADF may therefore decrease the digestibility of fodder tree foliage when ingested mature in

Table 1. Chemical composition (g/kg DM) of *Acacia angustissima* (Aa), *Leucaena pallida* (Lp) and *Mimosa scabrella* (Ms) cut at 30 or 100 cm height (H).

H (cm)	Species	DM	Ash	OM	CP	NDF	ADF	CF	Cellulose.	TP	P	Ca	Mg	K
	Aa	910^{b}	53^{a}	857^{b}	261^{a}	638^{c}	539^{b}	180^{c}	133^{b}	13^{a}	2.7^{a}	8.3^{a}	3.7^{a}	11.2^{b}
30	Lp	909^{b}	58^{a}	851^{bc}	255^{ab}	620^{c}	519^{b}	168^{c}	111^{b}	13^{a}	2.5^{a}	9.8^{a}	4.1^{a}	13.3^{a}
	Ms	922^{a}	37^{c}	885^{a}	196^{c}	725^{b}	688^{a}	306^{b}	268^{a}	9^{b}	1.6^{b}	6.7^{b}	4.3^{a}	8.0^{c}
	Aa	911^{b}	48^{b}	863^{b}	284^{a}	731^{b}	598^{b}	192^{c}	132^{b}	13^{a}	2.7^{a}	7.7^{b}	4.0^{a}	12.2^{b}
100	Lp	911^{b}	48^{b}	863^{b}	245^{b}	566^{c}	480^{b}	140^{c}	113^{b}	14^{a}	2.7^{a}	7.5^{b}	4.4^{a}	14.2^{a}
	Ms	925^{a}	50^{a}	875^{a}	182^{c}	846^{a}	723^{a}	362^{a}	282^{a}	12^{ab}	3^{a}	9.7^{a}	4.1^{a}	10.7^{b}
	SEM	0.2	0.3	0.4	0.9	3.2	2.9	1.4	0.9	0.1	0.02	0.1	0.1	0.1
p -value	Species	<.0001	0.0011	<.001	<.0001	<.0001	<.0001	<0001	<.0001	<.0001	0.0627	0.0006	0.8345	<.0001
	Height	0.3737	0.2026	0.5994	0.0632	0.0012	0.097	0.0146	0.4343	0.0496	0.0015	0.0089	0.9464	0.0076
	Species×height	0.6145	0.0033	0.0417	0.0400	0.6369	0.6608	0.1082	0.3731	0.1108	0.0007	0.0001	0.5467	0.1785

SEM, Standard error of mean. [a, b, c:] Values within columns with different letters differ significantly (p<0.05); DM, dry matter; OM, organic matter; CP, crude protein; NDF, neutral detergent fibre; ADF, acid detergent fibre; CF, crude fibre; TP, total polyphenols; Aa, *Acacia angustissima*; Lp, *Leucaena pallida*; Ms, *Mimosa scabrella*.

Table 2. Effect of mixing *Acacia angustissima* (Aa), *Leucaena pallida* (Lp) and *Mimosa scabrella* (Ms) cut at 30 or 100 cm height with baseline *Chloris gayana* (Cg) on feed composition (g/kg DM).

H (cm)	Feed	DM	Ash	OM	CP	NDF	ADF	CF	Cellulose	TP	P	Ca	Mg	K
	AaCg	921^{c}	77.5^{a}	851^{a}	191^{a}	703^{ab}	594^{ab}	162^{b}	141^{b}	12.7^{a}	1.9^{a}	7.5^{b}	3.6a	15.9^{bc}
30	LpCg	921^{c}	74.6^{a}	855^{a}	182^{ab}	666^{b}	570^{b}	147^{b}	125^{b}	12.5^{ab}	2.0^{a}	9.1^{a}	4^{a}	18.6^{b}
	MsCg	930^{b}	56.7^{b}	863^{a}	161^{c}	725^{a}	658^{a}	306^{a}	276^{a}	9.6^{b}	1.5^{b}	6.4^{bc}	4.1^{a}	13.8^{c}
	AaCg	918^{c}	77.2^{a}	852^{a}	198^{a}	738^{a}	646^{a}	217^{b}	141^{b}	13^{a}	2.0^{a}	7.3^{b}	3.9^{a}	17.2^{b}
100	LpCg	920^{c}	77^{a}	857^{a}	179^{b}	670^{b}	564^{b}	189^{b}	124^{b}	14.3^{a}	2.1^{a}	7.1^{b}	4.4^{a}	17.7^{b}
	MsCg	929^{b}	70^{a}	865^{a}	139^{d}	785^{a}	697^{a}	341^{a}	288^{a}	11^{b}	2.3^{a}	8.8^{a}	4^{a}	16.4^{b}
	Cg	938^{a}	86.4^{a}	852^{a}	84^{e}	772^{a}	652^{a}	332^{a}	294^{a}	9.6^{b}	1.3^{b}	6.4^{bc}	3.1^{a}	22.4^{a}
Significance	SEM	2.0	5.8	3.9	5.6	24.6	23.5	13.8	6.8	0.5	0.2	0.4	0.3	0.8
	P-value	<0.0001	0.0408	0.0937	<0.0001	0.0058	0.0016	<0.0001	<0.001	<0.0001	0.0005	<0.0001	0.0895	<0.0001

SEM, Standard error of means. [a, b, c, d, e:] Values within columns with different letters differ significantly (p<0.05). DM, dry matter; OM, organic matter; CP, crude protein; NDF, neutral detergent fibre; ADF, acid detergent fibre, CF, crude fibre; TP, total polyphenols; AaCg, *A. angustissima +C. gayana*; LpCg, *L. pallida +C. gayana*; MsCg, *M. scabrella +C. gayana*.

Table 3. *In vitro* degradability and kinetics parameters of *Acacia angustissima* (Aa), *Leucaena pallida* (L.p) and *Mimosa scabrella* (Ms) cut at 30 or 100 cm height (H).

H (cm)	Feed	GP (mL/200 g)	a (g/kg DM)	b (g/kg DM)	c (%/h)	$t_{1/2}$ (h)	IVOMD (g/kg DM)	ME (MJ/kg DM)
30	Aa	14[b]	-2.4[a]	16.4[a]	0.026[a]	27.4[a]	327[a]	7[b]
	Lp	15.1[ab]	-7.4[a]	22.5[a]	0.026[a]	21.0[a]	342[a]	7[b]
	Ms	14.7[b]	6.6[a]	8.1[a]	0.049[a]	25.6[a]	322[a]	6[b]
100	Aa	19[a]	8.7[a]	10.2[a]	0.039[a]	23.4[a]	299[a]	8[a]
	Lp	16.7[a]	4.2[a]	12.5[a]	0.020[a]	31.1[a]	349[a]	7[b]
	Ms	21.3[a]	8.4[a]	13[a]	0.024[a]	28.6[a]	296[a]	6[b]
	SEM	1.7	8.1	7.9	0.01	3.9	14.1	0.3
P-value	Species	0.4319	0.5397	0.6793	0.2922	0.9084	0.0288	0.0006
	Height	0.0031	0.2271	0.5635	0.4319	0.3484	0.1842	0.0422
	Species × height	0.03119	0.7914	0.6255	0.1166	0.2145	0.3696	0.0497

SEM, Standard error of means. [a, b, c, d, e:] Values within columns with different letters differ significantly ($p<0.05$). Gp, gas production (mL/200 g); a (g/kg DM), rapidly degradable portion; b (g/kg DM), slowly degradable portion; c (%/h), degradation rate; $t_{1/2}$ (hour), time needed to produce half of all gas produced; IVOMD (g/kg DM), *In vitro* organic matter degradability; ME (MJ/kg DM), metabolisable energy; Aa, *Acacia angustissima*; Lp, *Leucaena pallida*; Ms, *Mimosa scabrella*.

Table 4. Effect of mixing *Acacia angustissima* (Aa), *Leucaena pallida* (Lp) and *Mimosa scabrella* (Ms) cut at 30 or 100 cm height with baseline *Chloris gayana* (Cg) on kinetics and *in vitro* degradability.

H (cm)	Feed	GP (mL/200 g)	a (g/kg DM)	b (g/kg DM)	c (%/h)	$t_{1/2}$ (h)	IVOMD (g/kg DM)	ME (MJ/kg DM)
30	AaCg	22.3[c]	3.0[a]	19.3[b]	0.019[a]	44.9[a]	401[a]	5[b]
	LpCg	24.8[bc]	10.4[a]	14.4[b]	0.022[a]	24.1[b]	357[b]	5[b]
	MsCg	20.7[c]	-18.1[a]	38.8[b]	0.019[a]	37.6[a]	354[b]	6[a]
100	AaCg	33.6[b]	105.3[a]	-71.7[b]	0.014[b]	47.2[a]	339[b]	6[a]
	LpCg	31.4[b]	68.1[a]	-36.6[b]	0.016[ab]	41.6[a]	356[b]	6[a]
	MsCg	28.7[b]	2.51[a]	26.2[b]	0.018[ab]	44.1[a]	291[c]	5[b]
	Cg	40.8[a]	-771.8[b]	812.7[a]	0.015[ab]	39.3[a]	329[b]	5[b]
Significance	SEM	2.0	192.5	192.1	0.002	3.9	15.4	0.2
	P-value	<0.0001	0.039	0.034	0.022	0.0032	0.0013	<0.0001

SEM, Standard error of mean. [a, b, c:] Values within columns with different letters differ significantly ($p<0.05$); Gp, gas production; a (g/kg DM), rapidly degradable portion; b (g/kg DM), slowly degradable portion (g/kg DM); c(%/h), degradation rate; $t_{1/2}$ (h), time needed to produce half of all gas produced; IVOMD (g/kg DM), *in vitro* organic matter degradability; ME (MJ/kg DM), metabolisable energy; AaCg, *A. angustissima +C. gayana*; LpCg, *L. pallida +C. gayana*; MsCg, *M. scabrella +C.gayana.*

the dry season. The fibre content could perhaps be lowered by harvesting fodder tree leaves at shorter intervals or in the wet season and preserving them for use in the dry season. However, some studies report high variability in NDF content (20-80%) in subtropical forages (Jung and Allen, 1995; Harper and McNell, 2015). Although legumes species have higher CP than grass, their higher NDF and ADF content could limit their potential as a supplement to low-quality feeds, by limiting feed intake through physical fill effects and by reducing the digestibility (McDonald et al., 2011). This effect would be more pronounced for *A. angustissima* and *M. scabrella* cut at 100 cm, since they had the highest NDF content.

Total polyphenol content was not affected by cutting height in the three legumes, but was much lower than values reported by Abdulrazak et al. (2000) and Rubanza et al. (2005) for *A. angustissima* grown in Kenya and Tanzania, respectively, and for *L. pallida* grown in Rwanda (Mutimura et al., 2013b). The low total polyphenol content in this study may be explained by a combination of proportion of stem and leaves in the samples and seasonal fluctuations. Parissi et al. (2018) found higher total polyphenol content in leaves than stems and lower content in autumn than spring for different browse species. However, our values were similar to those found by Rubanza et al. (2006) and Mokoboki (2011) for *Acacia* spp. and by Salem et al. (2013) for browse tree species. Moreover, differences in analytical procedures can lead to large differences in total polyphenol concentration (Makkar, 2003). The low levels found can be beneficial, by improving utilisation of the high CP content. Calcium, P and K content were affected by cutting height and were within the range found in most tropical legumes (Abdulrazak et al., 2000; Rubanza et al., 2006). The Ca and P concentrations did not meet ruminant requirements (11 g Ca/kg DM and 7.7g P/kg DM) (NRC, 2001). Thus, when using *A. angustissima, M. scabrella* and *L. pallida* to supplement forage grasses, minerals supplementation would be needed.

The lower IVOMD was expected due to the high cell wall content in the legumes. The values were low compared with those reported in some studies (Abdulrazak et al., 2000; Hove et al., 2001; Diriba et al., 2013) for *A. angustissima*, *L. pallida* and different browse legume species, but in line with values reported in others (Datt et al., 2008; Mutimura et al., 2013b). The combined effect of high cell wall, high crude fibre and relatively low ME content resulted in the low degradability observed in these fodder legumes. This corroborates findings that cell wall content constitutes a set of limits potential feed intake by physical fill effect and by reducing the digestibility (Elseed et al., 2002; McDonald et al., 2011). Buxton (1996) found a negative relationship between NDF and potential forage intake and between ADF and forage digestibility. Datt et al. (2008) found negative effects of crude fibre and cell composition on *in vitro* digestibility and ME, probably because lignin depresses digestibility.

Mixing *A. angustissima, L. pallida* and *M. scabrella* with a basal diet of grass increased dietary CP from an initial 8.4 to 19.8%, 18.1% and 16.1%, respectively. It also increased the IVOMD of the diet compared with legumes alone. Mauricio (1996) suggest that the main chemical components involved in fermentation are proteins, carbohydrates and cellulose. All the feed mixtures, irrespective of cutting height, had CP >130 g/kg DM, that is more than required to allow multiplication of rumen microorganisms (Dal Pizzol et al., 2017). Therefore, all three legume species can be used to improve low-quality forage, while cutting management can be driven by other potential benefits, such as reforestation, boundary demarcation, soil fertility and land conservation, fuelwood production and competition.

Conclusion

The chemical composition, *in vitro* degradability characteristics and gas production of *A. angustissima, M. scabrella* and *L. pallida* showed that these tree legumes can be good feeds for livestock and their inclusion can improve nutritional quality of a grass-based diet. Cutting height (30 or 100 cm) had no major effect on the nutritional value of *A. angustissima*, *L. pallida* and *M. scabrella*. Therefore, farmers do not have to consider cutting height when planning to use these species as supplement feeds. Other functions of the trees such as hedging, fertiliser, fuelwood production, etc. should be determined based on the choice of the cutting height applied at on-farm level.

CONFLICT OF INTERESTS

The authors declare that they have no conflict of interest.

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Full Length Research Paper

Population dynamics of white mango scale, *Aulacaspis tubercularis* Newstead (Hemiptera: Diaspididae) in Western Ethiopia

Ofgaa D.[1*], Emana G.[1] and Kahuthia-Gathu R.[2]

[1]Department of Zoological Sciences, Addis Ababa University, P. O. Box 54704, Addis Ababa, Ethiopia.
[2]Kenyatta University, School of Agriculture and Enterprise Development, P. O. Box 43844-00100 Nairobi, Kenya.

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Mango (*Mangifera indica* L.) is the third most important fruit crop in the tropics following citrus and banana. It is consumed as a fresh fruit and different forms of preparations for its multifaceted nutritional values. Mango production in Ethiopia is constrained by infestation of white mango scale (WMS), *Aulacaspis tubercularis* Newstead. White mango scale was recorded from Ethiopia for the first time in 2010, in a mango orchard in Loko in the western part of the country. This study was conducted from June 2013 to May 2014 to document the population dynamics of white mango scale in Western Ethiopia. Randomized Complete Block Design was used for the sampling in two mango orchards, Arjo and Bako. Scale population peaked in April at Arjo and in May at Bako showed marked decline with decreasing precipitation. Abundances of eggs, crawlers and sessile stages of the scale showed significant differences among most of the study months ($P<0.05$). The abundance of sessile scales was significantly higher at Bako than at Arjo ($P<0.05$). In both study areas, white mango scales were significantly more abundant on the upper leaf surfaces than the lower ($P<0.05$). At Bako, male scale numbers were significantly higher than those of the females ($P<0.05$). The study found that the decline and build-up of white mango scale populations are affected by rainfall, whereas the effects of other environmental factors on scale numbers need to be investigated.

Key words: Developmental stages, fluctuation, infestation, orchard, rainfall, sessile.

INTRODUCTION

Mango is the third most important fruit crop in the tropics after citrus and banana (Louw et al., 2008). It is consumed as a fresh fruit and as other kinds of preparations for its high contents of sugar, protein, fats, salts and most of the vitamin types, among others (Griesbach, 2003; Kayode and Sani, 2008; Shah et al., 2010; Nabil et al., 2012). Mango production is constrained by white mango scale, *Aulacaspis tubercularis* Newstead, in countries such as Mexico, India, Pakistan, Italy, Ghana, Kenya, Madagascar, Mauritius, Tanzania, Uganda

*Corresponding author. E-mail: ofgaa.djirata@gmail.com.

and Zimbabwe, among others (Labuschagne et al., 1995; Pena et al., 1998; El-Metwally et al., 2011; Salem et al., 2015; Hodges and Harmon, 2016). White mango scale inserts its stylets in the soft parts of mango tree and sucks saps. As a result it causes yellowing of leaves, development of conspicuous pink blemish on mature and ripe fruit and dieback to mango plantation (El-Metwally et al., 2011; Abo-Shanab, 2012). Infestation in young trees may lead to excessive fall off leaves, retarded growth and death of the whole plant (Nabil et al., 2012). The development of conspicuous blemishes on mango fruit skin which was infested by white mango scale markedly damages mango fruit export potential and eventually leads to economic loss (USDA, 2006, 2007). Three mineral oils, Diver®, CAPL2® and super masrona®, were tested in field against white mango scale and showed different levels of effectiveness (Abo-Shanab, 2012). In Kenya, deltametrine and pyrethrin were recommended for the control of white mango scale (Findlay, 2003).

Infestation of mango by *A. tubercularis* in Ethiopia was first reported in 2010 in a mango orchard owned by Green Focus Ethiopia Ltd. (Dawd et al., 2012) which used to import mango seedlings from South Asia and hence it is deduced that the pest probably entered Ethiopia accidently on imported seedlings. Within one-year of first record, white mango scale was reported to have dispersed 100 km west of the original site (Fita, 2014). The damages of white mango scale induced panic and frustration in Western Ethiopia for the loss in crop production and indirect sociological consequences, since mango plantation serves as shade for animals and conference hall for the people, in addition to generating income and serving as food in the region (Dako and Degaga, 2015). This study was planned with the objective of understanding the population dynamics of different developmental stages of white mango scale which would be the most important and prior step for the purpose of management of the pest.

MATERIALS AND METHODS

Description of the study area

This study was conducted in Arjo district of East Wollega Administrative Zone and Bako Tibe district of West Shoa Administrative Zone in Western Ethiopia. Arjo orchard was located at 09° 03´N and 036° 17´E while Bako orchard was located at 09° 07´N and 037° 03´E. Both districts received unimodal rainfall with mean annual precipitation of 1649 and 1219 mm at Arjo and Bako, respectively (Ethiomet, 2016).

Study design, sampling procedure and data analyses

In each orchard, five blocks were specified, one at each of the four corners and the centre. Hence, Randomized Complete Block Design was used. From upper, middle and lower canopies of a mango tree within every block, a total of ten leaves were plucked. Sampling started from the trees at each corner in the blocks and continued toward the centre, and that started from central block continued in the four cardinal directions on successive trees, once within a month for 12 consecutive months, from June 2013 to May 2014. The leaves collected from each tree were placed in a separate cloth bag, labelled, kept in a plastic bag and taken to Addis Ababa University, Science Faculty, Insects and Vector Research Laboratory. The leaves were observed under stereomicroscope and numbers of white mango scales were recorded. In this study, the first instar was recorded as *crawler* whereas all the remaining developmental stages and the adult were collectively considered as *sessile* stage. Male and female sessile stage mango scales were identified and recorded. In this study it was impossible to include fully matured live male scales, as they fly out immediately up on achieving maturity. Accordingly, male mango scale armours were broken open by the use of dissecting needle to avoid counting empty scales. Furthermore, the needle was used to lift the armour of the adult female for ease of counting the eggs underneath. Weather data on rainfall and temperature of the study area were obtained from National Meteorology Agency of Ethiopia (Ethiomet, 2016).

Microsoft Excel was used to summarize data on population fluctuations of white mango scale. Data on scale counts were analysed using Proc ANOVA of SAS software V9 (SAS, 2002). Significant means were separated by Fisher's Least Significant Difference (LSD) at 5% error level. Square root transformation was used to normalize data obtained from white mango scale count prior to running analysis of variance (ANOVA) and was back transformed for reporting.

RESULTS

Population abundance of white mango scale

Population of sessile white mango scale per leaf was significantly abundant ($P<0.05$) at Bako orchard (24.87±0.36) than Arjo (18.55±0.37). Population of male white mango scale was higher than that of the female in the study area in general and the difference was significant ($P<0.0001$) at Bako orchard (Table 1).
Population sizes of all the developmental stages of white mango scale showed statistically significant differences ($P<0.0001$) among most of the study months at both study orchards (Tables 2 to 4).

All developmental stages of white mango scale were found to have been significantly abundant ($P<0.0001$) on upper surface of mango leaf than the lower at both study orchards (Tables 5 to 7).

Population fluctuations of white mango scale

Population fluctuations of eggs, crawlers and sessile mango scales followed a more-or-less similar pattern over the months of the study year. Marked population fluctuations were observed, with a general trend of decline with decreased precipitation. Detectable infestations persisted more-or-less throughout the year at Arjo but scale population fell below detectable levels in some of the dry season months at Bako (Figures 1 to 6).

Table 1. Mean numbers of sessile male and female mango scales present in the study orchards.

Study site	Mean ± SE		LSD
	Male WMS	Female WMS	
Arjo	22.43±0.62[a]	15.00±0.40[a]	1.16
Bako	35.09±0.61[a]	16.34±0.35[b]	0.29

Means followed by the same letter within a row are not significantly different at the 5% level (LSD).

Table 2. Mean numbers of sessile mango scale population present during the study months.

Month	Mean ± SE	
	Arjo	Bako
June	48.32±1.23[b]	16.76±0.34[e]
July	38.20±1.88[b]	11.29±0.55[e]
August	6.95±0.84[c]	2.83±0.25[f]
September	6.47±0.47[c]	0.37±0.15[gh]
October	2.65±0.44[c]	0.07±0.04[h]
November	1.22±0.15[c]	0.23±0.06[gh]
December	4.83±0.41[c]	2.13±0.20[fg]
January	2.69±0.59[c]	2.99±0.24[f]
February	5.38±0.79[c]	52.03±0.96[d]
March	37.41±2.13[b]	92.04±7.23[c]
April	100.07±1.59[a]	150.31±1.33[b]
May	58.36±1.22[ab]	225.22±1.28[a]
LSD	2.83	0.71

Means followed by the same letter(s) within a column are not significantly different at the 5% level, (LSD).

Table 3. Mean numbers of crawler populations present during the study months.

Month	Mean ± SE	
	Arjo	Bako
June	2.44±0.38[ab]	1.34±0.28[b]
July	2.24±0.37[abc]	0.12±0.23[b]
August	1.42±0.45[abcd]	0.01±0.00[b]
September	0.09±0.27[cd]	0.01±0.00[b]
October	0.34±0.01[d]	0.00±0.00[b]
November	0.00±0.00d	0.00±0.00[b]
December	0.00±0.00[d]	0.00±0.00[b]
January	0.03±0.01[d]	0.45±0.13[b]
February	2.07±0.47[abcd]	0.09±0.03[b]
March	0.88±0.30[abcd]	0.34±0.06[b]
April	3.16±0.50[a]	16.39±0.99[a]
May	0.44±0.11[bcd]	25.34±0.94[a]
LSD	0.77	0.98

Means followed by the same letter(s) within a column are not significantly different at the 5% level (LSD).

Table 4. Mean numbers of egg populations in the study months.

Month	Mean ± SE	
	Arjo	Bako
June	31.28±1.29[cd]	1.72±0.44[e]
July	89.24±2.35[b]	0.55±0.25[e]
August	42.39±1.28[c]	0.00±0.00[e]
September	9.19±0.70[ef]	0.15±0.07[e]
October	6.60±0.63[ef]	0.00±0.00[e]
November	0.00±0.00[f]	0.57±0.25[e]
December	2.45±0.29[f]	2.95±0.44[e]
January	7.35±0.52[ef]	3.43±0.39[e]
February	41.65±1.40[c]	21.51±1.28[d]
March	104.95±1.90[b]	84.23±1.92[c]
April	193.94±2.84[a]	136.15±2.14[b]
May	16.72± 0.64[de]	216.59±2.92[a]
LSD	2.30	2.26

Means followed by the same letter within a column are not significantly different at the 5% level (LSD).

Table 5. Mean numbers of sessile mango scales on upper and lower surfaces of mango leaves at Arjo and Bako orchards.

Study site	Mean ± SE		LSD
	Upper	Lower	
Arjo	33.70±0.90[a]	7.71±0.56[b]	1.16
Bako	40.02±0.59[a]	13.19±0.36[b]	0.29

Means followed by the same letter within a column are not significantly different at the 5% level (LSD).

Table 6. Mean numbers of crawlers on upper and lower leaf surfaces of mango in Arjo and Bako orchards.

Study site	Mean ± SE		LSD
	Upper	Lower	
Arjo	1.84±0.17[a]	0.19±0.04[b]	0.31
Bako	2.87±0.29[a]	1.02±0.15[b]	0.40

Means followed by the same letter within a column are not significantly different at the 5% level (LSD).

Table 7. Mean numbers of eggs on upper and lower leaf surfaces of mango in Arjo and Bako orchards

Study site	Mean ± SE		LSD
	Upper	Lower	
Arjo	62.55±0.90 (7.97)[a]	10.82±0.33 (3.44)[b]	0.94
Bako	35.80±0.99 (6.10)[a]	5.55±0.36 (2.56)[b]	0.92

Means followed by the same letter within a column are not significantly different at the 5% level (LSD).

DISCUSSION

Populations of white mango scales in Arjo and Bako begin to build up in February and reach their peaks in April in Arjo and in May in Bako. Population peaks of scale crawlers were also evident in these months. This is

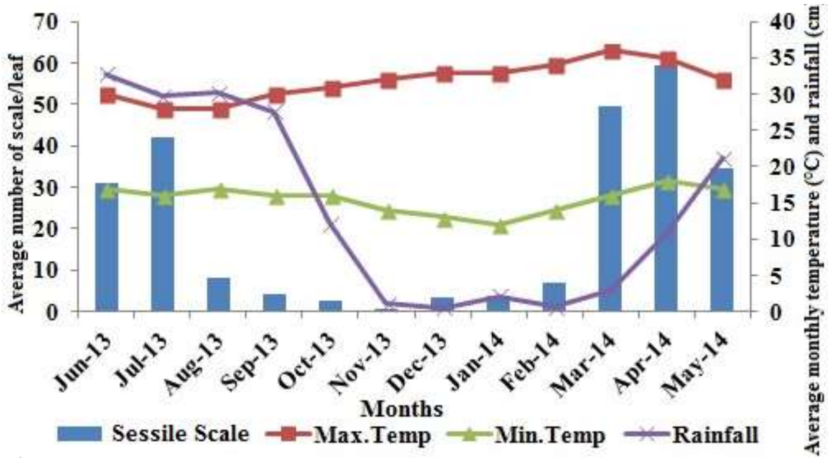

Figure 1. Population fluctuations of sum of male and female sessile stages mango scale at Arjo.

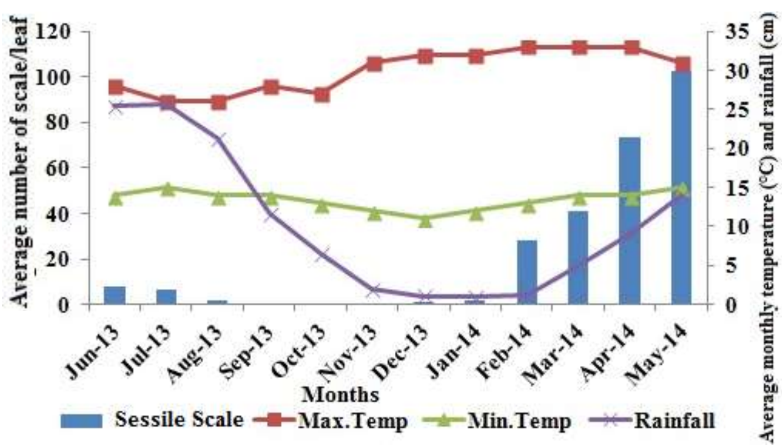

Figure 2. Population fluctuations of sum of male and female sessile stage mango scale at Bako.

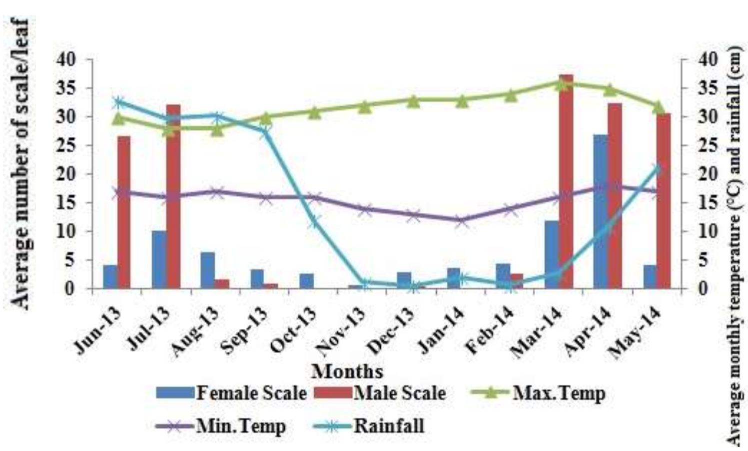

Figure 3. Population fluctuations of males and females mango scale at Arjo.

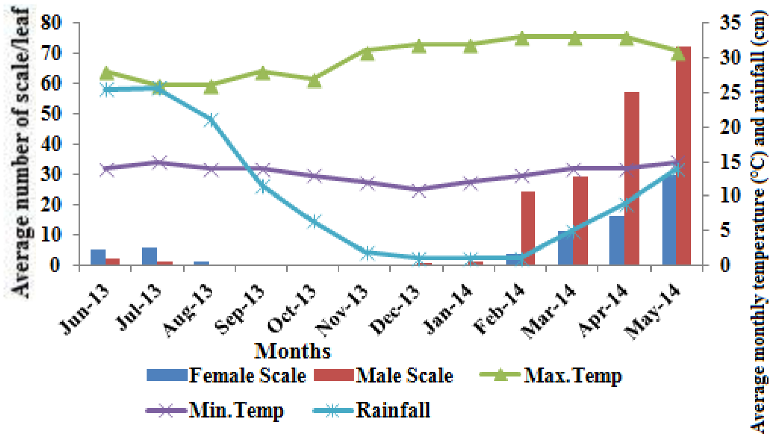

Figure 4. Population fluctuations of mango scale males and females at Bako.

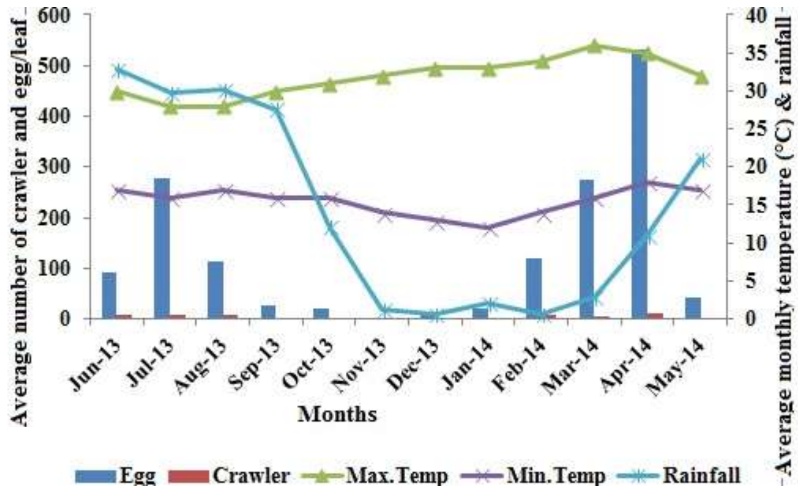

Figure 5. Population fluctuations of the scale crawlers and eggs at Arjo.

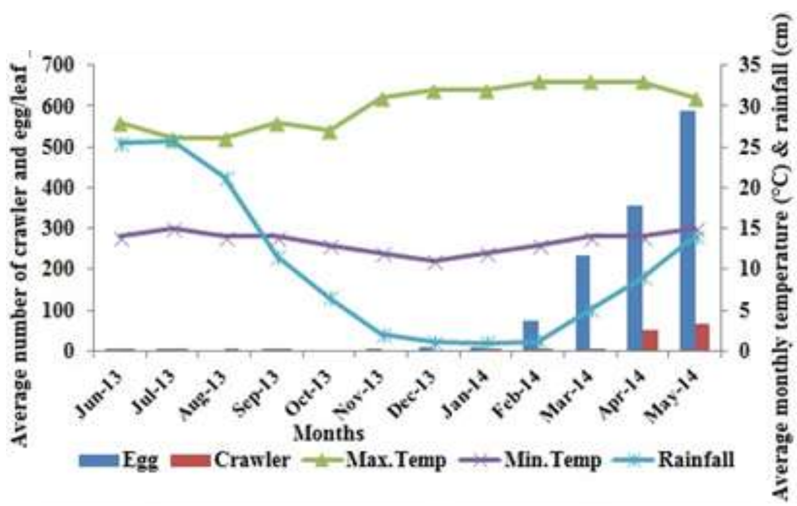

Figure 6. Population fluctuations of the scale crawlers and eggs at Bako.

an essential finding for control of the pest through targeting the crawler stage, which is sensitive to both systemic and contact insecticides (Buss and Turner, 2006). Population of white mango scale remained at an extremely low level when average monthly rainfall was below 10 mm, implying that white mango scale is highly affected by drought.

The current study identified three phases of mango scale population. In Arjo, the first phase was from February to July, when the population began to build up towards its peak. The second phase, in August, September and October was characterized by sharp decline of the population. The last one was from November to January during which the population remained low and inconspicuous. In Bako, the first phase began in February as in Arjo but continued to May only. In June, July and August, the population declined abruptly, denoting the second phase. The last phase in which population remained low to undetectable was between September and January in Bako.

This study, therefore, indicates that the decline and build-up of mango scale population is affected by rainfall in two ways, though other contributing factors need to be investigated further.

Firstly, a minimum average monthly rainfall of about 50 mm is required to initiate build-up of the scale population. The optimum rainfall for the insect to reach its peak population may vary spatially and temporally, as it was found to be 110 mm in April at Arjo and 140 mm in May at Bako. The build-up of the scale population coincides with the physiological maturity of mango fruit, both happening at the beginning of the rainy season in the study area. Dako and Degaga (2015) reported that maturation and ripening of mango fruit begin during the first months of rainy season, that is, in March to April and continues for few months, vis-à-vis significant infestation of mango fruits by white mango scale, in Western Ethiopia.

Secondly, prolonged heavy rainfall may affect mango scale population negatively. A swift population decline of mango scale followed prolonged heavy rain probably because the rain washes the scale off mango leaves. This finding agrees with Salem et al. (2015) who recorded low population density of white mango scale from the end of rainy season in Egypt. El-Metwally et al. (2011) also recorded low population of white mango scale during the rainy season. It is evident that strong rain can kill small or immobile stages of insects (Moran et al., 1987).

Crawler and sessile stages of mango scale populations were more abundant at Bako than at Arjo. One possible explanation, among others, may be associated with the negative impact of high heavy rain intensity on the scale population at Arjo, as this site receives a higher amount of annual rainfall than that at Bako (Ethiomet, 2016).

Both minimum and maximum temperatures at the current study sites were more or less stable; and this study did not evaluate the impact of extreme temperatures on the population dynamics of white mango scale. However, the size of the scale population was higher during the months with relatively more extreme maximum and minimum temperatures. Peak populations were recorded in the months with maximum monthly temperatures of 35 and 31°C at Arjo and Bako, respectively, indicating that *A. tubercularis* tolerates higher temperatures. This record does not agree with the conclusion of Labuschagne et al. (1995) which found that white mango scale had a low tolerance to high temperature, and as a result its population declined in temperatures above 30°C. In all observed cases during this investigation, crawler-stage population of mango scale was much smaller than any of the other developmental stages. One possible explanation for this would be that white mango scale stays as crawler stage for shorter period of time compared to sessile stages (Labuschagne et al., 1995). Moreover, crawlers move to different parts of the host plant in search of suitable settling sites and may also be dispersed away from the plant by various factors all of which would reduce their numbers on the sampled leaves.

All developmental stages of mango scale were found to be more abundant on the upper leaf surfaces in both study orchards. This finding agrees with the study by Nabil et al. (2012) on mango in Egypt which also recorded that *A. tubercularis* preferred the upper leaf surface compared to the lower one. Investigations as to why the scale prefers the upper leaf surface to the lower seems to have been overlooked. However, Beardsley and Gonzalez (1975) said that McLaren (1971) associated the settlement of the majority of California red scale crawlers, *Aonidiella aurantii* (Maskell), on the upper surfaces of citrus leaves with geotaxis behavioural response. On the other hand, the male crawler of Florida red scale (*Chrysomphalus ficus* Ashmead) was associated with a positive response to light direction (Beardsley and Gonzalez, 1975).

Conclusions

This study confirmed that white mango scale is present in Ethiopia throughout the year, with its population fluctuation being highly influenced by the amount of rainfall. It was observed that white mango scale attained population peaks at temperatures as high as 31 to 35°C with the scales being more concentrated on the upper leaf surfaces and the population is male-biased.

RECOMMENDATIONS

The best period for application of insecticide for the control of white mango scale is from April to June, when white mango scales in general and the vulnerable crawlers in particular are the most abundant in Western Ethiopia.

To better understand the optimum temperature range for white mango scale, controlled experiments, under laboratory conditions, may be required.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Influence of markets on fish farming adoption: The case of Chingale in Malawi

Regson Chaweza[1*] and Joseph Nagoli[2]

[1]Department of Economics, Faculty of Social Sciences, University of Malawi, Chancellor College, Zomba, Malawi
[2] WorldFish Malawi Office, National Aquaculture Center, Domasi, P.O. Box 229, Zomba, Malawi.

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The challenges constraining the contribution of aquaculture to food security and household incomes have mostly been documented as low utilization of improved feed, lack of improved seed and unfriendly financing services. This study looked at the influence of markets including market information on adopting aquaculture technologies. Data were collected from 110 farmers in Zomba District, Malawi. Using a logit model, farmers' adoption of new technologies was mainly influenced by market information, level of education and number of ponds owned by a farmer. Therefore, linking rural farmers to urban markets can improve the adoption of fish farming technologies.

Key words: Adoption, aquaculture, livelihoods, marketing access.

INTRODUCTION

The productivity of artisanal and commercial fishing on major lakes and river systems in Malawi has declined by more than 37% over the period of 1974 to 2004 (World Bank, 2004) due to overfishing and poor conservation practices. This decline, coupled with rapid population growth in Malawi has reduced the per capita consumption from 16 - 18 kg/year in the 1980s (Allison, 2011) to about 8.12 kg/year in 2014, (GOM, 2015). The recommended per capita consumption by FAO is 15 kg/capita/year (FAO, 2014). With no significant gains in fish production expected from capture fisheries to sustain the current per capita fish supply, aquaculture provides a viable option. Small-scale pond aquaculture in particular can improve both productivity and cash flows with little or no external input (Sungas and Manus, 2014).

However, as technologies for aquaculture development improve, determinants of their adoption need to be investigated. In general, the adoption of agricultural innovations are determined by farm size, capacity to bear risks (Sungas and Manus, 2014), human capital, labor availability tenure systems, access to credit and commodity markets (Maina et al., 2014). Ndah et al. (2011), Farnworth et al. (2015) and Olaoye et al. (2016) found that the adoption of agricultural fish farming practices are directly linked to access to agricultural markets, gender, improvements in rural infrastructure and marketing institutions. These determinants are essential for the transformation of subsistence-oriented smallholder agriculture to commercially orientated agriculture. Particularly, improved access to agricultural input and

*Corresponding author. E-mail: rchaweza@cc.ac.mw.

output markets is important for increased productivity. Well-functioning markets transmit price signals, which allow changes in demand to be met by supply. In so doing, markets support flow of goods from areas of surplus to areas of deficit to ensure that food is efficiently distributed (Hebebrand and Wedding, 2010).

Aquaculture production in Chingale, west of Zomba in Malawi, has been facilitated and supported by several partners including Non-Governmental Organizations (NGOs) and the Malawian Department of Fisheries. Other notable organizations assisting the development of aquaculture in Chingale are World Vision and WorldFish. As such, pond aquaculture in Chingale area has grown from about 300 farmers in the 1980s to over 1000 farmers in 2009 (Nagoli et al., 2009). The main driver to this growth is the perennial water supply from the Zomba Mountain providing fish farming area of about 200 km^2, with an estimated population of 30,000 (Kambewa et al., 2009). With the water flowing by gravity, pond aquaculture is well integrated with irrigation farming through diversion canals from main streams and rivers. Water from the canals is used both for filling and refilling of fish ponds and irrigating crops. Irrigation is practiced on a wider scale with the following major crops: maize, beans and vegetables for both subsistence and commercial purposes (Kambewa et al., 2009).

Despite aquaculture's growth in numbers of ponds and area, productivity has remained low. The fish pond productivity in Chingale is about one tone per hectare accounting for an annual production of about 40 tones. Additionally, the fish produced is sold locally at about 50% of the retail price in urban and peril-urban markets. The main challenges to low production are said to be low utilization of improved feed, lack of improved seed and financing to access these inputs (Jatto et al., 2013). This study analyzed the influence of markets on the adoption of new fish farming technologies by Chingale fish farmers. The hypothesis being, farmers will adopt improved technologies when they are assured of markets and have information regarding product pricing and marketing costs.

MATERIALS AND METHODS

Study design

A market study used a value chain approach. The idea for a value chain approach was to identify various channels through which fish move from producers to consumers, with the aim of identifying stakeholders, activities, costs incurred along the chain and respective returns. Data was collected using individual questionnaires which were administered to randomly selected farmers (n=110) and fish sellers (n= 80), where 53.6% were males and 46.4 % were females. The data was collected on cost of production from primary producers, transportation cost and available markets in urban centers of Zomba and Blantyre. The respondents were sampled across the various clubs under Chingale Integrated Agriculture Aquaculture Farmers Association (CIAAFA), enabling the survey to include both old (n=70) and newly (n=40) established farmers. The rule of thumb for determining sample size proposes that sample sizes larger than 30 are appropriate for most research (Hogg et al., 2015) and this justified the sample size.

Data analysis

Using logit and linear probabilities, seven independent variables that influence farmers to adopt the farming of tilapia (*Oreochromis shiranus)* and factors that influence these farmers to have more fish ponds were analyzed.

The logit model:

1. $$adopt = f(sex, educn, extmkt, pondreq, age, mar\_stat,)$$

The linear probability model of number of ponds required carries the following variables

2. $$Pond\_reqd = (sex, educn, age, mar\_stat, adopt, farmYrs)$$

Where the variables are defined as: adopt = adoption of *Oreochromis shiranus;* sex = male, female; educn = highest level of education of a respondent; pond_reqd= ability to increase the number of ponds; age = age of the respondent; mar_stat = marital status of the respondent (married or not married); farm years = number of years the farmer has been involved in fish farming
extmkt = external markets, that is, markets outside Chingale area.

From market analysis, recommendations for an optimal market channel that can increase income by reducing costs of various participants for Chingale farmers were developed.

RESULTS AND DISCUSSION

Fish farming and marketing in Chingale

Table 1 gives descriptive statistics of fish farmers in Chingale. The table shows that fish farmers in Chingale have an average age of 47 ranging from 21 to 86 years. This is also reflected with fish farming experience where the maximum number of years is 30 and minimum is 1 year, giving an indication that fish farming has been practiced in Chingale for a long time. Chingale fish farmers that have at least attained primary education were 67%. The table also indicates that 83% of the respondents were married, with 51% being males.

In a study by Oyieng et al. (2013), fish farming was dominated by male farmers (Meru, 71%: Nkubu, 79%; Mburigini, 80%). This is because most of the activities in pond making are strenuous. However, the Chingale statistics show that there is a balance between male and female participants. Apart from pond construction, fish pond management activities such as weed clearing, feeding and predation control are equally shared between

Table 1. Description of Chingale fish farmers.

Variable	Mean	Minimum	Maximum
Age	46.93	21	86
Gender*	0.508	-	-
Education*	0.667	-	-
Farming Experience	6.34	1	30
Marital Status*	0.828	-	-

For all categorical variables (*), mean is the proportion of those respondents with dummy variable 1.

Table 2. Fish farming by species.

Species	Frequency	Percentage
O. shiranus (old)	52	47.3
O. shiranus (new)	34	30.9
O. karongae	15	13.6
Tilapia rendalli	87	79.1

men and women. In fact, women dominated in the feeding of fish in ponds.

In the study, about 79% of the respondents indicated that they mostly kept *Tilapia rendalli*, 47% kept the unimproved[1] *Oreochromis shiranus*, 30% kept the new strain[2] of *O. shiranus* and 14% kept *O. karongae*, this is clearly indicated in Table 2. The two species (*T. rendalli* and *O. shiranus*) are very popular in the area mostly because they have been locally known by the farmers for a long time than the other species that were recently introduced. *T. rendalli* was mostly favoured because it mostly feed on phytoplankton with little supplementary feed.

As observed by Oyieng et al. (2013), *T. rendalli* responds well to fertilized ponds. The other perceived advantage of *T. rendalli* by farmers was that it is fleshy and grows faster than *O. shiranus*. While many farmers would want to grow *O. karongae* which is commonly known as *chambo*, the premium fish for Malawians, seed supply was the biggest challenge. It was mentioned by farmers that *O. karongae* has low fecundity and does not reproduce during cold months.

The primary objective of fish farming in Chingale is to produce fish for food. The study found that about 84% of the respondents allocated some of their harvest to home consumption and the same percentage of respondents also produced fish for sell (Figure 1). Even those that sold their fish, usually smaller fish were used for home consumption. About 64% of the respondents gave away fish for free as an enhancement to social relationships. In Chingale, about 85% of the respondents had ever sold fish after harvesting. It was found that 74% of those that sold fish had done so within the village mostly at the village markets. It was also observed that 18% of the farmers preferred selling at the pond site soon after harvesting and as low as 4% of farmers preferred urban markets.

Fish sold at the pond site and village markets often fetched lower prices than the fish that was sold at urban markets. Both pond sale and village market selling points provide less profit margins to the farmers as the customers prices haggle and take into consideration family or relations ties. However, the fact that few farmers sold at urban markets at higher prices contradicts with the conventional thinking that farmers like any other producers would respond to market demand. Ideally it was expected that more farmers would sell their fish at the urban market where prices were higher. However, a number of factors affected the choice of a market where producers would sell their fish.

The main constraining factor was limited access to the markets by the farmers because of high transport costs, lack of proper handling and storage facilities given the perishable nature of fish with respect to distance and road conditions. Transportation to various markets was mostly done on bicycles (42%), seconded by head-loading (34%). Those that have ever sold fish in urban areas transported their fish with subsidies from NGOs such as C-Fish project[3]. This finding indicates that marketing is a broader concept that should include the market infrastructure itself, transportation to markets and storage facilities.

A marketing strategy of farmed from rural smallholder farmers must be looked at keenly because the fish value chain is generally short. The current production level (40 tones) does not provide enough incentives for targeting urban markets. This production level is mostly aimed at

[1] Unimproved tilapia in this case was the wild species that had not undergone genetic improve through selective breeding.

[2] The new *O. shiranus* is an improved strain (fourth generation) from the national selective fish breeding program that has shown a 30% growth improvement over the wild strain.

[3] Captive Fisheries for Income and Strengthened Households, a USAID funded project that promoted commercialization of smallholder pond fish farming.

Table 3. Adopt and pond requirement results.

Variable	Marginal effects (dependent: adopt)		LPM (dependent: pond required)	
	dy/dx	p>|z|	Coefficient	p>|t|
Sex	0.048	0.962	0.467	0.206
Educn	-0.125	0.089*	0.081	0.854
Ext mkt	0.143	0.078*		
Pond no.	0.057	0.059*		
Age	-0.015	0.664	-0.026	0.043*
Mar_stat	0.530	0.005**	0.566	0.633
Adopt			0.101	0.077*
Farm Yrs			0.002	0.067*

*, **, *** denotes significance at 10, 5 and 1 levels, respectively.

providing cheaper animal protein. As such, only communities in Chingale benefit from aquaculture production by accessing fish at low prices. It was observed from this study that food security benefits of having fish ponds within the communities spread beyond the fish farming households but the fish farmer loses on income by selling fish at low prices within the village markets or at pond sites. This result was also found by Salau et al. (2014) and Jatto et al. (2013). However, subsistence aquaculture on one hand will neither address the poverty that impacts rural farmers nor meet the food and nutritional security needs the Malawian population. On the other hand, producing fish for markets would increase production and productivity that will increase household incomes which may result in accessibility to other protein sources apart from fish by rural poor farmers.

Furthermore, the study observed that many farmers in Chingale sold fish once a year (52%), another 28% of the respondents indicated that they sold twice a year. These results indicate that most of the fish farmers kept fish in ponds for more than the recommended time of six months (Malawi Gold Standard). The study observed that 78% of the respondents sold their fish individually without involving other farmers or consulting them. However, 6 and 3% sold fish as a group or in consultation with other farmers, respectively. This is an indication that there is no coordination in marketing of fish among the farmers in Chingale.

The lack of coordination (78.2%) means that the farmers do not gain the economies of scale of selling whereby they would present a common front of prices and supply to the market for a long time there by putting up a brand of their own.

Mode of payment for fish sales

The study showed that 84% of the farmers preferred receiving payment in cash as opposed to payment by credit (19%). This is supported by the indication that about 66% of the farmers sold fish to non-regular customers who were considered to have no ties with the sellers. On the other hand, 17% of the farmers sold to regular customers (those that the farmers knew). This figure is highly correlated to figures of those that sold on the pond site (18%) and those that sold on credit (19%). This implies that farmers that sell on pond site do not only sell at low prices but also offer their fish on credit. The lack of cash payment basis on the pond or home market may not be surprising. Even as early as in the 1990s, Brummet (1995) observed that village customers, especially during hungry seasons lack cash income to purchase food and relied on traditional or barter systems to get them through the seasons. This category of village population comprises the major part of the fish customers.

Adoption of technologies

Using a logit model (marginal effect analysis), level of education, information on the external markets, number of ponds required, and marital status significantly affected adoption of new technologies (Table 3). Surprisingly, education was estimated to decrease probability of adoption by 13% points. This can be explained by the fact that educated people leave farming (in the village) in search of employment or other businesses in urban areas. This is unlike cases where fish farming isorganized in unions and have well established markets. The results also show that age of the respondent reduces the probability of adopting by 0.2 percent points. The older the person, the less likelihood of adopting fish farming. This is probably due to the fact that pond construction and maintenance are energy, money, and time demanding.

The limited availability of external market information

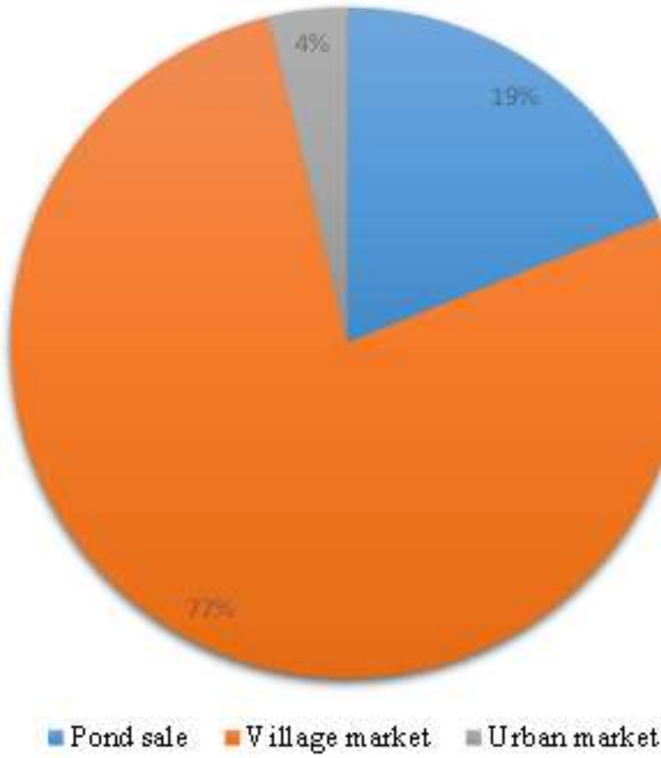

Figure 1. Chingale farmers' selling points.

reduced the probability of adoption by 14%. This makes both theoretical and practical sense. The accessibility to external markets or external market information would be an incentive for adopting the use of *O. shiranus* (Hebebrand and Wedding, 2010). The ability to increase the number of ponds increased the probability of adopting fish farming technologies by 6%. This is significant at 10% level. On the other hand, only three variables were significant under factors that influenced requirement of more ponds over time, using linear probability model (LPM). These variables are age at which one adopts; farm size; and number of years in farming fish. The more a farmer adopts new technologies, the more he/she requires more ponds because of the speculation to attain higher margins. When a farmer attains more years in fish farming, he/she is likely to attain more ponds as the need for additional capital costs decline through the use of already acquired equipment and knowledge.

Production and marketing constraints

Farmers in Chingale have shown in this study that they experienced a number of marketing problems that have been indicated in Figure 2. It has been indicated that lack of good markets which would offer higher and competitive prices was a major problem as indicated by the 73% of the respondents. Transport was another problem that was raised by 40% of the respondents. It was expensive to access outside markets in Chingale mainly because of poor road infrastructure that made transport costs high. Lack of market information (26%) was also identified as a major problem as farmers did not have information on what was required at the urban markets in terms of prices offered, fish species and sizes required. A noticeable production constraint that is cited in literature is the lack of credit (DOF, 2005). Findings in Chingale showed that Fishermen, traders and intermediaries did not have easy access to bank and microfinance operators due to too much official paperwork and collateral arrangements.

Apart from production constraints, farmers faced problems in disposing their output at a higher margin. Some of these limitations were related to how urban markets were structured. A marketing study of the urban markets showed a long chain of middlemen that affected buying price. The markets were heavily controlled by unscrupulous middlemen that limited entry by producers or any new middlemen. It was also observed that urban lucrative markets especially in Zomba and Blantyre had size preference for fish. Premium prices were offered to sizes ranging from 150 to 250 g. On the contrary, the farmers' production sizes were between 40 and 75 g. The

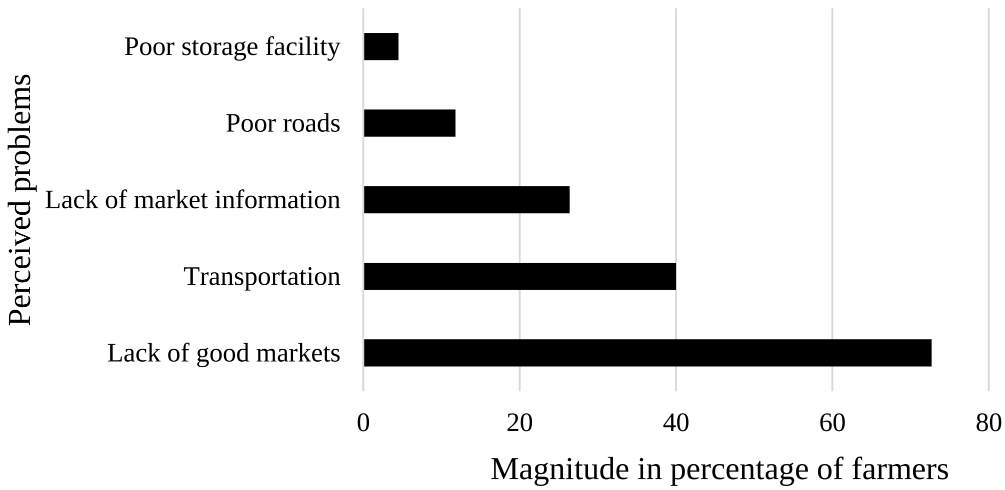

Figure 2. Problems associated with pond fish farming.

main fish marketing by the farmers in Chingale was where adverts were made before harvesting to employees from organizations in the Zomba urban. This marketing arrangement is termed “institutional arranged markets”. This market had a wide range of size preferences. It also had the highest preference for pond fish as compared to fish from natural water.

CONCLUSION AND RECOMMENDATIONS

Although, Chingale is a success story for small-scale fish farming in Malawi, its success is not built on market forces hence the low productivity. The adoption of fish farming in Chingale is supported and subsidized by NGOs and projects. This poses a serious sustainability issues once life-spans of NGO projects end. Fish production from Chingale is currently very low for urban or peri-urban markets. In the current situation where farmers do not have much to offer, marketing and production linkages need to be promoted if farmers are to be motivated by higher fish prices in urban markets. Better technologies that ensure high production and better fish sizes preferred in lucrative markets should therefore be given priority. Work on the dissemination of new *O. shiranus* strain is therefore a right step towards lucrative market breakthroughs. Similarly, the current marketing system through arranged institutional market is just ideal for the farmers. There are clubs and an association, the Chingale Integrated Aquaculture-Agriculture Farmers’ Association (CIAAFA) which can be organized to act as marketing organizations in the form of a cooperative. The CIAAFA will need to strengthen linkages between improved production practices and other institutional arrangements that link farmers and markets in appropriate market chains.

As much as the study indicates that most farmers sold/harvested once a year, it would be recommended that farmers produce at least twice a year to take advantage of the availability of peri-urban market. Furthermore, individual marketing of fish should be discouraged for group marketing in order to enjoy economies of scale especially on transport (Salau et al, 2014). In this case, farmers ought to work in groups where fish stocking and harvesting are done at the same time within a group. The group stocking and harvesting should then be spread across the year to ensure uniform supply. Different groups would stock at different times to avoid flooding the fish market which result in low prices when the demand is low. However, poor land transport links and means of transportation between Chingale and urban markets as a result of poor road infrastructure is currently the major impediment to aquaculture growth in Chingale. It is therefore recommended that government and non-governmental organizations should play an active role in the improvement of both the vertical and horizontal dimensions of the fish marketing chain in Chingale for profitable fish farming.

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CONFLICT OF INTERESTS

The authors declare that there is no conflict of interest.

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