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INFLUENCE OF FLOODING PATTERN ON WEED SPECIES DIVERSITY AND MAIZE YIELD IN FLOOD RECESSION FARMING IN THE OKAVANGO DELTA, NORTHERN BOTSWANA.

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ABSTRACT

Flood recession farming, locally known as *molapo* farming is a significant livelihood for the riparian communities that live along the Okavango Delta. However, this system is threatened by variability in flooding patterns which influence weed diversity and crop yield. This study aimed to determine the influence of flood patterns on weed species diversity and maize yield in *molapo* farming. Vegetation sampling was conducted in twelve fields across two flooding patterns: lake flats and saucer-shaped. A line transect with squared-meter quadrats spaced 10 meters apart was used to sample weeds. Each field's center row had four square-meter quadrats that were systematically spaced five meters apart to collect samples of weed and crop biomass. The weed and maize biomass in each quadrat were then oven-dried for 48 hours at 80°C. The Shannon diversity index and species richness for each flooding pattern were determined using Paleontological Statistics version 3.12. The most abundant weed species in the saucer-shaped flooding pattern was *Cyperus esculentus* with a density of 110,967.74 while in the lake flats, *Sida cordifolia* was the most abundant, with a density of 144,459.46 individuals ha^{-1}. The weed species diversity and evenness of weed species were 2.60 and 0.67 in saucer-shaped and 2.13 and 0.50 in lake flat flooding pattern, respectively. Lake flats produced two times higher maize biomass than saucer-shaped flooding pattern. These findings indicate that flooding patterns influenced weed species diversity, which in turn affect maize yield. Further, they imply that flood dynamics and weed species diversity should be considered when developing weed management strategies to improve maize yield in flood recession farming.

Keywords: *Molapo* farming, flood dynamics, diversity indices, productivity, biomass.

INTRODUCTION

Climate change is one of the most remarkable environmental challenges of the present time, with its multidimensional impacts cutting across diverse sectors, posing a threat to environmental sustainability, socio-economic stability, and agricultural productivity of many countries (Makondo & Thomas, 2018; Nyadzi *et al*., 2021). Among these, rainfed agriculture, particularly in Sub-Saharan Africa (SSA), appears to be one of the most directly and adversely affected systems (Nkomwa *et al*., 2013). This system is excessively vulnerable to climate change due to its heavy dependence on increasingly irregular rainfall and limited adaptive capacity (Leal Filho *et al*., 2025; Sinore & Wang, 2025). Further, the SSA is prone to frequent drought, irregular rainfall and extreme temperatures (Molla *et al*., 2023), resulting in low crop yields and food insecurity among smallholder farmers (Demissie *et al*., 2021). Notwithstanding, agriculture continues to play a critical role in the livelihoods of SSA, with nearly two-thirds of the people depending on it as their primary source of income and sustenance (Kamwamba-Mtethiwa, 2016; Li *et al*., 2021). Focusing specifically on Botswana, UNDP (2012) opined that more than 70 % of the population lives in rural areas, where the majority, approximately 70 %, depend on subsistence agriculture as their primary means of livelihood.

In view of the constraints limiting rainfed agriculture in SSA, flood recession has emerged as a viable alternative farming system that can enhance food security and rural livelihood. This type of farming system depends on residual soil moisture and soil nutrients deposited on the floodplains by receding floodwater (Balana *et al*., 2019). Therefore, flood recession farming serves as a key livelihood for many of the farming communities that live in proximity to the floodplains and wetlands (Bruckmann *et al*., 2025). It is estimated that, of the 27.5 million hectares of flood-based farming systems in SSA, three million hectares are under flood recession farming (Kool *et al*., 2018), further buttressing the significance of the farming in cushioning against food insecurity, hunger and the impacts of climate change (Fwaya *et al*., 2025). Flood recession farming is practised by a variety of African countries that reside near rivers, lakes and wetlands (Mabe *et al*., 2025). For example, it is practiced along the Niger Basin and Senegal River, Lake Chad, Sudd in Sudan, Zambezi Valley and the Okavango Delta (Barbier *et al*., 2011; Dieye *et al*., 2020).

In Botswana, flood recession farming is locally called *molapo* farming and is commonly practised along the floodplains of the Okavango Delta and in some instances, crops are planted on an "island" utilising a raised water table (Magole & Thapelo, 2005; Motsumi *et al*., 2012). The staple grain, maize, is cultivated in almost all *molapo* fields alongside crops such as beans, melons, squash and sorghum (Kashe *et al*., 2015). Crops are planted during the summer months, around September, in nutrient-rich moist soils deposited by receding floodwaters; however, the timing of sowing varies across locations and from year to year (Nthaba *et al*., 2018). *Molapo* farming is reported to produce substantially higher yields than the traditional dryland farming. For example, Kashe *et al*. (2015) found maize grain yield in *molapo* farming (3.4 t ha^{-1}) to be significantly greater than in dryland farming (< 1 t ha^{-1}). The high yield was attributed to nutrient rich moist soil in the floodplains. However, this conducive environment also favors the rapid proliferation and establishment of weed species. The weeds compete with crops for nutrients, light and water leading to a reduction in yield if not controlled (Zingsheim & Döring, 2024). Globally, weeds are notorious for causing more crop yield reduction than any other pest (Oerke, 2006).

The influence of flooding patterns on weed species diversity under *molapo* farming has not been extensively investigated, despite the fact that *molapo* farming in the Okavango Delta is practised across diverse flooding patterns such as saucer shape and lake flats. Furthermore, the composition and diversity of weed species are not uniform but are driven by ecological and environmental gradients, including moisture regimes induced by varying flood patterns. Although it is acknowledged that flood pattern dynamics play a significant role in shaping *molapo* farming, there is still a knowledge gap on how variations in flooding patterns affect weed species composition and diversity in this farming system. Therefore, a primary question is how does variability in flooding pattern influence weed species composition and diversity in *molapo* farming? Previous studies on *molapo* farming investigated the yield of maize (Kashe *et al*., 2015) and the influence of frequency of cultivation on weed species composition (Nthaba *et al*., 2018). However, none of these studies explored the effect of variability in flooding patterns on weed species diversity in *molapo* farming.

Understanding how different flood patterns affect weed communities would guide the development of weed management strategies, minimize the negative impact of weeds, and enhance the sustainability of *molapo* farming practices. Additionally, this insight could inform land-use planning and coping mechanism for smallholder farmers who depend on *molapo* farming. Thus, a study was conducted to determine the influence of variability in flooding pattern on weed species diversity in *molapo* farming. Specifically, the study addressed the following research questions: (a) How does variability in flooding pattern influence the composition, species richness, diversity and evenness of weed species in *molapo* farming? (b) How does variability in flooding pattern influence maize yield in *molapo* farming? (c) How do weed species affect maize yield in different flooding pattern?

MATERIAL AND METHODS

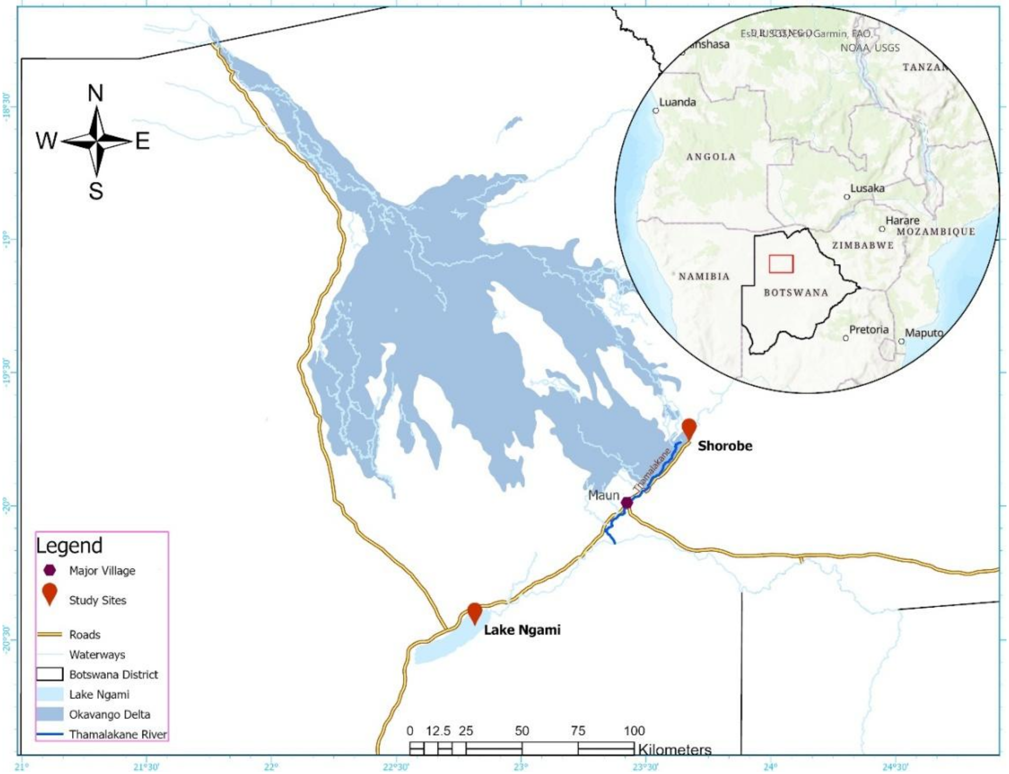
Study area

The study was carried out during the 2016–2017 cropping season in Lake Ngami and the southern edges of the Okavango Delta, along the floodplains of the Thamalakane River in Shorobe (Nthaba, 2019). The study sites are depicted in (Fig. 1). There are three primary hydrological zones in the Okavango Delta: seasonally flooded floodplains, occasionally flooded floodplains, and permanent wetlands (Gumbricht *et al*., 2024). Occasionally flooded floodplains are located further downstream on the periphery, and are only inundated during years of heavy rainfall and flooding. In contrast, the panhandle and upper Delta are home to permanent wetlands because they are perennially flooded. Milzow *et al*. (2010) defined seasonally flooded floodplains (low-lying primary floodplains) as those that experience flooding four to eight months out of the year under typical flooding conditions. The Okavango River releases over 10 km^3 of water into the Delta, which is supplemented by 6 km^3 of local rainfall. This water supply supports up to 8000 km^2 of seasonal wetlands and roughly 2500 km^2 of permanent wetlands (McCarthy, 2005). For the communities that live inside the Delta's boundaries, the seasonal wetlands provide a source of income. Among these is *molapo* farming, which is mostly carried out on the Okavango Delta's seasonal flood plains (Nthaba *et al*., 2018).

Selection of *molapo* fields

The sites were selected on the basis of the variation in flooding patterns. Lake flats and saucer-shape flooding patterns were selected in Lake Ngami and Shorobe, respectively. Out of the 24 *molapo* fields, 12 fields were chosen for each flooding pattern. At 19 ° 45′ 43″ S, 23° 40′ 37″ E, Shorobe is situated 30 km east of Maun in the eastern portion of the Okavango Delta. Located northwest of the village, the *molapo* fields are flooded by the Gomoti and Santantadibe Rivers as well as backflow from the Thamalakane River (Nthaba *et al*., 2018; Nthaba, 2019). The Shorobe *molapo* fields are primarily located on islands and flood in a saucer-like configuration. The main river systems' backflow or spillover water provides them with moisture (Bendsen, 2002). The flood usually reaches its peak in this area in August or September and starts to recede by the end of October. An extension of the Kunyere Fault, located at 20 ° 28′ 57″ S, 22 ° 46′ 21″ E, forms the northeast portion of Lake Ngami, which is surrounded to the southeast by a short escarpment of Karoo and Ghanzi formation rocks (Nthaba *et al*., 2018; Nthaba, 2019). The Kunyere and Nhabe rivers pump floodwaters into the lake, with October often seeing the greatest extent of flooding (Nthaba, 2019). Farming in *molapo* was mostly done in the Lake flats.

Fig. 1: Map of the Okavango Delta showing the study sites



Vegetation sampling

During the rainy season, when the majority of plants were in blossom for simple identification, weed flora was surveyed in saucer-shaped and lake flat flooding patterns. In each flooding pattern, twelve fields were sampled, giving a total of twenty-four fields. According to Morgan (1998), line transects were placed from the lower to upper gradient in each *molapo* field, parallel to one another and 20 meters apart. After that, weed species, abundance, and frequency of occurrence were noted in square-meter quadrats spaced 10 meters apart along each transect (Morgan, 1998). Transect and quadrat placement was done using gradient-oriented transects and a modified stratified sampling technique taken from Gillison & Brewer (1985). The number of quadrats studied varied from site to site because to the tiny area (often less than 0.5 hectare) and variable shape of *molapo* fields. For example, 74 quadrats were examined under the lake flats and 93 under the saucer form (Nthaba, 2019). All species were identified in each quadrat, and the number of individuals was noted. The plant species were identified to species level using the nomenclature followed by Germishuizen & Meyer (2007). For identification, the unidentified plants were mounted, compressed, and transported to the Peter Smith University of Botswana Herbarium (PSUB).

To ascertain the impact of weeds on maize yield, two weed-free and two weedy fields were chosen at random for biomass sampling at both locations. For the investigation of crop and weed biomass, four 1 m^2 quadrats were methodically sampled at 5 m intervals along the middle row in each field (Shemdoe *et al*., 2008). In accordance with Gaskin *et al.* (2015), maize plants were sampled within the quadrat for biomass analysis. Weed species were identified, noted, and collected for biomass analysis within the same quadrat. At the soil surface, each species was cut (Moore *et al*., 1994). Following that, the weeds were placed in oven proof envelopes. Biomass from weeds and maize was oven-dried for 48 hours at 80 °C. After that, the biomass from dry weeds and maize was measured and converted to kg ha^{-1} and t ha^{-1}, respectively.

Data analysis

The Shannon diversity index and species richness for each flooding pattern were determined using Paleontological Statistics (PAST) version 3.12. An independent t-test was used to evaluate the effect of weed biomass on maize yield. The mean differences were tested at $p \leq 0.05$. The importance of a significant finding was determined using the effect sizes which provided a measure of the magnitude of the difference. Mean differences were also explored between flooding pattern using the Whitney U test (Shorobe and Lake Ngami). The statistical analysis was performed using SPSS version 16.

RESULTS

Species richness and diversity across the flooding patterns

The most dominant weed species across the flooding patterns were the broadleaved weeds (11) followed by six (6) grasses and four (4) sedges (Table 1). Under saucer-shaped, *Cyperus esculentus* and *Bulbostylis hispidula* had the highest density. Under the lake flats, weed species with the highest density were *Sida alba*, *Ipomea sinensis* and *Panicum repens* Saucer-shaped flooding pattern recorded a large number of individual species with species richness of 20 compared with the lake flats (17). Furthermore, it recorded higher diversity (2.60) and eveness (0.67) than lake flats (2.13 and 0.50) (Table 2).

Table 1: Weed species density (Individuals ha-1) for each flood recession type. The growth forms are: B = broad leaves, G = Grasses and S = Sedges. NA = shows that the weed species was not present in the flood recession type

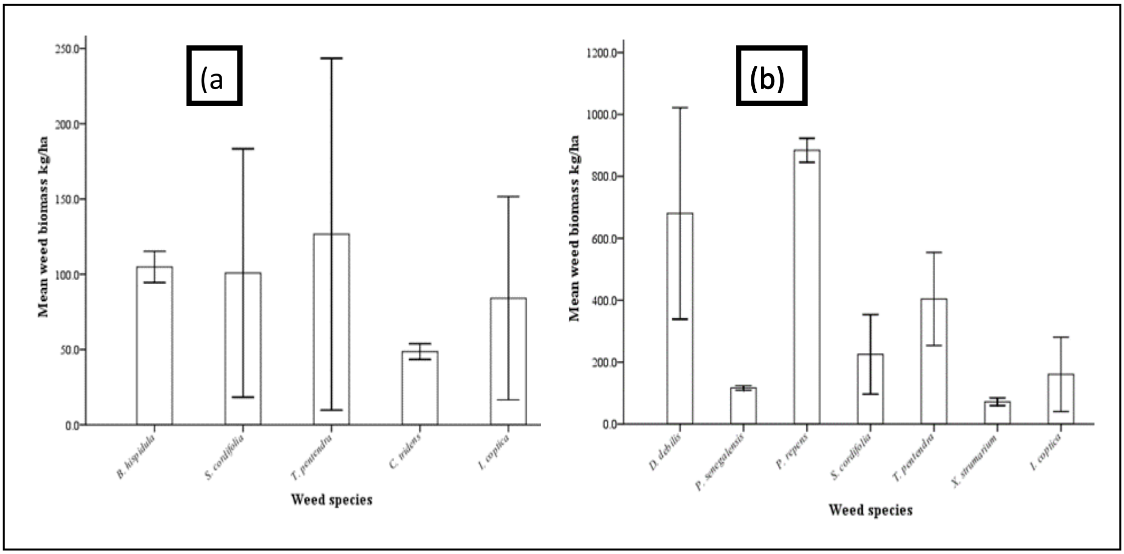
Species		Saucer Shaped	Lake Flats
	Growth Form	Density (Individuals /ha)	Density (Individuals /ha)
Cyperus esculentus	S	110967.74	405.41
Bulbostylis hispidula	S	63763.44	2837.84
Corchorus tridens	B	52903.23	8513.51
Ipomea coptica	B	48602.15	3243.24
Cynodon dactylon	G	46881.72	6891.89
Sida cordifolia	B	41290.32	144459.46

Triumfetta pentandra	B	37526.88	18243.24
Cyperus articulatus	S	37204.30	N/A
Digitaria debilis	G	36666.67	10270.27
Heliotropium ovalifolium	B	31935.48	4189.19
Panicum coloratum	G	23978.49	N/A
Hibiscus cannabinus	B	10322.58	16756.76
Urochloa mosambicensis	G	9139.78	N/A
Panicum repens	G	7634.41	23648.65
Pavonia senegalensis	B	7311.83	14324.32
Glinus oppositifolius	B	6881.72	6351.35
Echinochloa colona	G	6559.14	N/A
Xanthium strumarium	B	4731.18	17027.03
Ipomea sinensis	B	1612.90	29864.86
Sida alba	B	860.22	50810.81
Cyperus longus	S	N/A	6621.62

Table 2: Weed diversity indexes for different flooding patterns in Molapo farming in the Okavango Delta

Diversity index	Saucer Shaped	Lake flats
Shannon_H	2.595	2.131
Evenness	0.670	0.496
Richness	20	17

Fig. 2: Mean biomass in kg ha^{-1} of weed species in saucer shape (a) and Lake flats (b).



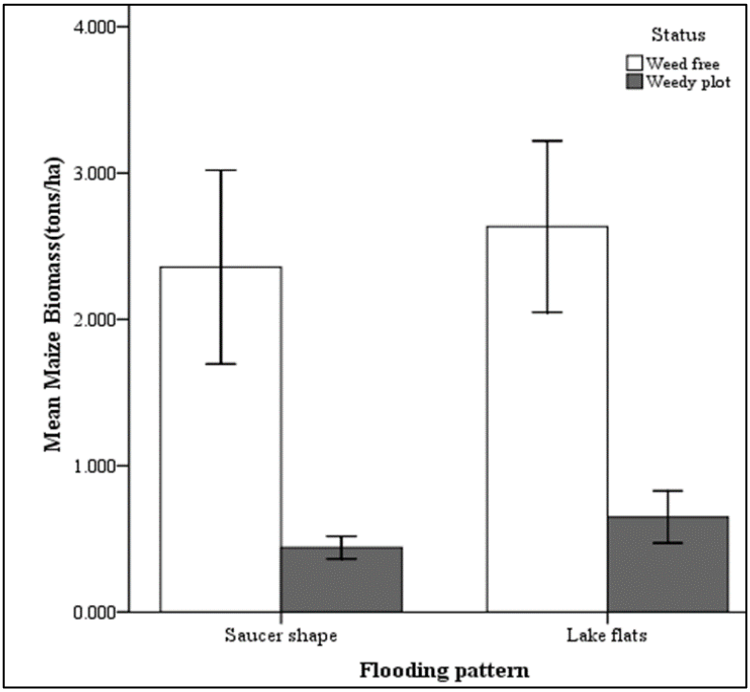
Weed biomass in different flooding patterns

In the saucer-shaped flooding pattern, *Sida cordifolia* produced the highest biomass (135.8 kg ha^{-1}) followed by *Triumfetta. pentandra* (126.6 kg ha^{-1}) and *Ipomea coptica* (84.1 kg ha^{-1}). *Corchorus tridens* and *Bulbostylis hispidula* produced the least biomass of less than 50 kg ha^{-1} (Fig. 2a). In the lake flats, the members of the poaceae family were mostly dominating in terms of biomass production. *Panicum repens* produced the highest weed biomass followed by *Digitaria debelis*. Among the broad-leaved weeds, *Triumfetta pentandra* and *Sida cordifolia* produced 404 and 225.3 kg ha^{1} of biomass, respectively. *Pavonia senegalensis, Ipomea coptica* and *Xanthium strumarium* produced the least biomass of less than 170 kg ha^{-1}(Fig. 2b).

Maize and weed biomass in different flooding patterns

Weed biomass had a significant effect ($t\ (14) = 7.553$, $p \leq 0.001$) on maize biomass. Maize under weed-free conditions produced more biomass than under weedy conditions. Flooding pattern did not have a significant effect on maize biomass under weed-free contions ($p \geq 0.05$). However, flooding pattern had significant effect ($p \leq 0.05$) on maize biomass under weedy conditions. Lake flats produced a significantly higher maize biomass (0.80 t ha^{-1}) than saucer-shaped type (had 0.41 t ha^{-1}) (Fig. 3).

Fig. 2: Mean Maize biomass under weed-free and weedy conditions in different flooding pattern



DISCUSSION

The study found that the saucer-shaped flooding pattern facilitated greater richness, evenness, and diversity of weed species compared to lake flats, suggesting that flooding patterns influence weed species diversity. These findings corroborates the explanation by Tsheboeng *et al.* (2014) that variation in flooding patterns shape the plant species composition and diversity. Further, the revelation aligns with the assertion by Middleton (2009) that projected hydrological changes driven by climate change are likely to influence species composition and distribution. The contrasting trend was observed for maize biomass, which was notably greater in lake flats in comparison to the saucer-shaped flooding pattern. This finding aligns with those of Kashe *et al.* (2015) in the Okavango Delta, who observed that maize grain yield and plant height were significantly greater at Lake Ngami (lake flat) compared to Matsaudi (saucer-shaped). This can be linked to the gradual rate of flood recession resulting from the gentle and flat topography at Lake Ngami. The late planting of crops aligned with the rainfall in November, resulting in consistent and ample soil moisture. This condition positively influenced the performance of maize in the lake flat compared to the saucer-shaped flooding pattern (Kashe *et al.* 2015). In a similar study in Ghana, Mabe (2025) found that rice yield under flood recession farming (3.53 Mt/ha) was significantly higher than in conventional rainfed farming system (1.96 Mt/ha). In another cereal crop, Sidibé *et al.* (2016) reported sorghum (*Sorghum bicolor* (L.) Moench) yield of 2.5 t/ha in flood recession farming compared with less than 1 t/ha under rainfed conditions. The higher yield observed under flood recession farming are largely due to abundant soil moisture and nutrients that are deposited on the flood plain by receding flood water (Traore *et al*., 2020; Smits *et al*., 2024).

Furthermore, yield losses primarily result from significant weed pressure and substantial weed biomass (Yeganehpoor *et al*., 2014). This was largely due to a negative correlation between weed biomass and yield components as was observed in others studies (Yagenehpoor *et al*., 2014; Mahmood *et al*., 2015). In this study, under both saucer-shape and the Lake flats flooding patterns, maize under weed-free conditions was free from any competition for resources and thus produced significantly high biomass than under weedy conditions. Presence of weeds such as*Panicum repens, Digitaria debilis, Sida cordifolia, Triumfetta pentandra and Ipomea coptica* were largely responsible for 73.2 % reduction on average in maize biomass under both Lake flats and Saucer shaped flooding patterns. It suffices to suggest that heavy weed infestation was therefore largely responsible for poor maize biomass production under weedy conditions. Weeds decreases water and nitrogen use efficiency (Fanadzo *et al*., 2007), the two most essential resources for high yields (Thomson *et al*., 2000). In addition, these interactions are influenced by hydrological dynamics, as flooding patterns and duration can shape weed species diversity and biomass, thus affecting both the magnitude of weed infestation and crop yield.

The diversity and eveness of the weed species differed between the flooding patterns, with the saucer-shaped type recording higher values than lake flats for these diversity indices. The difference in flooding patterns may have contributed to this variation. There was a great variety of broadleaf weeds under both saucer-shaped and Lake flats flooding pattern. However, *Corchorus tridens* was the most abundant weed under saucer shaped type followed by *Ipomea coptica* and *Sida cordifolia*. These species are usually found in dryland farming and their presence in *molapo* farming may be due to conducive growing environment created by tillage. In addition, *Sida cordifolia* is found principally on disturbed lighter soils, and occurring as a weed in cultivated fields and degraded pastures (Parsons & Cuthbertson, 2001) and classified as an increaser, further explaining its presence in *molapo* farming. Other broadleaf weeds that were imposing their presence under saucer shaped flooding pattern, were *Triumfetta pentandra, Heliotropium ovalifolium* and *Hibiscus cannabinus*.

There was notifiable shift in abundance of broadleaf weeds in fields under Lake flats. Presence of these fields depend on the extent of flooding at the lake and as such they have low frequency of cultivation which might mean that the soil is exposed to less disturbance by tillage. *Sida cordifolia* was the most abundant followed by *Sida alba*, *Ipomea sinensis, Triumfetta pentandra* and *Xanthium strumarium*. Notably, *Sida alba* is normally found in seasonal pans and spillways (Heath & Heath, 2009) while *Xanthium strumarium* favours wet areas and heavier soils (Phillips, 1991). This explains their abundance in fields situated in seasonal floodplains and around lake flats. There was also a notifiable presence of high moisture tolerant broadleaf weed species which were also recorded under saucer shaped flooding pattern like *Glinus oppositifolius* and *Heliotropium ovalifium*, eventhough the latter occurred in lower densities under lake flats compared to saucer shape type. These species were observed to infest fields that normally get inundated during flooding.

Grass weeds were almost similar in presence under all the flooding patterns. *Cynodon dactylon* and *Panicum repens* were the most abundant and dominant grass weeds in both saucer-shaped and lake flats respectively. Despite them appearing under both the types, *Cynodon dactylon* was mostly found on the upper gradients of the fields. This was also supported by Tsheboeng *et al* (2014) who noted that *Cynodon dactylon* co-existed with *Nidorella resedifolia* and *Cyperus longus* in the tertiary flooding zone in the Okavango Delta. On the other hand, *Panicum repens* was found located in the lower gradients of the fields where there was high moisture content. The other grass weed found to have similar habitat characteristics to *Panicum repens* was *Digitaria debilis.* According to Heath & Heath (2009), this grass weed is found occasionally in dump areas and often rooted in water. This may explain why it is mostly dominant in seasonal floodplains under saucer shaped than lake flats.

A total of four different species of sedges were found in *molapo* farming during the survey. Their presence may suggest that some of the fields were located around dried out areas on the edge of lagoons and in some instances, damp parts of the floodplain. *Bulbostylis hispidula* and *Cyperus esculentus* were found across all the flooding patterns where *molapo* farming is practiced with *Cyperus esculentus* being the most abundant sedge weed under saucer-shaped than under lake flats. However, *Bulbostylis hispidula* is a non-tuber sedge and grows well under free draining sandy soils (Phillips, 1992), this might explain its abundance in areas where *molapo* fields are permanently placed and tilled for several years compared to those fields under lake flats. Conversely, previous studies by Bangarwa *et al*. (2012) and Stoller *et al.* (1972) indicated that tubers for *Cyperus esculentus* are equally sensitive to soil disturbance. *Cyperus longus* seem to prefer fields under lake flats.

CONCLUSIONS

The study provides invaluable insights into how flooding patterns shape weed species diversity and maize yield in flood recession farming. Flooding pattern influences weed species diversity and maize yield in *molapo* farming. The diversity and eveness of weed species were higher in saucer-shaped than lake flat flooding pattern. Under weedy conditions, lake flats produced more biomass than saucer-shaped flooding pattern. Heavy weed biomass was largely responsible for low maize biomass in *molapo* farming in the Okavango Delta. Grass weed, *Panicum repens* was the dominant species and largely responsible for reduction in maize biomass under the lake flats type and saucer shaped flooding pattern. Broad-leaved weeds *Triumfetta pentandra* and *Sida cordifolia* were the main species responsible for poor biomass production in maize. These findings underscore the significant role of flood dynamics and weed species diversity in influencing crop yield, highlighting the need for targeted weed management strategies in flood recession farming.

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CONFLICT OF INTEREST

The authors declare that they have no competing interests.

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