BINDURA UNIVERSITY OF SCIENCE EDUCATION

OPTIMISING MAIZE YIELD UNDER FLOOD-RECESSION CROPPING IN THE ZAMBEZI VALLEY FLOODPLAINS, NORTHERN ZIMBABWE

BY

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DECLARATION

I declare that the work contained in this thesis is my own and has not been submitted by me or any other person for any other award. Assistance towards the production of this thesis and other scholars' work have been duly acknowledged and referenced in the respective sections.

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ABSTRACT

Optimising Maize Yield under Flood-Recession Cropping in the Zambezi Valley Floodplains, Northern Zimbabwe

Flood-recession cropping (FRC) can alleviate effects of droughts, dry spells, and poor soil fertility, which are the major constraints to improving food security for smallholder farmers in semi-arid areas. The study aim was to evaluate sustainable options for optimising flood-recession maize (*Zea mays* L.) yield in the mid-Zambezi Valley. This study determined: farmers' perceptions on FRC's socio-economic importance and production challenges; maize agronomic practices; floodplain soil fertility; crop establishment method (tillage); cultivar and fertilizer effect on maize yield; and seasonal rootzone water content and salinity in maize fields. Questionnaires were administered to 123 FRC households for baseline survey. Soil samples were collected at 0.20-m depth increments to 1.00 m, from 24 sampling points and analysed using core method for bulk density (BD), hydrometer method for texture, loss on ignition for organic carbon (OC), Kjeldahl procedure for total N, 0.01M $CaCl_2$ method for pH and ICP for Mehlich-3 extractable elements. Field experiments were conducted from 2016-2018 at Zhoubvunda 1, Zhoubvunda 2 and Mukumbura, replicated thrice per site. Experiment-1 was a 4*4 factorial CRD comprising NPK basal fertilizer [7:6:6 (6-8% S)] and N top-dressing fertilizer (NH_4NO_3), each at 0, 75, 150 and 225 kg/ha using an early-maturing maize cultivar (SC513); Experiment-2 was a 3*4*4 factorial split-split plot design with two cultivars, medium (SC627) and late maturing (SC727) added to Experiment-1; and Experiment-3 was a CRD that compared two crop establishment methods namely furrow only (F) and furrow+holing-out (F+H). Percent emergence was determined 3 weeks after crop emergence (WACE) in 6.0 m × 2.7 m net plots. Days to 20%, 50% and 80% tasselling and silking were determined from 7-7.5 WACE. Maize yield was measured from 1.8 m × 1.8 m net plots. Soil moisture content was measured using the TDR method and salinity samples were collected up to 1.0 m-depth at 7-14-day intervals. Salinity was measured using an Electrical conductivity and Temperature Meter. Survey data were analysed using descriptive statistics and Binary Logistic Regression Model in SPSS Version 20.0. Soil and crop data were analysed using ANOVA, Pearson's correlation and t-Test in GenStat 18th Edition. Flood-recession cropping was ranked first among livelihood sources, contributed >50% household income, and produced food and high value crops. Major production challenges were pest damage, inadequate labour and equipment. Maize plant spacing was 1.00 m × 0.60 m, 69% of farmers practised F+H, 97.6% did not apply fertilizers, 68.3% planted retained seed, and 87.0% planted >4 seeds per station. Better-resourced farmers were more likely to practise F+H. Floodplain soils were medium textured and fertile: 1.20-1.40 g/cm^3 BD, 0.36% N, 2.04% OC, 7.70-8.60 pH, and had high base concentrations. Across sites, the mean exchangeable sodium percentage values ranged from 4.14 to 7.32, were therefore below 10 which is the critical level for soil structure damage. Maize yield and percent emergence were >20% higher under F+H than F. High SC513 grain yield, 6.20-8.45 t/ha, ≥2 times yield from farmers' fields, was recorded without fertilizer. Averaged over NPK and N top-dressing fertilizer rates, the late-maturing cultivar, SC727, out-yielded earlier maturing cultivars, but had a low harvest index (<0.40). NPK fertilizer response was higher at 75 and 150 kg/ha for early and later-maturing cultivars respectively. Benefit from N top-dressing fertilizer, up to 75 kg/ha was evident at 0 kg/ha NPK fertilizer, in an increasing trend with increasing days to maturity of cultivar. Soil moisture depletion was higher in the effective maize rootzone (0.0-0.4 m) but mostly remained above wilting point. Soil salinity reached levels that can reduce maize yield by 10-50%, with highest potential effect on cultivars that require >100 days to mature. It was concluded that productivity of FRC can be improved through selecting appropriate crop establishment methods and maize cultivars; micro-dosing with NPK fertilizer and; nutrient stewardship to reduce rootzone salt accumulation. Further studies should focus on long-term experiments for (i) developing FRC fertilizer recommendations, (ii) screening maize cultivars for tolerance to salinity and determining: (iii) effect of crop establishment method on (a) maize root development and yield; and (b) erodibility and erosion of floodplain soils.

Key words: Crop emergence; Fertilizer; Flood-based farming; Production challenges; Soil fertility; Soil moisture content; Soil salinity.

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DEDICATION

I dedicate this work to my children, Ropafadzo and Taropafadzwa Chisuro.

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LIST OF ABBREVIATIONS

AGRITEX	Agricultural, Technical and Extension Services
BD	Bulk Density
CRD	Completely Randomised Design
RCBD	Randomised Complete Block Design
DR&SS	Department of Research and Specialist Services
EC	Electrical Conductivity
FAO	Food and Agriculture Organisation of the United Nations
FGD	Focus Group Discussion
FRC	Flood-Recession Cropping
ICP	Inductively Coupled Plasma
IKS	Indigenous Knowledge Systems
NGOs	Non-Governmental Organisations
RCD	Root Collar Diameter
SSA	Sub-Saharan Africa
US$	United States Dollar
WACE	Weeks After Crop Emergence
ZIMSTAT	Zimbabwe National Statistics Agency

CHAPTER 1: GENERAL INTRODUCTION

1.1 Food Security in Smallholder Farming Systems of Sub-Saharan Africa

Sub-Saharan Africa (SSA) remains the region with the highest food insecurity in the world, with 22.7% of the population affected in 2016 (FAO et al., 2017). In 2018, two hundred and fifty six (256) million Africans, 20% of the population, were food insecure of which, 239 million were in SSA and 17 million in Northern Africa (FAO et al., 2018). In Southern Africa, Zimbabwe had the highest proportion of the food insecure population, contributing 5.8 million people (OXFAM et al., 2020).

The major causes of food insecurity in SSA are relatively low yields of the major staple food crops compared to other regions. For example, in Asia maize (*Zea mays* L.) grain yield was between 2.5 and 4.5 t ha^{-1} (FAO, 2008) whilst the regional average maize yields were 1.7 t ha^{-1} in West Africa, 1.5 t ha^{-1} in East Africa, and 1.1 t ha^{-1} in Southern Africa (Smale et al., 2011). The relatively low crop yields in SSA are partly due to heavy dependency of the region on rainfed cropping, which occupies more than 95% of the land; while the corresponding land areas are 90% for Latin America, 60% for South Asia, 65% for East Asia and 75% for the Near East and North Africa (FAO, 2008). In SSA, there is high temporal and spatial variation in rainfall in semi-arid regions and the rainfall is usually inadequate for rainfed cropping. Thus, inadequate, and poorly distributed rainfall (Steiner & Rockström, 2003) is a major constraint to increasing crop yields often leading to complete crop failure in some years (Rockström et al., 2003; Moroke et al., 2010; Nyakudya et al., 2014).

Projections point towards the likelihood of increase in extreme weather events (floods and droughts), and water stress due to climate change in SSA in the 21st century (Postel, 2000; Moroke et al., 2010; Ebi & Bowen, 2016; Rakib & Anwar, 2016). Therefore, water stress under rainfed crop production is likely to worsen. Rainwater harvesting (RWH) (Mugabe, 2004; Kahinda et al., 2007; Vohland & Barry, 2009; Nyamadzawo et al., 2013; Nyagumbo et al., 2019) and irrigation (Shar et al., 2002; Xie et al., 2014) are the main strategies that have been employed to mitigate against water stress experienced under rainfed crop production. Whilst these strategies have been beneficial, their contribution to food security has been limited by a range of socio-economic and hydrophysical conditions. Rainwater harvesting is not universally applicable, for example, inorder to maximise crop yield benefits, it requires ideal slope ($\leq 5\%$), deep soils for adequate water storage capacity and runoff areas with low infiltration rates (Anschütz et al., 2003). Due to high establishment and maintenance costs (Brown & Funk, 2008; Mutiro & Lautze, 2015), there is limited irrigation development in SSA, and the irrigated area is 6 million hectares, which is only 5% of the total cultivated area, compared to 37% in Asia and 14% in Latin America (Zhi, 2008). The other major biophysical constraint to raising productivity in smallholder farming systems is poor soil fertility (Nyamangara et al., 2000; Sanchez, 2002;

Rusinamhodzi et al., 2013). The soil generally has low nutrient and water holding capacity due to low clay and organic carbon content. However, less than 5% of the farmers commonly applied fertilizers (Rusike et al., 2003). Mapfumo and Giller (2001) reported that, in general smallholder farmers in Zimbabwe did not apply fertilizers. The smallholder farmers are resource-constrained and cannot afford technologies needed to improve soil fertility (Smale et al., 2011). Kelly and Naseem (2009) reported that the average fertilizer application rate in SSA, 10 kg ha^{-1} in 1997, was much lower compared to 54 kg ha^{-1} in Latin America, 80 kg ha^{-1} in South Asia, and 87 kg ha^{-1} in Southeast Asia. This is regrettable given that maize, the staple food crop for more than 200 million people in SSA, is a heavy consumer of fertilizer with a large response to fertilizer for improved cultivars and it is the second most heavily fertilized crop on a global scale, after Irish potato (*Solanum tuberosum* L.) (Heisey & Norton, 2007). Fertilizer use is extremely low due to high prices and unavailability in remote areas.

Floodplains generally have abundant water resources and fertile alluvial soils (Duvail & Hamerlynck, 2007) that alleviate water and soil fertility stress that limit productivity in smallholder farming areas. Thus, floodplains of major rivers and tributaries in SSA, have potential to cushion smallholder farmers against the negative impacts of infertile soils and droughts. It is, therefore, not surprising that floodplains have for long provided a safety net for the resource-constrained farmers (Scudder, 1989; Pwiti, 1996; Hassan, 1997; Shorr, 2000).

1.2 Flood-Based Farming Systems in Sub-Saharan Africa

Floodplains are among the most productive ecosystems in the world (Adams, 1993; Pwiti, 1996; Lynch & Brown, 2000; Koschorreck & Darwich, 2003; Rinklebe et al., 2007). The three most ancient civilizations on earth developed on fertile floodplains: the Mesopotamian civilization on Tigris and Euphrates rivers (Seton et al., 1867); the Harappan civilization on the Indus River in Asia and the Egyptian civilisation on the Nile River (Ahmed, 1960; Hassan, 1997; FAO, 2000; Abate, 2011). Therefore, where they exist, floodplains have historically played a major role in food security, social and economic development. There is potential to develop sustainable systems of utilising floodplains by mainstreaming them into national development, based on thousands of years of indigenous knowledge. Africa is endowed with large floodplain areas, for example floodplains adjoining the Nile, Congo, Senegal, Niger and Zambezi Rivers occupy about 30 million hectares of land (CGIAR, 2015). However, in comparison to Asian and American floodplains, African floodplains are underutilized, and their governance is not properly structured (Buri et al., 1999; Fox & Ledgerwood, 1999; Darmody & Marlin, 2002; Tsheboeng et al., 2014; Sidibé et al., 2016).

Flood-based farming systems (FBFS) are farming systems that depend on floods. Whilst rainfed farming depends on rainfall and localized runoff; FBFS depend on larger flood events that vary in intensity and duration from a few hours to months. Flood-based farming systems are usually practiced in plains with gentle slopes where water levels rise from local precipitation and rainfall collecting from catchment area upslope, and rising rivers or lakes, which cause inundation of floodplains. Flood-based farming systems can be classified based on the nature of flood and inundation use: flood-recession farming, flood-recession and flood-rise farming, spate irrigation, *dambo* irrigation, and inundation canals (Garcia-Landarte et al., 2014; Kool et al., 2018) (Table 1.1). In these farming systems, floods form the basis for crop cultivation, livestock grazing and fisheries (Simwinji, 1997; Chidanti-Malunga, 2011; Kpadonou et al., 2012; Coulibaly et al., 2015; Kool et al., 2018).

Table 1. 1: Flood-based farming systems in Sub-Saharan Africa

Flood-based farming system		**Examples of regions or countries where practiced**	**Reference**
Name	**Description**		
Flood-recession farming	Uses post-inundation residual moisture.	Zimbabwe, Ghana, South Sudan, Zambia, Mozambique, Central Africa	Mavhura et al., 2013; Mavhura et al., 2015; Sidibé et al., 2016; Balana et al., 2019; Comptour et al., 2020;
Flood-recession and flood-rise farming	Uses residual moisture stored in the soil after recession of seasonal floods and rising floodwater levels for flood-tolerant crops	Botswana	Turpie et al., 2006; Kashe et al., 2015; Kolawole & Kashe, 2019;
Spate irrigation	Uses bunds and canals to guide flash floods to fields during flood events	North and East Africa.	Kool et al., 2018;
Dambo irrigation	Uses margins of *dambos* or bas-fonds (shallow, seasonally waterlogged local depressions)	Zambia, South Africa Zimbabwe	Chidumayo, 1992; Nyamadzawo et al., 2015;
Inundation canals	Uses canals that guide floodwater across the floodplain to fields. Inundation canals are constructed next to rivers or floodplains that are fed by seasonal high water levels in rivers	Sudan, Egypt	Kool et al., 2018.

Flood-based farming systems have largely been neglected by governments, donors, and development agencies (Sidibé et al., 2016). Kool et al. (2018) attributes the neglect to lack of understanding of how these systems work and their potential for agricultural development. Comprehensive research that encompasses, hydrophysical, socio-economic, agronomic, and environmental potential is therefore required to increase understanding of the FBFS and their contribution to food security. From an agronomic perspective, there is scope to improve productivity through selection of improved crop cultivars and agronomic practices (van Steenbergen et al., 2010). In Zimbabwe, FBFS are practised in Mount Darwin, Mbire and Muzarabani districts in Mashonaland central and Malipati in the south-east and Gokwe in the west Zimbabwe (Appendix 1a). This study focused on flood-recession cropping (FRC), an element of flood-recession farming.

1.3 Flood-Recession Cropping

1.3.1 Description, occurrence and crops grown

Flood-recession cropping is the growing of crops post-inundation using residual soil moisture (Postel, 2000). Flood-recession cropping has been labelled 'traditional' (Saarnak, 2003), 'pro-poor livelihood activity' (Scudder, 1989; Kashe et al., 2015) because it is a low input farming system, largely based on indigenous knowledge systems (IKS). Kolawole and Kashe (2019) reported that the majority (86%) of the farmers who were interviewed indicated that high soil fertility and favourable moisture content in the floodplains were the main motivations to practise FRC.

In SSA, FRC is practised in all the four regions: Western, Eastern, Central and Southern Africa (Table 1.2). Crops grown include both staple food and cash crops, and thus it contributes to household food security and nutrition, and income (Kashe et al., 2015; Sidibé et al., 2016; Balana et al., 2019). In some cases, FRC enables double cropping by extending the growing period for crops. Usually crops grown under FRC must tolerate semi-saturated soils at early stages and high ground water tables (Garcia-Landarte et al., 2014).

Table 1. 2: Sub-Saharan Africa river basins where flood-recession cropping is practiced and crops grown

Region	**River basin**	**Crops grown**	**Reference**
West Africa	Niger Senegal White Volta Red Volta	Beans (*Phaseolus vulgaris* L.), rice (*Oryza* spp.), Maize (*Zea mays* L.), Sorghum [*Sorghum bicolor* (L.) Moench], Okra [*Abelmoschus esculentus* (L.) Moench], Leaf vegetables (*Brassica* spp.), Tomato (*Lycopersicon esculentum* Mill.), Onion (*Allium cepa* L.), Chillies/ pepper (*Capsicum* spp.), Watermelons [*Citrullus lanatus* (Thunb.)], Tobacco (*Nicotiana tabacum* L.), Soybean [*Glycine max* (L.) Merr.], Cowpea [*Vigna unguiculata* L. (Walp)]	Saarnak, 2003; Adamczewski et al. (2011); Balana et al., 2019; Sidibé et al., 2016; Owusu et al., 2017;
East Africa	Rufiji Tana Awash	Maize, Sorghum, Rice, Chickpea (*Cicer arietnum* L), Lentils (*Lens culinaris* Medukus), Grass pea (*Lathyrus sativus* L.), Haricot beans (*P. vulgaris*), Tomato, Onion, Watermelons	Duvail & Hamerlynck, 2007; Leauthaud et al., 2013;
Central Africa	Congo	Manioc/cassava (*Manihot esculenta* Crantz), Maize, Roselle (*Hibiscus sabdariffa* L.), Sweet potato [*Ipomoea batatas* (L.) Lam.]	Comptour et al., 2020;
Southern Africa	Shire Okavango Zambezi	Beans, Rice, Maize, Sorghum, Okra, Leaf vegetables, Tomato, Onion, Chillies/Pepper, Watermelons, Groundnut (*Arachis hypogaea* L.), Pumpkins (*Cucurbita* spp.), Millets (family Poaceae), Sweet sorghum (*S. bicolor*), Sweet potato	Timberlake, 1997; Turpie et al., 2006; Chidanti-Malunga, 2011; Mavhura et al., 2013; Kolawole & Kashe, 2019

1.3.2 Floodplain soil fertility

Floodplain soils have higher natural fertility levels (Abdulai et al., 2013). The sediment load in floodwater is often high, carrying fine particles to the floodplains. Therefore, floodplain soils have a high proportion of fine alluvial deposit often resulting in vertisols, fluvisols, gleysols and cambisols (Kool et al., 2018). The soils are usually medium to heavy textured (FAO, 1986; Buri et al., 1999; Comptour et al., 2020). Because of their medium to heavy texture, although the floodplain soils have higher natural fertility levels, they are more difficult to till and are prone to seasonal waterlogging (Abdulai et al., 2013; Donkoh et al., 2013) Floodplain soils usually have more soil organic carbon (SOC) (Buri et al., 1999; Comptour et al., 2020), than the often-degraded upland soils that are less responsive to inorganic fertilizers (Tittonell & Giller, 2013). Floodplain soil pH values are usually above 5.0 (Buri et al., 1999; Kashe et al., 2015), which is the range suitable for most crops (Nyamangara et al., 2000). These favourable attributes explain why floodplain soils have high agricultural potential. However, soil salinity may reduce yields of salt-sensitive crops under FRC (Van Hoorn & van Alphen, 2006; Tavakkoli et al., 2010). Although floodplains exhibit common attributes, differences naturally exist. Research is therefore required to ensure FRC-based recommendations that take into account local variability in soil fertility (Giller et al., 2006), socio-economic conditions and production objectives of the farmers (Dimes et al., 2004).

1.3.3 Agronomic practices and crop yields

Agronomic practices under FRC should differ from those under rainfed conditions because the two ecosystems are different. For example, dominant soil processes, and soil water and nutrient dynamics between the two ecosystems differ. Leaching, eluviation and soil water erosion processes, which result in nutrient loss in upland areas, may not be as dominant in the floodplains. In floodplains nutrient loss may occur through denitrification, but capillary rise may result in nutrient deposition in the rootzone. The natural soil fertility renewal and water replenishment in floodplains is a huge advantage to resource-poor smallholder farmers because it minimizes crop production costs (Kolawole & Kashe, 2019); as a result, most farmers do not apply fertilizers (Chidanti-Malunga, 2011; Kashe et al., 2015; Sidibѐ et al., 2016).

Flood-recession season length varies with timing, duration, and height of floods. Planting may be delayed due to slow flood-recession. Farmers utilise pre-conceived knowledge in adapting to each year’s scenario in relation to past or related experience (Everard, 2016). Tillage can be used a water management tool (FAO, 2011). When moisture is inadequate, farmers utilize soil moisture conservation techniques to enable crops to reach maturity. In the Shire River Valley, Chidanti-Malunga (2011) reported use of mulching with grass or crop residue, digging of deep (0.15 m) planting holes. If the conditions are drier the author reported that the planting holes are dug in furrows. In wetter seasons, Chidanti-Malunga (2011) reported that farmers constructed ridges to maintain favourable moisture content within the crop rootzone. Comptour et al. (2020) reported that farmers in the Congo River basin built large earthen structures “raised fields” up to 1.5 m high, on which they planted crops. In Ouémé Valley in Benin, Kpadonou et al. (2012) reported that crop dykes were constructed to facilitate early planting of late maturing crops, for example, pepper (*Capsicum* spp.). Thus, tillage (crop establishment method) in floodplains is designed to adapt to climate-related phenomena, floods, and droughts, turning threats into opportunities (Kpadonou et al., 2012). However, in the Okavango Delta, farmers reported that they were banned by government from constructing earth and grass bunds because the bunds change the natural course of the floods (Kolawole & Kashe, 2019).

Due to limited research, documented information on crop yields in FRC is scarce. Nederveen and Steenbergen (2011) reported a seven year mean maize yield ranging from 1.6 to 2.2 t ha^{-1} from farmers' fields in Boru district in Ethiopia. Kashe et al. (2015) obtained 2.4 to 3.4 t ha^{-1} from a low yielding very early maturing maize cultivar (SC403), without application of fertilizer in the Okavango Delta. Sidibé et al. (2016) reported that under ideal crop management, sorghum [*Sorghum bicolor* (L.) Moench] yields can reach 2.5 t ha^{-1}. Traore et al. (2016) recorded sorghum yield of 2.5 t ha^{-1} in the second year of a three-year fertilizer-yield experiments in Mali. In the Okavango Delta, Vanderpost (2009) reported up to 2.0 t ha^{-1} sorghum yields in FRC fields against 0.144 t ha^{-1} under rainfed cropping. Similarly, low rainfed crop yields were reported in the mid-Zambezi Valley in northern Zimbabwe, where the mean rainfed yields were 0.2 to 0.4 t ha^{-1} for maize and sorghum and 0.2 t ha^{-1} for pearl millet (*Pennisetum glaucum* L. R. Br.) (AGRITEX, 2015a, 2015b). The limited yield data available from FRC show large differences in yield between upland and FRC fields, suggesting that FRC could be a viable option for better and more stable crop yields. However, information on yield gaps between current farmers' yields and achievable yields under FRC is not available

1.3.4 Challenges

Flood-recession cropping farmers face biophysical and socio-economic production challenges. Biophysical challenges include soil salinity (Van Hoorn & van Alphen, 2006), crop damage by pests and diseases (Balana et al., 2019; Traore et al., 2016; Kolawole & Kashe, 2019), livestock and wildlife (Kolawole & Kashe, 2019), and inadequate residual moisture caused by low flood levels (Chidanti-Malunga, 2011; Kolawole & Kashe, 2019). Generally, farmers lack knowledge on integrated pest and disease management (Balana et al., 2019) and best practices under FRC. Socio-economic constraints include inability to acquire supplementary irrigation equipment due to failure to access credit or affordable equipment leasing options, and shortage of improved seeds (Balana et al., 2019). Governance of FBFS including FRC in African countries is not properly structured (Buri et al., 1999; Fox & Ledgerwood, 1999; Darmody & Marlin, 2002; Tsheboeng et al., 2014; Sidibè et al., 2016) and there is general uncertainty regarding land tenure. The resultant tenure insecurity and uncertainty impede development in floodplains (Namara et al., 2010). For example, the Land Board of Botswana does not issue of usufruct certificates to *molapo* farmers, thus denying them modern use rights to farming (Kolawole & Kashe, 2019). In Zimbabwe, FRC is not officially recognised hence FRC farmers do not benefit directly from annual free input schemes that are availed to rainfed and irrigated cropping. There are knowledge gaps on the extent to which challenges experienced under FRC impact on crop yield, therefore, there is need to quantify effects of these challenges and develop management options. Research is needed to provide information on achievable yields, sustainable agronomic practices and recommended cultivars.

1.4 Rationale of the Study and Theoretical Framework

Food insecurity in the mid-Zambezi Valley in northern Zimbabwe is mainly due to low agricultural productivity (Figure 1.1). Upland rainfed (conventional) farming is prone to severe weather extremes: droughts, long dry spells and heat waves, which lead to reduced soil moisture on one hand; and floods, which result in waterlogging on the other hand. Unfortunately, maize, the staple and most preferred crop, is susceptible to both waterlogging and drought (Mashingaidze, 2006). In Mashonaland Central Province of Zimbabwe, in which the study area is located, maize is grown by the majority of the farmers, for example, in the 2018/19 season, maize was grown by 87% of the households, compared to 22% for sorghum and 1% each for finger millet [*Eleusine coracana* (L.) Gaertn] and pearl millet (ZimVac, 2019); hence the focus on maize in this study.

The frequency of failure of upland rainfed cropping has been worsened by the increased incidence of extreme weather events in recent years caused by climate change, particularly in semi-arid areas as reflected by the downgrading of the part of the mid-Zambezi Valley from Natural Region IV according to (Vincent & Thomas, 1960) to Natural Region Va (Manatsa et al., 2020). In addition to the hydrophysical limitations, low productivity is partly due to management-related suboptimal performance by smallholder farmers caused by lack of science-based knowledge, resource constraints and poor agronomic practices. The smallholder rainfed farming systems are characterised by poor soil fertility management, relatively high unproductive water losses, planting of inappropriate crops and/or uncertified cultivars, inappropriate crop establishment methods, and poor weed, pest and disease management.

The low-lying terrain (<400 m a.s.l.) and existence of extensive floodplains predisposes the area to flooding (Mavhura et al., 2013). The floods deposit fertile sediments and cause extensive flooding in floodplains. Farmers cope with the adverse upland rainfed cropping conditions and their resource constraints by practicing FRC in the floodplains. The fertile alluvial soils and abundant water resources in the floodplains provide a huge incentive for farmers to practice FRC (Kolawole & Kashe, 2019). Despite decades of practice (Pwiti, 1996), FRC remains under “prohibition by law” in Zimbabwe and, because of this, it is scantly documented and its productivity and potential to contribute to household food security is generally unknown. There is need to conduct research on fertility of floodplain soils, cultivars, crop establishment methods, fertilizer application rates, and soil and water management in order to develop recommendations for improving maize productivity. The ultimate goal is to achieve food security for FRC households.

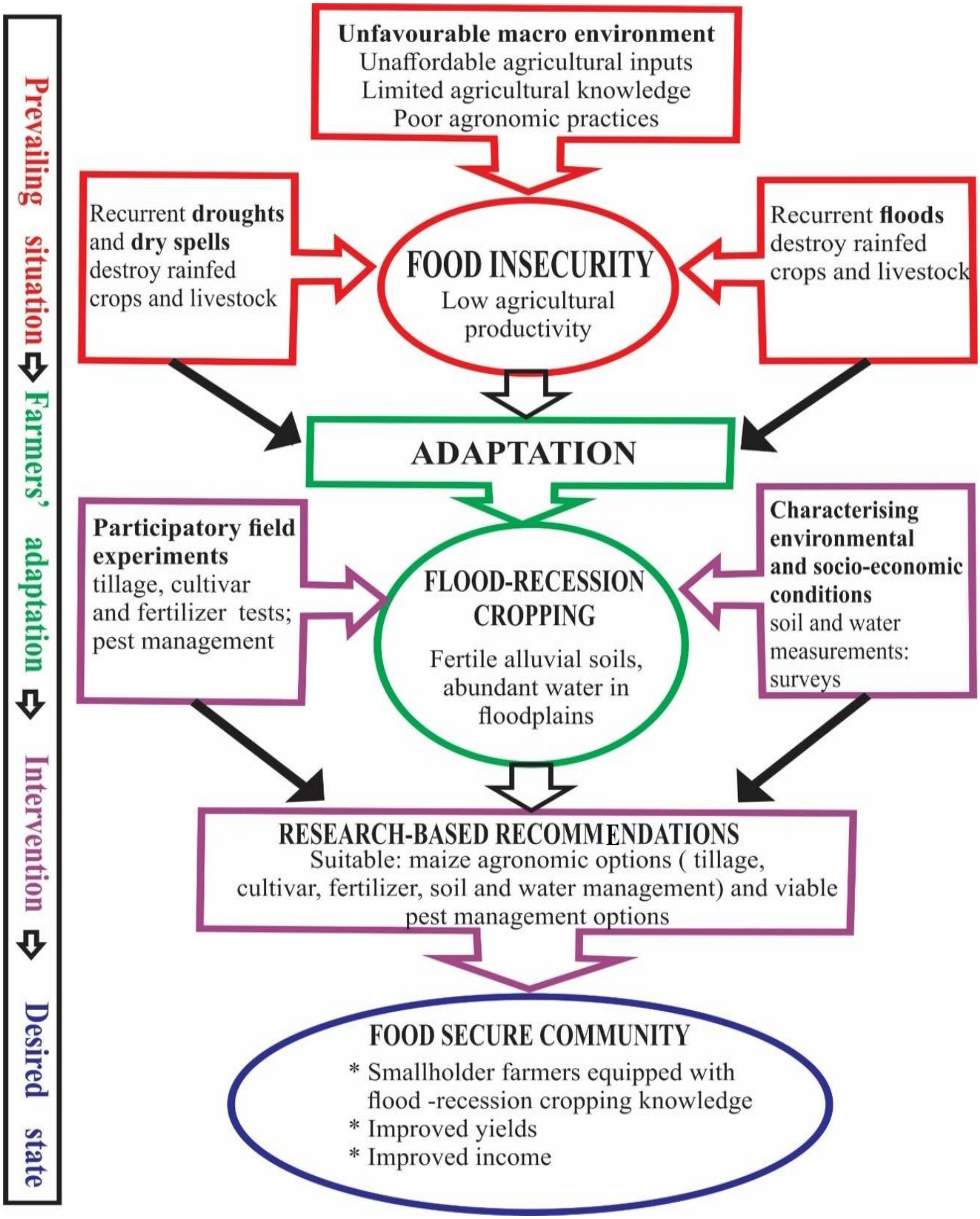

Figure 1: Theoretical framework for the study

1.5 STUDY AIM, OBJECTIVES AND RESEARCH QUESTIONS

1.5.1 Aim

The aim of this study was to evaluate sustainable options for optimising maize yield under FRC in Zambezi Valley, Northern Zimbabwe.

1.5.2 Objectives

The specific objectives of the study were to:

1.5.2.1 determine: perceptions of smallholder farmers on the socio-economic importance and production challenges; maize agronomic practices; and opportunities of FRC in the mid-Zambezi Valley;

1.5.2.2 establish soil fertility status in cultivated floodplains in the mid-Zambezi Valley;

1.5.2.3 determine the effect of crop establishment method, maize cultivar and fertilizer application rate on maize yield under FRC in the mid-Zambezi Valley;

1.5.2.4 determine seasonal rootzone water content and salinity in flood-recession maize fields in the mid-Zambezi Valley

1.5.3 Research questions

1.5.3.1 What are the perceptions of smallholder farmers on the socio-economic importance and production challenges; maize agronomic practices; and opportunities of FRC in the mid-Zambezi Valley?

1.5.3.2 What is the soil fertility status in the cultivated Zambezi Valley floodplain?

1.5.3.3 What is the yield gap between the current farmers' yields and achievable yields under FRC?

1.5.3.4 How does maize yield respond to crop establishment method, cultivar and inorganic fertilizers?

1.5.3.5 What are the implications of soil moisture and salinity dynamics during the flood-recession season on maize production?

1.6 Thesis Outline

Chapter 1 is the general introduction. Chapter 2 reviewed literature on FRC in SSA and reported the perceptions of smallholder farmers on the socio-economic importance and production challenges; maize agronomic practices; and opportunities of FRC in the mid-Zambezi Valley. In Chapter 3, information on the fertility status of the Zambezi Valley floodplain soils was presented and discussed. Results of participatory field experiments that tested maize response to crop establishment method, cultivar and inorganic fertilizer are reported in Chapter 4. Chapter 5 reported on seasonal rootzone soil moisture content and salinity and their implications for FRC maize production. Chapter 6 is the

Synthesis which summaries the main conclusions and provides a general discussion of the research project.

CHAPTER 2: FLOOD-RECESSION CROPPING IN THE MID-ZAMBEZI VALLEY: A NEGLECTED FARMING SYSTEM WITH POTENTIAL TO IMPROVE HOUSEHOLD FOOD SECURITY AND INCOME

Abstract

Floodplains have potential to contribute significantly to food security and household income through flood-based farming systems (FBFS) in Sub-Saharan Africa. Flood-recession cropping (FRC), one of the FBFS, allows farmers to grow crops in floodplains after floods have receded, thereby extending the crop growing period. The objectives of this study were to: (i) assess the socio-economic importance of FRC to smallholder farmers; (ii) identify the major crop production challenges; (iii) characterise agronomic practices with respect to maize (*Zea mays* L.) production; (iv) determine factors that affect selection of crop establishment method; and (v) identify opportunities to improve productivity and farmers' livelihoods under FRC. The study was conducted in 2015 in the mid-Zambezi Valley. Data were collected through a questionnaire survey on 123 respondents, 11 focus group discussions with 88 participants and field observations through transect walks. Factors affecting selection of crop establishment method were analysed using the binary logistic regression model and the rest of the data were analysed using descriptive statistics in SPSS Version 20.0. Flood-recession cropping was ranked highest among sources of livelihood. Crops grown and allocated mean land areas were: maize (0.56 ha), okra [*Abelmoschus esculentus* (L.) Moench] (0.32 ha, sweet potato [*Ipomoea batatas* (L.) Lam] (0.25 ha), cowpea [*Vigna unguiculata* L. (Walp)] (0.21), watermelon [*Citrullus lanatus* (Thunb.)]) (0.19 ha), sugar beans (*Phaseolus vulgaris* L.) (0.16 ha) and tomato (*Lycopersicon esculentum* Mill.) (0.14 ha). Food and cash crops complemented each other, serving socio-cultural and economic needs, respectively. Crop production challenges were ranked in the order: pest damage, inadequate labour, inadequate equipment, weeds, high temperature, inadequate draught power, inadequate knowledge, inadequate moisture, poor soil fertility and theft. Most farmers (69%) performed crop establishment by holing out planting stations in furrow, 12.2% made furrows only, and 17.9% dug planting stations only. Maize plant spacing averaged 0.86 m × 0.64 m and 75% of the farmers planted ≥ 4 seeds per planting station at a mean depth of 0.28 m. Only 8.9% of the farmers used inorganic fertilizers and 4.3% used certified seed. Furrow + holing out was more likely to be practised by farmers who: resided in Muzarabani district, had more members who provided labour, perceived their fields as inadequate, owned more draught power animals, and cited high temperature as a production challenge. The more the years a farmer had practised FRC, the less likely they were to practise furrow + holing out. There are opportunities to: (i) improve crop yields through: using certified seed; developing agronomic practices, for example, appropriate crop establishment methods, optimising plant spacing and fertilizer application rates, (ii) create more employment by intensifying cultivation of high value crops and (iii) further diversify food and income through post-harvest processing and value addition of crop produce. Further research should address inadequate labour and equipment and yield benefits of the different crop establishment methods.

Key words: Floodplain; Floods; Maize agronomic practices, Crop establishment methods

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2.1 Introduction

Food insecurity is a perennial challenge in smallholder farming communities in semi-arid Sub-Saharan Africa (SSA). The prevalence of undernourished people (22.7%) and severe food insecurity (2.3%) in the world were highest in SSA (FAO et al., 2017). These statistics imply that more still needs to be done to achieve sustainable development goal number 2: “End hunger, achieve food security and improved nutrition and promote sustainable agriculture” in the region (FAO, 2020). The major constraints to achieving food security in SSA are inadequate and poorly distributed rainfall, and poor soil fertility (Sanchez, 2002; Nyakudya et al., 2014; Badu-Apraku & Fakorede, 2017). Floodplains are usually endowed with abundant groundwater resources and fertile alluvial soils (Adams, 1993; Laisi, 2016) that counter these major crop production constraints. Therefore, floodplains can contribute significantly to food security. Not surprisingly, early civilizations and settlements thrived on flood-based farming systems (FBFS) (Pwiti, 1996; Laisi, 2016; Russell et al., 2014). However, some of the early civilizations collapsed because of the build up of soil salinity.

Flood-based farming systems: spate irrigation, flood-recession farming, flood-recession and flood-rise farming, inundation canals and depression (*dambo*) agriculture are practised throughout SSA where they occupy an estimated 25 million hectares (Kool et al., 2018). Examples of rivers whose floodplains have been used for agriculture because of their natural fertility include the Bafra (Cemek et al., 2007), the Orinoco (Barrios & Trejo, 2003), the Euphrates and Tigris, the Rhine, the Mississippi, the Danube, the Po, the Yangtze and the Ganges (Verhoeven & Setter, 2010), the Nile and the Rio Grande (Hassan, 1997) the Niger and the Senegal (Postel, 2000; Sidibé et al., 2016; Kool et al., 2018), the Amazon (Hassan, 1997; Shorr, 2000), the Okavango (Magole & Thapelo, 2005), and the Zambezi (Pwiti, 1996; Kool et al., 2018). The fact that in comparison to Asian and American floodplains, African floodplains are underutilized and their governance is not properly structured has been iterated (Buri et al., 1999; Fox & Ledgerwood, 1999; Darmody & Marlin, 2002; Tsheboeng et al., 2014; Sidibé et al., 2016; Kool et al., 2018). Therefore, there is need for comprehensive research on African floodplains aimed at improving their productivity.

A major crop production constraint in FBFS is development of saline soils (soils with excess soluble salts that reduce the growth of most crops) (Tavakkoli et al., 2010). In floodplains, soil salinity develops during dry periods when there is no downward flow; capillary water is taken up by plant roots or evaporates at the soil surface and salts accumulate in the rootzone or top soil layer leading to saline conditions (Van Hoorn & van Alphen, 2006). Reduction in crop growth from high soil salinity is caused by osmotic stress that induces water deficit, and the deleterous effects of excess Na^+ and Cl^-

ions on critical biochemical processes (Munns & Tester, 2008). Extreme ratios of Na^+/Ca^{2+}, Na^+/K^+, Ca^{2+}/Mg^{2+}, and Cl^-/NO_3^- lead to specific ion toxicities (e.g., Na^+ and Cl^-) and ionic imbalance (Grattan & Grieve, 1999). Another floodplain soil fertility-related challenge is that flooding may cause metallic nutrient elements to become less available due to the formation of sulphide complexes (Allen, 2003) such as iron sulphide, zinc sulphide and aqueous Cu-(poly) sulfide.

Flood-recession cropping (FRC), cropping after floods recede, is a form of flood-recession farming. Flood-recession cropping allows farmers to grow crops outside the rainy season; thus giving farmers an opportunity to secure food throughout the year and to earn additional income. The removal of water and nutrient-related constraints affords smallholder farmers the opportunity to venture into high value crops required by the market, especially for women who are more involved in vegetable production (Sidibé et al., 2016; Balana et al., 2019; Comptour et al., 2020).

Table 2. 1: Crops grown in Sub-Saharan Africa floodplains under flood-recession cropping

Crop	**River floodplain**	**Reference**
Beans (*Phaseolus vulgaris* L.)	Senegal; Shire; Okavango	Saarnak, 2003; Chidanti-Malunga, 2011; Turpie et al., 2006;
Chillies / pepper (*Capsicum* spp.)	Red Volta; White Volta	Sidibé et al., 2016; Balana et al., 2019;
Cowpea [*Vigna unguiculata* L. (Walp)]	White Volta; Red Volta	Balana et al., 2019; Sidibé et al., 2016;
Groundnut (*Arachis hypogaea* L.)	White Volta ; Okavango	Turpie et al., 2006; Balana et al., 2019;
Leaf vegetables (*Brassica* spp.)	Shire	Turpie et al., 2006; Chidanti-Malunga, 2011;
Maize (*Zea mays* L.)	Red Volta; White Volta Okavango, Shire	Turpie et al., 2006; Chidanti-Malunga, 2011; Sidibé et al., 2016; Balana et al., 2019;
Millets (family Poaceae)	Senegal; Red Volta; White Volta; Okavango	Saarnak, 2003; Turpie et al., 2006; Sidibé et al., 2016;
Okra [*Abelmoschus esculentus* (L.) Moench]	White Volta	Balana et al., 2019;
Onion (*Allium cepa* L.)	Red Volta; White Volta	Sidibé et al., 2016; Balana et al., 2019;
Pumpkins (*Cucurbita* spp.)	Okavango	Kolawole & Kashe, 2019;
Rice (*Oryza* spp.)	Shire, Red Volta, White Volta	Chidanti-Malunga, 2011; Sidibé et al., 2016; Balana et al., 2019;
Sorghum [*Sorghum bicolor* (L.) Moench]	Senegal, Red Volta, White Volta, Okavango	Saarnak, 2003; Turpie et al., 2006; Sidibé et al., 2016;
Soybean [*Glycine max* (L.) Merr.]	Red Volta; White Volta	Sidibé et al., 2016;
Sweet potatoes [*Ipomoea batatas* (L.) Lam]	Shire	Chidanti-Malunga, 2011;
Sweet sorghum (*S. bicolor*)	Okavango	Turpie et al., 2006;
Tobacco (*Nicotiana tabacum* L.)	Red Volta; White Volta	Sidibé et al., 2016;
Tomato (*Lycopersicon esculentum* Mill.)	Shire, Red Volta; White Volta	Chidanti-Malunga, 2011; Sidibé et al., 2016; Balana et al., 2019;
Watermelon [*Citrullus lanatus* (Thunb.)]	Senegal; Red Volta; White Volta; Okavango	Saarnak, 2003; Sidibé et al., 2016; Balana et al., 2019; Kolawole & Kashe, 2019.

In addition to improved income from high value crops, FRC offers socio-cultural opportunities to smallholder farming communities. Crops cultivated under FRC usually include main staple foods; yields of these crops can be improved if the appropriate cultivars are selected. For example, Sidibé et al. (2016) reported that under ideal crop management, sorghum [*Sorghum bicolor* (L.) Moench] yields can reach 2.5 t ha^{-1}, compared to the less than 1 t ha^{-1} under rainfed conditions. Although adoption of improved seed has increased in SSA, 44% of maize (*Zea mays* L.) area in Eastern and Southern Africa (excluding South Africa), and 60% of maize area in West and Central Africa (Smale et al., 2011); there are areas where adoption of certified seed is lagging behind. For example, Houssou et al. (2016) reported that in Ghana, crop yields are constrained by the low availability and use of certified seeds. In 2012, less than five percent of Ghanaian maize producers planted hybrid seed (Ragasa et al., 2013).

Flood-recession cropping started as early as 1500 years B.C. and has been reported to be productive and sustainable in the Mekong Delta where it is has been practised for over two thousand years (Fox & Ledgerwood, 1999; Tien & Ni, 2014). In addition, FRC is an adaptation to climate change because it takes advantage of climate-change induced floods to increase overall agricultural production by growing adapted crops once the floodwater recedes. However, the potential of this farming system has not been adequately quantified and in most cases it has been neglected in research and policy development (Sidibé et al., 2016; Kool et al., 2018).

Challenges faced by FRC farmers include absence of tenure security, uncertainty over implementation of buffer zones (Namara et al., 2010); birds and pest damages, flood insufficiency, inadequate equipment, low N and organic matter levels (Traore et al., 2016). In some cases there are hydrophysical limitations that determine temporal and spatial distribution of crops, for example, in Campo Alegrans floodplain, crop selection was influenced by growing season length as dictated by zonation based on time above water in the order watermelon [*Citrullus lanatus* (Thunb.)], maize, bitter cassava (*Manihot esculenta* Crantz)/sweet cassava, bitter cassava (*M. esculenta*) /maize intercrop, bananas (*Musa* spp.) and fruit trees from lower to higher zones (Shorr, 2000). In Orinoco floodplain, crop selection and cropping patterns were partially based on soil texture, for example, watermelon was planted in sandy soil, beans (*Phaseolus vulgaris* L.) in clay soil and cotton (*Gossypium hirsutum* L.) in mixed soil, but maize and cowpeas [*Vigna unguiculata* L. (Walp)] were ubiquitous (Barrios, 1997).

A major environmental challenge often linked to FRC is nutrient enrichment of water bodies (eutrophication). Bambaradeniya (2003) stated that the Green Revolution increased rice yields but the degree of sustainability of rice cultivation decreased due to problems with eutrophication. However, eutrophication may not be a problem in semi-arid SSA because fertilizer use is minimal. Kelly and

Naseem (2009) reported that the average fertilizer application rate in SSA increased from 3 kg ha^{-1} in 1970 to 10 kg ha^{-1} in 1995 and then declined to 9 kg ha^{-1} in 1997, remaining much lower than 54 kg ha^{-1} in Latin America, 80 kg ha^{-1} in South Asia, and 87 kg ha^{-1} in Southeast Asia. Nyamudeza (1999) reported non-application of fertilizers on vertisols and alluvial soils in the south-eastern Zimbabwe lowveld. This observation was supported by Mapfumo & Giller (2001) who reported that in general smallholder farmers in Zimbabwe did not apply mineral fertilizers. Rusike et al. (2003) added that in southern Zimbabwe, less than 5% of the farmers commonly applied mineral fertilizers.

Crop establishment method in floodplains is usually designed to optimise water use by crops. Chidanti-Malunga (2011) reported on adaptive use of furrows and planting holes depending on soil moisture content: when the soil moisture content was low furrows were reinforced with holing out of planting stations and when the soil moisture content was relatively high only holing out was practised. Under conditions of extended inundation, crop ridges or dykes were constructed. Crop dykes reduce waterlogging stress and facilitate early planting of late maturing crops and high value crops (Kpadonou et al., 2012). Early planting of high value crops ensures that the produce is sold in periods of best prices. Donkoh et al. (2013), recogns that although floodplains have higher natural fertility levels, they are more difficult to till and therefore they require more draught power or labour for crop establishment.

The total floodplain area including area occupied by water bodies in the mid and lower Zambezi Valley is 5 747 809 ha of which 750 583 ha are in northern Zimbabwe (Appendix 1b). Farmers practice FRC, however, there is dearth of information on FRC to guide interventions aimed at increasing crop productivity. The lack of information on FRC is not peculiar to Zimbabwe. Sidibé et al. (2016) reported that Mauritania is the only country in West Africa for which there is reliable information on the contribution of FRC to total national food production. Research is therefore required to improve understanding of FRC and reveal opportunities under this farming system. The objectives of this study were to:

(i) assess the socio-economic importance of FRC to smallholder farmers;
(ii) characterise agronomic practices with respect to maize production;
(iii) determine factors that affect selection of crop establishment method;
(iv) identify the major crop production challenges under FRC; and
(v) identify opportunities to improve productivity and farmers’ livelihoods under FRC.

Research questions that motivated the study were:

(i) What are the FRC farmers' top three sources of livelihood?
(ii) What do farmers use their riparian crop produce for?
(iii) What are the maize agronomic practices used by farmers under FRC?
(iv) What are the factors that affect selection of crop establishment method used by farmers?
(v) What are the top three crop production challenges under FRC?
(vi) What do farmers think should be done to improve crop yields under FRC?
(vii) Which opportunities exist in FRC farming communities?

2.2. Materials and Methods

2.2.1 Description of the study area

The study was conducted in the mid-Zambezi Valley in lower Centenary district (16.12°S; 31.15°E, altitude 334 m a.s.l) and Mbire district (16.17°S; 30.55°E, altitude 356 m a.s.l) (Figure 2.1). The area has a unimodal rainy season (November to March) and it lies in Zimbabwe's agro-ecological regions IV and Va (Manatsa et al., 2020).

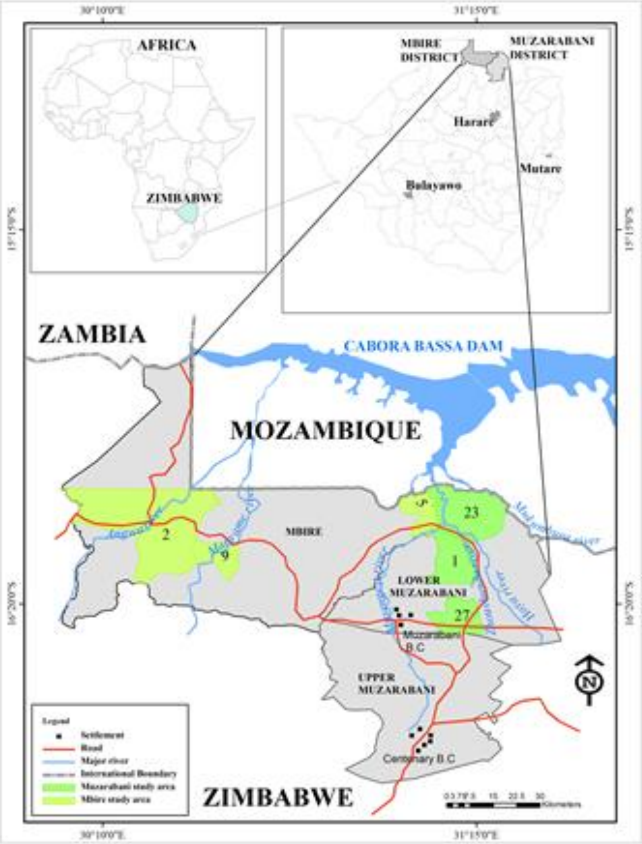
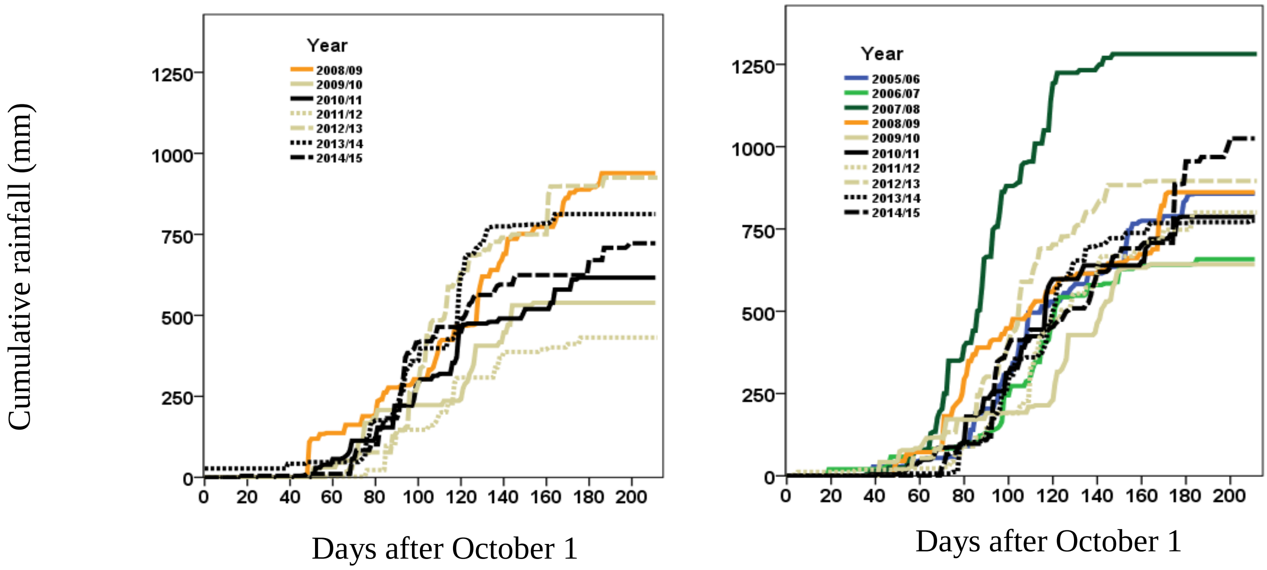


Figure 2.1: Map of the study area

Cumulative seasonal rainfall exhibits high inter-annual variability (Figure 2.2). The mean annual temperature is 25^{o}C and the area is frost free (Pwiti, 1996). Therefore, in this area, summer crops can be grown in winter.



(a)

(b)

Figure 2.2: Cumulative rainfall measured at (a) Mushumbi Pools (16.17^{o}S; 30.57^{o}E) from the 2008/2009 to 2014/2015 rainy seasons and (b) Muzarabani (16.12^{o}S; 31$^{\cdot}$15^{o}E) from 2005/2006 to 2014/2015 rainy seasons in northern Zimbabwe

The area experiences seasonal flooding along Angwa, Manyame and Musengezi rivers in January and February. Floods along Musengezi River are intensified by backflow from Lake Cahora Bassa (Figure 2.1).

Soil type ranges from fine-grained loamy sands to sandy clays or vertisols (Anderson et al., 1993). According to the FAO/UNESCO soil classification system, these include Calcaric Cambisols, Eutric Vertisols, Vertic Cambisols, Chromic Cambisol, Calcic/Chromic Luvisols (Anderson et al., 1993). Based on soil capability classification, these soils generally have high agricultural potential. Maize, cotton, sorghum, and pearl millet (*Pennisetum glaucum* L. R. Br.) are the major upland rainfed crops. The vegetation is typically dry savanna (Hoare et al., 2002) dominated by *Colophospermum mopane* Kirk ex Benth. and species of *Combretum*, *Sterculia* and *Vachellia* (previously *Acacia*). The naturalised *Ziziphus mauritiana* Lam., is dominant along waterways. Dominant grasses include spear grass *Heteropogon contortus* (L.) Beauv. ex Roem. and Schult. and some *Digitaria* species.

Flood-recession cropping is practised from end of March to as late as end of October. The existence of smallholder farming communities' close to the Lower Zambezi-Mana Pools Transfrontier Conservation Area and Mavhuradonha Wilderness, and the existence of perennial rivers intensify human wildlife conflicts (HWC) due to existence of both terrestrial and aquatic wildlife species. Floodplains maintain green vegetation compared to upland areas; the green vegetation and water attract livestock and wildlife that end up destroying crops. In high floods years, floods may destroy rainfed crops due to waterlogging; in such years, FRC becomes a fall-back option. Even if upland rainfed crops are not destroyed by floods, the yields are low due to frequent droughts and dry spells, and poor soil fertility management. For example in rainfed upland fields, in the wards in which riparian cropping is practised, the eight-year (2007/2008 through to 2014/2015 season) mean (standard deviation) yield (t ha^{-1}) was 0.5(0.1) and 0.5(0.3) for cotton; 0.2(0.1) and 0.4(0.2) for maize; 0.4(0.1) and 0.2(0.1) for sorghum in Mbire and Muzarabani Districts respectively (AGRITEX, 2015a and 2015b). Yield data for pearl millet were only available for Mbire and its mean yield was 0.2(0.1) (t ha^{-1}). These low yields result in most of the households failing to meet their food requirements making them heavily dependent on food aid.

Population pressure is increasing in the study area, leading to increased pressure on natural resources and this may intensify HWC. For example the population of Mbire district, which lies wholly in the Zambezi Valley, increased from 73901 in 2002 to 82380 in 2012 and the population of Muzarabani, which has 14 out of 29 wards in the valley increased from 73872 in 2002 to 122791 in 2012 (ZimStat, 2012).

2.2.2 Sampling

Wards 2 (Angwa), 9 (Neshangwe) and 5 (Chidodo) were purposively selected in Mbire district because they are drained by Angwa, Manyame and Musengezi rivers, where FRC is practiced (Figure 2.1). Similarly, wards 1 (Chadereka), 23 (Kairezi) and 27 (Museredza) were purposively selected in Muzarabani district because they are drained by Musengezi River, and its tributaries Mukumbura, Hoya and Zhoubvunda rivers, where FRC is concentrated.

One hundred and twenty three households (30 from Mbire and 93 from Muzarabani) were selected for interviews from a list of FRC farmers provided by AGRITEX. The farmers were drawn from 49 villages in the following river floodplains Angwa (7), Dande (2), Hoya (2), Hunyani (7), Mukumbura (15), Musengezi (82) and Zhoubvunda (8).

2.2.3 Data collection

The study was conducted at the beginning of the FRC season from March to April 2015 as a baseline study to a larger project that sought to optimize maize yield under FRC. A semi-structured questionnaire was the major data collection instrument (Appendix 2). Questionnaires were administered to the selected farmers through face-to-face interviews. Data collected using the questionnaires included household demographic characteristics; livelihood activities; farming experience, education and training; resource endowment; crops grown, maize agronomic practices, crop production challenges and institutional support. The questionnaire was piloted on ten respondents prior to being administered in the field. Piloting was done to pre-test the questionnaire and adjust questions and standardise interviewing techniques in order to improve reliability and validity of the survey. The interviews were conducted by four interviewers who had been trained and had participated in piloting the questionnaire.

In addition to the questionnaire survey, eleven Focus Group Discussions (FGDs) were conducted with a total of 88 farmers (27 males and 61 females) in groups of less than ten FRC farmers per group. According to Berg (2009) groups of six or eight participants are fairly easy to control. The FGDs were conducted in two stages: pre-survey to have an overview of FRC and obtain information for developing the questionnaire and post survey to clarify issues that required further explanation and to minimise omissions. The questionnaire interviews and FGDs were complemented by field observations through transect walks.

2.2.4 Data analysis

Data on socio-economic importance of FRC, crop production challenges; maize agronomic practices; and opportunities under FRC were analysed using descriptive statistics and factors that affected selection of crop establishment method were analysed using the Binary Logistic Regression Model. All data analysis was done using the Statistical Package for Social Sciences (SPSS) Version 20.0.

2.3 Results

2.3.1 Households demographic and socio-economic characteristics

Overall, the majority of FRC households (51%) were headed by women (Table 2.2). Flood-recession cropping contributed 38% and 50% of the total household income in Mbire and Muzarabani respectively. More than half of the respondents did not attempt secondary education. On average, three out of five members in a household provided labour in floodplain cropping activities. Less than 5% of the respondents had received training on FRC from Government and Non-Governmental Organisations (NGOs). Almost all farmers owned a hand hoe, but ≈60% owned an ox-drawn plough. The mean number of draught power animals was less than two per household. Most farmers (≥90%) practised both upland rainfed cropping and FRC. The mean number of cattle, the major draught power source in the study area, was three (3).

Table 2.2: Demographic and socio-economic characteristics of flood-recession cropping households in the mid-Zambezi Valley

Demographic or socio-economic variable		**Mbire district**		**Muzarabani district**		**Overall**	
		Frequency (Percent)	**Mean± SD[1]**	**Frequency (Percent)**	**Mean±SD**	**Frequency (Percent)**	**Mean±SD**
Gender of household head	Male	17 (56.7)		43 (46.2)		60 (48.8)	
	Female	13 (43.3)		50 (53.8)		63 (51.2)	
Age of household head			40.2±16.6		45.1±15.2		43.9±15.6
Education level of household head	No formal education	6 (20.0)		17 (18.3)		23 (18.7)	
	Primary school education	15 (50.0)		35 (37.6)		50 (40.7)	
	Secondary school education	9 (30.0)		41 (44.1)		50 (40.7)	
Floodplain farming training institution	Government extension department	0 (0.0)		2 (2.2)		2 (1.6)	
	Non-governmental organizations	1 (3.3)		3 (3.2)		4 (3.3)	
	None	29 (96.7)		88 (94.6)		117 (95.1)	
Source of extension advice	Government extension department	0 (0.0)		3 (3.2)		3 (2.4)	
	Other farmers	0 (0.0)		20 (21.5)		20 (16.3)	
	None	30 (100.0)		70 (75.3)		100 (81.3)	
Occupation	Formal	3 (10.0)		0 (0.0)		3 (2.4)	
	Informal	27 (90.0)		93 (100.0)		120 (97.6)	
Number of household members	Total		4.5±2.4		5.4±2.2		5.20±2.3
	Available for labour in floodplain fields		3.1±1.7		3.3±1.4		3.3±1.5
Number of years of practicing flood-recession cropping			15.8±11.9		14.1±12.3		13.3±12.2
Field cropped	Floodplain and rainfed upland	27 (90.0)	1.7±1.8	88 (94.6)		115 (93.5)	
	Floodplain only	3 (10.0)		5 (5.4)		8 (6.5)	
Area of floodplain field (ha)			1.0±0.8		1.1±1.5		1.0±0.7
Maize harvested as grain (t ha^{-1})			1.6±1.2		1.8±1.1		1.7±1.1
Household Income (US$)	Total		429.8±611.0		709.6±972.0		640.3±901.8
	From flood-recession cropping		164.7±140.2		356.7±360.0		322.4±339.1
Ownership of agricultural tools or equipment in good working condition	Ox-drawn plough	17 (56.7)		56 (60.2)		73 (59.3)	
	Ox- drawn ripper	2 (6.7)		5 (5.4)		7 (5.7)	
	Ox-drawn cultivator	3 (10)		5 (5.4)		8 (6.5)	
	Ox-drawn ridger	1 (3.3)		2 (2.2)		3 (2.4)	
	Slasher/Sickle	0 (0.0)		22 (23.7)		22 (17.9)	
	Hand hoe	30 (100.0)		92 (98.9)		122 (99.2)	
Livestock ownership	Cattle (*Bos Taurus* L.)		2.1±2.3		3.1±4.0		2.9 ±3.6
	Donkeys (*Equus africanus asinus* L.)		0.3±1.1		0.3±1.2		0.3±1.1
	Available for draught power		1.2±1.4		1.7±1.8		1.5±1.7

[1] SD =Standard Deviation

2.3.2 Main sources of livelihood for flood-recession cropping farmers

In addition to FRC, the major sources of livelihood for respondents were upland rainfed cropping, gardening, livestock production and non-timber forest products (Table 2.3).

Table 2.3: Ranking of sources of livelihood by flood-recession cropping farmers in the mid-Zambezi Valley

Livelihood source	**Mbire district**				**Muzarabani district**				**Overall**			
	Ranking by farmers			**Score**[1]	**Ranking by farmers**			**Score**[1]	**Ranking by farmers**			**Score**[1]
	First	**Second**	**Third**		**First**	**Second**	**Third**		**First**	**Second**	**Third**	
	Frequency (Percent)	**Frequency (Percent)**	**Frequency (Percent)**		**Frequency (Percent)**	**Frequency (Percent)**	**Frequency (Percent)**		**Frequency (Percent)**	**Frequency (Percent)**	**Frequency (Percent)**	
Flood-recession cropping	28 (93.3)	3 (10.0)	0 (0.0)	**90**	78 (83.9)	16 (17.2)	1 (1.1)	**267**	106 (86.2)	19 (15.4)	1 (0.8)	**357**
Upland rainfed cropping	1 (3.3)	19 (63.3)	2 (6.7)	**43**	12 (12.9)	43 (46.2)	13 (14.0)	**135**	13 (10.6)	62 (50.4)	15 (12.2)	**178**
Gardening	0 (0.0)	3 (10.0)	8 (26.7)	**14**	0 (0.0)	10 (10.8)	26 (28.0)	**46**	0 (0.0)	13 (10.6)	34 (27.6)	**60**
Livestock production	0 (0.0)	1 (3.3)	6 (20.0)	**8**	2 (2.2)	8 (8.6)	17 (18.3)	**39**	2 (1.6)	9 (7.3)	23 (18.7)	**47**
Non-timber forest products	0 (0.0)	1 (3.3)	6 (20.0)	**8**	0 (0.0)	10 (10.8)	18 (19.4)	**38**	0 (0.0)	11 (8.9)	24 (19.5)	**46**
Remittances	0 (0.0)	1 (3.3)	3 (10.0)	**5**	0 (0.0)	1 (1.1)	1 (1.1)	**3**	0 (0.0)	2 (1.6)	4 (3.3)	**8**
Buying and selling	0 (0.0)	0 (0.0)	0 (0.0)	**0**	1 (1.1)	2 (2.2)	0 (0.0)	**7**	1 (0.8)	2 (1.6)	0 (0.0)	**7**
Building	0 (0.0)	0 (0.0)	1 (3.3)	**1**	0 (0.0)	2 (2.2)	2 (2.2)	**6**	0 (0.0)	2 (1.6)	3 (2.4)	**7**
Fishing	0 (0.0)	2 (6.7)	0 (0.0)	**4**	0 (0.0)	1 (1.1)	0 (0.0)	**2**	0 (0.0)	3 (2.4)	0 (0.0)	**6**
Salary/Wage	1(3.3)	0 (0.0)	1 (3.3)	**4**	0 (0.0)	0 (0.0)	1 (1.1)	**1**	1 (0.8)	0 (0.0)	2 (1.6)	**5**
Casual labour	0 (0.0)	0 (0.0)	1 (3.3)	**1**	0 (0.0)	0 (0.0)	0 (0.0)	**Nil**	0 (0.0)	0 (0.0)	1 (0.8)	**1**

Key: [1]Three points earned for being ranked first, two points for being ranked second and one for being ranked third by the respondents.

2.3.3 Crops grown

Maize was planted by more than 70% of FRC farmers in both districts and it occupied more than 44% of the total cropping land (Table 2.4). The marketing period for crop produce was June to December. A significant proportion of households that grew food crops used them for home consumption only: maize (21%), sugar beans (21%) and sweet potato (39%) in Muzarabani; and sweet potato (57%) in Mbire. Other crops that were either observed during farmers interviews in crop fields or mentioned during FGDs were leaf vegetables (*Brassica* spp.), onions (*Allium cepa* L.), pumpkins (*Cucurbita* spp.), cucumbers (*Cucumis sativus* L.) and potatoes (*Solanum tuberosum* L.).

Table 2.4: Major crops grown under flood-recession cropping in the mid-Zambezi Valley (N = 123)

District	**Crop**	**Frequency (Percent)**	**Mean area ± [3]SD (ha)**	**Crop Use [1][Frequency (Percent)]**				**Marketing period (Peak period)**
				[2]Selling			**Home Consumption only**	
				Local buyers	**External buyers**	**Local plus External buyers**		
Mbire	Maize (*Zea mays* L.)	22 (73.3)	0.44±0.29	20 (90.9)	0 (0.0)	0 (0.0)	2 (9.1)	Jun-Dec (Aug-Nov)
	Okra [*Abelmoschus esculentus* (L.) Moench]	5 (16.7)	0.28±0.19	4 (80.0)	0 (0.0)	1 (20.0)	0 (0.0)	Jun-Jan (Aug-Sept)
	Cowpea [*Vigna unguiculata* L. (Walp)]	13 (43.3)	0.18±0.16	11 (84.6)	0 (0.0)	0 (0.0)	2 (15.4)	Jun-Dec (Oct-Nov)
	Sweet-potato (*Ipomoea batatas* L.)	14 (46.7)	0.45±0.76	4 (28.6)	0 (0.0)	2 (14.3)	8 (57.1)	Jun-Dec (Aug-Sep)
	Sugar Beans (*Phaseolus vulgaris* L.)	1 (3.3)	0.40	0 (0.0)	0 (0.0)	0 (0.0)	1 (100.0)	Not applicable
Muzarabani	Maize	72 (77.4)	0.60±0.39	53 (73.6)	3 (4.2)	1 (1.4)	15 (20.8)	Jun-Dec (Jul-Oct)
	Okra	58 (62.0)	0.32±0.28	22 (37.9)	26 (44.8)	10 (17.2)	0 (0)	Jun-Dec (Jul-Oct)
	Cowpea	35 (37.6)	0.22±0.22	29 (82.6)	1 (2.9)	1 (2.9)	4 (11.4)	Aug-Dec (Oct-Nov)
	Sweet-potato	31 (33.3)	0.17±0.16	18 (58.1)	0 (0.0)	1.(3.2)	12 (38.7)	Jun-Dec (Aug-Oct)
	Sugar Beans	28 (30.1)	0.15±0.10	16 (57.1)	3 (10.7)	3 (10.7)	6 (21.4)	Jun-Dec (Aug-Oct)
	Tomato (*Lycopersicon esculentum* Mill.)	15 (16.1)	0.14±0.18	10 (66.7)	0 (0.0)	4 (26.7)	1 (6.7)	Jun-Oct (Jul-Aug)
	Watermelon [*Citrullus lanatus* (Thunb.)]	2 (2.2)	0.19±0.15	0 (0.0)	0 (0.0)	2 (100.0)	0 (0.0)	Aug-Oct
Overall	Maize	94 (76.4)	0.56±0.37	71 (75.5)	3 (3.2)	1 (1.1)	19 (20.2)	Jun-Dec (Jul-Oct)
	Okra	63 (51.2)	0.32±0.28	25 (39.7)	26 (41.3)	11 (17.5)	1 (1.6)	Jun-Dec (Jul-Oct)
	Cowpea	48 (39.0)	0.21±0.20	39 (81.3)	1 (2.1)	1 (2.1)	7 (14.6)	Aug-Dec (Oct-Nov)
	Sweet-potato	45 (36.6)	0.25±0.45	22 (48.9)	0 (0.0)	2 (4.4)	21 (46.7)	Jun-Dec (Aug-Sep)
	Sugar Beans	29 (23.6)	0.16±0.11	16 (55.2)	3 (10.3)	3 (10.3)	7 (24.1)	Jun-Dec (Aug-Oct)
	Tomato	15 (12.2)	0.14±0.19	10 (66.7)	0 (0.0)	4 (26.7)	1 (6.7)	Jun-Oct (Jul-Aug)
	Watermelon	2 (1.6)	0.19±0.15	0 (0.0)	0 (0.0)	2 (100)	0 (0.0)	Aug-Oct

[1] Frequency and percent of farmers who grew a particular crop.

[2] Local buyers represent buyers from the Zambezi Valley, external buyers represent buyers from outside the Zambezi Valley

[3] SD =Standard Deviation

2.3.4 Maize agronomic practices

At least 50% of the farmers (75% in Muzarabani and 50% in Mbire) prepared planting stations by making furrows and holing out. This entailed opening furrows using the ox-drawn mouldboard plough by making three runs in a single furrow followed by holing out planting stations using a hand hoe. Making furrows only was practised by 10% of the farmers in Muzarabani and 20% in Mbire while holing out only was practised by 15% of the farmers in Muzarabani and 30% in Mbire. Farmers (57% in Muzarabani and 37% in Mbire) stated that the major reason for furrow + holing out was to reach a depth with adequate soil moisture for successful crop emergence and establishment. Other reasons cited in both districts were that it was easier to dig in a furrow than on unploughed land (<10%) and that making furrows helped in weed management (<10%).

Reasons for furrow only were cited by few farmers: inadequate labour for digging planting holes (<2%); the need to do operations timeously (8% in Muzarabani and 3% in Mbire); minimizing costs (0% in Muzarabani and 13% in Mbire); 0% of the farmers in Muzarabani and 3% in Mbire perceived that furrow only was not different from furrow and holing out. Reasons cited for holing out only were: lack of draught power (9% in Muzarabani and 10% in Mbire); soil conservation (4% in Muzarabani and 7% in Mbire) and moisture conservation (2% Muzarabani and 13% in Mbire).

Mean (standard deviation) dimensions (m) of planting hole reported by farmers were: depth, 0.28(0.13) and 0.28(0.11); and diameter, 0.24(0.11) and 0.16(0.14) m in Muzarabani and Mbire respectively. Maize in-row spacing (m) was 0.63(0.25) in Muzarabani and 0.69(0.30) in Mbire; and inter-row spacing was 0.87(0.21) in Muzarabani and 0.83(0.18) Mbire. Most farmers planted ≥4 maize seeds per planting station (63% in Muzarabani and 100% in Mbire). During FGDs, farmers reported that as the maize grew, part of the soil dug from the pit was gradually returned to the pit to create a ‘mulching effect’. At 0.15 m maize plant height above ground level, the pit was completely covered with soil and plants were left to grow till maturity.

More farmers applied inorganic fertilizer in Mbire (23%) than Muzarabani (4%). Most farmers (91% in Muzarabani and 100% in Mbire) planted retained seed of which 68% in Muzarabani and

93% in Mbire planted *Kanongo/kamudande* (a local yellow cultivar with some black-brown stains) and retained seed from hybrid cultivars. *Kanongo* was perceived to be drought-tolerant and to have a relatively high harvest index. Only 9% of the farmers in Muzarabani planted certified seed namely SC403, SC513, SC627 and PAN43 and none planted certified seed in Mbire. In the two districts, all farmers practiced mechanical weeding using hand hoes while only 4% in Muzarabani and 7% in Mbire applied herbicides. At least three quarters of the farmers (75% in Muzarabani and 80% in Mbire) performed two or less weeding operations in their fields. The most problematic weed was the yellow nutsedge (*Cyperus esculentus* L.), which the farmers reported to have come with floodwaters.

2.3.5 Factors affecting selection of crop establishment method

A combination of furrow + holing out was more likely to be practised by: farmers from Muzarabani district, households with more members who provided labour, farmers who perceived area of their fields as being inadequate, farmers who owned more draught power animals, and farmers who cited high temperature as a production challenge. However, the more the years a farmer had practised FRC, the less likely they were to practise furrow + holing out (Table 2.5).

Table 2.5: Factors affecting selection of crop establishment (furrow + holing out)

Factor	**B**	**S.E.**	**Wald**	**df**	**Sig.**	**Exp(B)**
Farmers' floodplain field location (district)	1.329	.667	3.965	1	.046	3.776
Number of members of the household available for labour in floodplain fields	.865	.275	9.875	1	.002	2.375
Number of years farmer had practised flood-recession cropping (FRC)	-.096	.035	7.340	1	.007	.909
Ownership of a mouldboard plough	-.752	.664	1.284	1	.257	.471
Gender of household head	.011	.652	.000	1	.987	1.011
Household annual income	-.001	.000	3.114	1	0.078	.999
Farmer training on FRC	-.320	1.243	.066	1	.797	.726
Land area under FRC	.644	.491	1.718	1	.190	1.903
Farmer's perception of FRC land area as inadequate	1.788	.610	8.597	1	.003	5.980
Number of draught power animals owned	.555	.241	5.325	1	.021	1.743
Farmer's perception of too much sand deposition in the floodplain field	1.506	.956	2.481	1	.115	4.511
Farmer's perception of high temperature as a production challenge	2.080	.968	4.617	1	.032	8.003
Farmer's access to FRC advice	-1.212	.984	1.519	1	.218	.298
Level of education of household head	.368	.497	.547	1	.459	1.444
Constant	**10.022**	**4.768**	**4.418**	**1**	**.036**	**.000**

[1] Model Summary: -2 Log likelihood =81.837; Cox and Snell R Square = .384; Nagelkerke R Square =.547
Where B = coefficient, S.E = Standard error, Wald = Wald statistic, df = Degrees of freedom, Sig. = Significance, Exp(B) = Exponent B.

2.3.6 Crop production challenges

The highest ranked production challenge was crop destruction by pests (Table 2.6). The major pests were: red-billed quelea bird (*Quelea quelea* L.); mice (*Mus musculus*); crickets (superfamily Grylloidea), including armoured bush crickets (*Acanthroplus discoidalis* Walker); armyworms (Superfamily Noctuidae); maize stalkborer (*Busseola fusca* Fuller); and locusts (*Locusta migratoria* L.). Fall armyworm [*Spodoptera frugiperda* (J. E. Smith)] was new in the area and some farmers mistook it for maize stalkborer and referred to it as "maize stalkborer-like worm". The second and third ranked production challenges were inadequate labour and inadequate equipment respectively.

Table 2.6: Ranking of crop production challenges by flood-recession cropping farmers in the mid-Zambezi Valley

Challenge	**Mbire**				**Muzarabani**				**Overall**			
	Ranking by respondents			**Score[1]**	**Ranking by respondents**			**Score[1]**	**Ranking by respondents**			**Score[1]**
	First (n=17)	**Second (n=7)**	**Third (n=4)**		**First (n=55)**	**Second (n=33)**	**Third (n=27)**		**First (n=72)**	**Second (n=40)**	**Third (n=31)**	
	Frequency (Percent)	**Frequency (Percent)**	**Frequency (Percent)**		**Frequency (Percent)**	**Frequency (Percent)**	**Frequency (Percent)**		**Frequency (Percent)**	**Frequency (Percent)**	**Frequency (Percent)**	
Pest damage	9 (30.0)	3 (10.0)	0 (0.0)	**33**	20 (21.5)	9 (9.7)	6 (6.5)	**84**	29 (23.6)	12 (9.8)	6 (4.9)	**117**
Inadequate labour	4 (13.3)	0 (0.0)	0 (0.0)	**12**	12 (12.9)	1 (1.1)	2 (2.2)	**40**	16 (13)	1 (0.8)	2 (1.6)	**52**
Inadequate equipment	3 (10.0)	2 (6.7)	0 (0.0)	**13**	9 (9.7)	3	0 (0.0)	**33**	12 (9.8)	5 (4.1)	0 (0.0)	**46**
Weeds	0 (0.0)	0 (0.0)	1 (3.3)	**1**	2 (2.2)	4 (4.3)	6 (6.5)	**20**	2 (1.6)	4 (3.3)	7 (5.7)	**21**
High temperature	0 (0.0)	0 (0.0)	0 (0.0)		4 (4.3)	4 (4.3)	1 (1.1)	**21**	4 (3.3)	4 (3.3)	1 (0.8)	**21**
Inadequate draught power	0 (0.0)	1 (3.3)	0 (0.0)	**2**	4 (4.3)	3 (3.2)	1 (1.1)	**19**	4 (3.3)	4 (3.3)	1 (0.8)	**21**
Inadequate knowledge	0 (0.0)	0 (0.0)	1 (3.3)	**1**	2 (2.2)	3 (3.2)	5 (5.4)	**17**	2 (1.6)	3 (2.4)	6 (4.9)	**18**
Inadequate moisture	0 (0.0)	0 (0.0)	2 (6.7)	**2**	2 (2.2)	1 (1.1)	4 (4.3)	**12**	2 (1.6)	1 (0.8)	6 (4.9)	**14**
Inadequate land	1 (3.3)	0 (0.0)	0 (0.0)	**3**	0 (0.0)	4 (4.3)	1 (1.1)	**9**	1 (0.8)	4 (3.3)	1 (0.8)	**12**
Poor soil fertility	0 (0.0)	0 (0.0)	0 (0.0)		0 (0.0)	1 (1.1)	1 (1.1)	**3**	0 (0.0)	1 (0.8)	1 (0.8)	**3**
Theft	0 (0.0)	1 (3.3)	0 (0.0)	**2**	0 (0.0)	0 (0.0)	0 (0.0)	**84**	0 (0.0)	1 (0.8)	0 (0.0)	**2**

Key: [1]Three points earned for being ranked first, two points for being ranked second and one for being ranked third by the respondents.

2.3.7 Crop destruction by animals

Crop destruction by terrestrial wildlife that included elephants (*Loxodonta africana*), baboons (*Papio ursinus*), monkeys (*Cercopithecus* spp.), warthogs (*Phacochoerus africanus*), duikers (*Philantomba monticola*) was reported by more respondents in Muzarabani (30%) than Mbire (17%); whilst crop destruction by marine wildlife that included hippopotamus (*Hippopotamus amphibius*) was more common in Mbire (27%) than Muzarabani (8%). Damage by livestock; cattle (*Bos Taurus* L.), goats (*Capra aegagrus hircus* L.) and donkeys (*Equus africanus asinus* L.) was more prevalent in Muzarabani (40%) than Mbire (17%).

2.3.8 Farmers' perceptions on improving flood-recession cropping

Over one third of the farmers in both districts conceded that they needed training and extension support for them to improve FRC productivity. More than a quarter of the respondents in Mbire and close to half in Muzarabani mentioned that certified seed was essential for improved FRC. Less than a quarter of the respondents (13% in Mbire and 24% in Muzarabani) perceived improving market availability and accessibility as important requirements for improving FRC productivity.

2.4 Discussion

Results showed that a significant proportion of households that practise FRC are female-headed (Table 2.2), therefore, this farming system can be used a tool to empower women. However, in line with findings elsewhere (Oyebande, 2001; Koundouri *et al*., 2003; Sidibé et al., 2016), FRC is neglected by both Government and NGOs in Zimbabwe as only 5% of the respondents had received some training. This can be attributed to the stigma associated with FRC in Zimbabwe, where it is often associated with illegal streambank cultivation. Zimbabwe's Environmental Management Act [Chapter 20:27] stipulates a minimum riparian buffer width of 30 m (Government of Zimbabwe, 2007). Whilst the buffer strip is important for reducing riverbank erosion, the requirement does not consider differences in river sections and management practices.

Existence of diversified sources of livelihood (Table 2.3) implies that FRC farmers have multiple sources of income, which make them more resilient in the event of natural disasters such as droughts or floods. The major livelihood sources are primary agricultural produce and exploitation of natural resources. This shows that natural resources are important to FRC farmers, therefore, natural resources management should promote best practices rather than preservation of environmental assets (Kolawole & Kashe, 2019). However, direct exploitation of natural resources should be coupled with post-harvest processing of and value addition to the crop produce in order to increase and diversify income sources. In line with findings by Mucherera and Mavhura (2020), more than 90% of the farmers practised both rainfed and FRC. Upland rainfed cropping and FRC are practised during different times of the year, albeit with a small overlap at the end of the rainy season. This implies that the period with competition for labour between the two complementary farming systems is minimal. In fact by extending the crop growing season, FRC has potential to reduce seasonal rural-urban migration during the dry season as reported by Balana et al. (2019).

Crops grown by FRC farmers in the mid-Zambezi Valley that include food crops (maize, sweet potato and sugar beans) and high value vegetable crops (okra, tomato, and watermelon) (Table 2.4) contribute to food security and household income. The majority of farmers (94%) grew maize, which is the main staple food and a major cash crop. During FGDs farmers reported that most of the maize was sold as green mealies that fetched good prices during the dry season. Therefore, although higher, the maize grain yield (1.7 t ha^{-1}) reported in this study (Table 2.2) possibly understated the actual yield.

At least a fifth of the farmers who grew staple food crops used the produce for home consumption in Muzarabani, thus underlying the importance of FRC to household food security. In most FRC systems, crops are less exposed to diseases because plants mature in dry conditions, therefore, the quality of grain and crop residue is good (Sidibé et al., 2016). This was found to be true in the mid-Zambezi

Valley, where cowpea, which is usually an important food crop, was a lucrative cash crop because of the good quality of its leaves and grain. The cowpea leaves were not contaminated by mud, which is usually added through raindrop splash or runoff water under rainfed cropping. The ripening and marketing period of most flood-recession crops covers the period when such crops are out of season in the Highveld. This creates viable local and external markets. Although local buyers dominated the market, we established from FGDs that they mainly act as ‘middlemen’ who export the products to urban centres in the Highveld.

This study revealed that one of the objectives of tillage under FRC is to enable planting into moist soil to improve crop emergence and reduce moisture stress during the crop growing period. Our results corroborate findings by Kpadonou et al. (2012) who reported that farmers used cropping dykes and agro-fingerponds for managing water and maximizing season length. Similar to our findings, Chidanti-Malunga (2011) reported that FRC farmers dug planting holes instead of making ridges in order to reduce the rate of drying out of the soil. The same author found out that in dry years, farmers dug planting holes in furrows, a practice that is common in the Zambezi Valley and unique to FRC in Zimbabwe. The percentage of farmers who used ox-drawn plough based crop establishment methods (furrow + holing out, and furrow only) exceeded the percentage of farmers who owned an ox-drawn plough (85% versus 60% in Muzarabani and 70% versus 57% in Mbire), implying that some farmers outsourced tillage. Outsourcing equipment was made easier by the fact that at the peak of the FRC period, rainfed crops were at ripening stage, therefore, there was no competition for crop establishment equipment and draught power between upland rainfed cropping and FRC. Outsourcing equipment may have been motivated by the fact that floodplain soils are more difficult to till; therefore they require more draught power or labour as stated by Donkoh et al. (2013). Given that labour, equipment and draught power were major production constraints, yield benefits of the different crop establishment methods identified in this study need to be quantified. Oosterbaan et al. (1986) reported that crop establishment method was influenced by the economic status of farmers; where the very poor used the hand hoe, the poor used donkeys, and the relatively wealthy used oxen-traction. In this study, the most resource and labour intensive crop establishment method, furrow + holing out, was practiced by better resourced households in terms of labour and ownership of draught power animals. Furrow + holing was perceived to improve crop establishment, therefore, farmers who regarded their flood-recession cropping land area as inadequate and those who perceived high temperatures as a production challenge might have opted for this crop establishment method as mitigation against low soil moisture.

Flood-recession cropping planting holes dimensions for maize mean (standard deviation): depth, 0.28 m; and diameter, 0.24 m in Muzarabani and 0.16 in Mbire, differ from those reported under conservation agriculture that are usually 0.15 m long, 0.15 m wide and 0.15 m deep for maize (Mupangwa et al., 2006; Twomlow et al., 2008). The differences stem from the tillage objectives, which are reaching a depth with adequate moisture for crop emergence and supporting crop growth during the entire growth cycle under FRC versus collecting adequate runoff water for crop emergence under rainfed cropping. The deep planting hole and practice of covering maize planting holes imply that some of the nodes that are usually aerial (du Plessis, 2003) are buried below the soil surface (Appendix 3) and this may lead to development of more roots at nodes below the soil surface. If more roots develop, this may lead to higher crop productivity.

Mean maize inter-row spacing fell within the range of spacing recommended by seed companies and those reported in literature but the in-row spacing (0.63 m in Muzarabani and 0.69 m in Mbire) was larger. Farmers probably opt for wider in-row spacing inorder to reduce labour, since digging planting holes is done manually. In order to compensate for the large in-row spacing, which reduces plant population, most farmers planted more seeds per station, targeting >4 plants per station. The high seeding rate can also be attributed to poor crop emergence because more than 90% of the farmers used uncertified seed, which is of unknown viability. Our results are in line with findings by Ragasa et al. (2013) who reported that less than 5% of Ghanaian maize producers used hybrids. Low use of certified seed can be attributed to its unaffordability to smallholder farmers.

Crop damage by pests was the topmost ranked challenge; this can be partially attributed to the emergence of the devastating fall armyworm in 2015. The mid-Zambezi Valley floodplains occur on the Zimbabwean and Mozambican sides thus pausing challenges with control of transboundary pests like the fall armyworm. This can be tackled through collaborative transboundary research involving scientists from the two countries. Given, the overlap between the rainy and the FRC seasons and the extension of the maize growing season, there is a danger that cultivated floodplains may create a reservoir for the fall armyworm and other pests, which then later migrate into the rainfed uplands. Farmers reported inadequate labour and inadequate equipment as the second and third most important production constraints (Table 2.6); therefore, there is need to develop FRC labour efficient technologies and avail affordable equipment financing schemes. These production challenges are similar to those identified by Traore et al. (2016).

In sharp contrast to their dominance as crop production constraints in rainfed smallholder systems of SSA, soil moisture deficit and poor soil fertility were among the least important challenges in FRC. In floodplains, soil infertility is usually linked to soil salinity (Cemek et al., 2007). Although soil salinity was not mentioned as a crop production constraint, flood- recession crops in the mid-Zambezi Valley have different tolerance levels to soil salinity (Appendix 4). It is highly likely that farmers planted crops in areas where they were best adapted based on salinity levels. This is a common practice, for example, Hassan (1997) reported that although wheat (*Triticum aestivum* L.) was preferred it was replaced by barley (*Hordeum vulgare* L.), which is more tolerant to soil salinity and moisture fluctuations. Therefore, there is need to determine soil physico-chemical characteristics, and moisture and salinity dynamics in the floodplain soils. Low fertilizer usage, evidenced by the fact that only 9% of the farmers applied inorganic fertilizer, may be regarded as confirmation that the floodplain soils are fertile. However, because there is generally low adoption of fertilizers in smallholder farming systems of semi-arid SSA (Nyamudeza, 1999; Mapfumo & Giller, 2001; Kelly & Naseem 2009), the fertility status of the floodplain soils should be confirmed through soil analyses. Depending on results from soil analyses, agronomic experiments may be required to quantify benefits of fertilizer application. Applying small quantities of fertilizers (microdosing) may prove beneficial for flood-recession crops.

There is scope to investigate yield gaps between current farmers' and achievable yields under FRC in the mid-Zambezi Valley floodplains and determine to what extent they can be bridged by modern agronomic practices e.g., use of hybrid seed. Priority should be given to implementation of relatively low-investment and low-skill interventions that have the potential to increase resource efficiency. For example, manipulating planting dates, crop spacing, cultivar selection and weeding intensities may increase crop productivity (Tittonell & Giller, 2013).

2.5 Conclusions

Flood-recession cropping is socio-economically important to FRC smallholder farmers in the mid-Zambezi Valley as evidenced by being ranked first among sources of livelihood. It contributes to at least half the annual household income. Crops grown under FRC include food crops (maize, sweet potato and sugar beans) and high value crops (okra, cowpea, tomato and watermelon), which complement each other by serving the socio-cultural and economic needs respectively.

The top three crop production challenges were pest damage, inadequate labour and shortage of equipment. Farmers practised minimum tillage that included opening furrows with the mouldboard plough, holing out and combinations of the two. Better resourced farmers were more likely to select a combination of furrow and holing out. Flood-recession farmers used unusually wider inrow spacing (≈0.60 m) and planted seeds at relatively deeper soil depth (≈0.30 m) and planted at high seeding rates that resulted in ≥ 4 plants per station. There was low use of inorganic fertilizers and certified seed.

There are opportunities to improve crop yields through using certified seed, utilising appropriate crop establishment methods, optimising plant spacing, and microdosing with inorganic fertilizers. Socio-economic opportunities of FRC include sale of fresh produce such as green mealies and leaf vegetables that has potential to fetch high market prices, create employment during the dry season, and diversify food and income.

2.6 Recommendations

There is need to conduct agronomic research, which prioritises the top three challenges cited by the farmers namely, crop damage by pests, inadequate labour and inadequate equipment. Crop yield benefits of using certified seed, applying inorganic fertilizers; and plant spacing and crop establishment methods used by farmers should be determined. Research on benefits of inorganic fertilizers should be preceded by determination of the productivity potential of floodplain soils through soil fertility analyses. There is also need to conduct research on optimisation of the FRC farming system using appropriate econometrics models. This should consider the optimum crop mix and land areas. Government should provide funding for research, extension and farmer training on FRC and extend production incentives to FRC farmers.

CHAPTER 3: FERTILITY STATUS OF CULTIVATED FLOODPLAIN SOILS IN THE ZAMBEZI VALLEY, NORTHERN ZIMBABWE

Abstract

Flood-recession cropping (FRC) improves smallholder farmers' household food security. The objective of this study was to determine the fertility status of cultivated Zambezi Valley floodplain soils, in northern Zimbabwe. The study was conducted at three sites, along tributaries of Musengezi River. Soil samples were taken at 0.20 m depth increments to 0.60 m from hydromorphologically stratified fields, between June and July 2015, during the FRC season. Sampling points were replicated twice in each stratum at points equidistant from river edges. Relative elevations of sampling points were measured using Leica Runner 20 Automatic level equipment. Soil was analysed using: core method for bulk density, hydrometer method for texture, loss on ignition for soil organic carbon (SOC), Kjeldahl procedure for total nitrogen (N), 0.01 M $CaCl_2$ for pH, and Inductively Coupled Plasma (ICP) for Mehlich 3 extractable elements; Potassium (K), Calcium (Ca), Magnesium (Mg), Sodium (Na), Copper (Cu), Zinc (Zn), Manganese (Mn), Boron (B), Molybdenum (Mo), Nickel (Ni), Cobalt (Co) and Iron (Fe). Data from soil analyses were subjected to One Way Analysis of Variance and Pearson's correlation analysis. Bulk density ranged from 1.2 to 1.4 g cm^{-3} and it was negatively related to distance from river; and positively related to elevation at two sites. Highest values for SOC and total N were 2.04 % and 0.36 % respectively. Soil pH ranged from 7.70 to 8.60. Soil organic C and N were positively related to distance from river but negatively related to elevation. Threshold concentrations for deficiency: <12 ppm for K, and <39 ppm for Mg, were exceeded. Calcium, Na, and micronutrients in most cases exceeded concentrations reported for floodplains. It was concluded that Zambezi Valley floodplain soils are relatively fertile but the high concentrations of basic cations increased the likelihood of occurrence of saline soils. Edaphic conditions were not necessarily better closer to the river channel. Where necessary, fertilizer microdosing may be applied based on soil analysis.

Keywords: Fertilizer microdosing; Flood-recession cropping; Relative elevation; Residual moisture; Riparian.

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3.1 Introduction

Floodplains are among the most productive ecosystems in the world, usually endowed with fertile alluvial soils and water resources (Adams, 1993; Pwiti, 1996; Lynch & Brown, 2000; Koschorreck & Darwich, 2003; Rinklebe et al., 2007). Flood-recession cropping (FRC), planting crops after a seasonal flood recedes, provides multifaceted adaptation to extreme weather conditions namely droughts and floods; poor rainfall distribution and poor soil fertility that often limit crop productivity in semi-arid Sub-Saharan Africa (SSA) (Postel, 2000; Motsumi et al., 2012). In addition, floodplains provide a unique setting that is able to support more crop production intensification than the adjacent upland areas. Flood-recession cropping is so lucrative that in some cases, smallholder farmers continue to live in areas where regular flood-related disasters that include drowning of people and livestock, disease outbreaks, attack of people and livestock by wildlife, and loss of property occur regularly (Mavhura et al., 2013). Efficient management and sustainable utilisation of floodplains reduces food import costs through improved crop productivity. The economic value of FRC in the Zambezi basin was estimated at US$50 million (Schuyt, 2005).

According to Postel (2000), the majority of water-stressed populations in 2025 will be in SSA and Asia. Therefore, the ability to thrive despite local extreme weather events that are associated with climate change implies that FRC will increase in importance as climate change intensifies. In addition, the need to meet the food requirements of an ever-growing population (Schuyt, 2005; Mathews et al., 2013; Schewe et al., 2014) and to support sustainable rural livelihoods (Andriesse et al., 2007), will contribute to pressure on floodplains. Low crop yields obtained in upland fields caused by extreme weather events will force more and more people to practise FRC in the fertile but environmentally fragile floodplains. Under these conditions, best management practices need to be developed to optimise crop productivity and environmental protection. In fact, opening up new areas in floodplains should be minimized in order to strike a balance between agriculture and nature. Therefore, as Nyamangara et al. (2000) asserts, with respect to communal areas, increases in crop production must be achieved by increasing the productivity of currently cultivated land rather than opening up virgin land. Although floodplains share some common attributes, differences exists, and this necessitates development of site-specific ‘best fit’ technologies and policies.

The ability of farmers to maintain soil fertility over time has been a major challenge in upland smallholder farming areas in SSA (Nyamangara et al., 2000; Tittonell & Giller, 2013). In these areas, a decrease in soil organic matter content has led to prevalence of degraded non-responsive soils (Mapfumo & Giller, 2001; Tittonell & Giller, 2013). The single most important nutrient element that limits crop production in SSA is nitrogen (N). Over 80% of the agricultural land is deficient in N (Liu et al., 2010). Although N enrichment in wetlands has been reported (Meybeck & Helmer, 1989; Isermann, 1990; Hefting et al., 2005), the problem of excess N may not exist in SSA as often reported in temperate zones. Low N fertilizer use in the catchment areas may result in limited N deposition; thus N management may require a different management route from that reported in temperate areas. In Zimbabwe’s communal areas, nutrient deficiencies are common for N, phosphorus (P), and sulphur (S) (Nyamangara et al., 2000). In addition, deficiencies of magnesium (Mg), potassium (K) and zinc (Zn) and copper (Cu) have been reported in degraded soils (Grant, 1981; Mugwira & Nyamangara, 1988; Zingore et al., 2007).

Whilst floodplains are generally regarded as fertile, landuse change from natural to agro-ecosystems alters the nutrient cycling regime. For example, in the short term, replacement of natural vegetation by annual crops during the terrestrial phase alters the carbon content and distribution in the soil profile. The magnitude of change in C distribution is likely to be influenced by crop residue and weed management methods employed by the farmers. According to Cemek et al. (2007), soil infertility is usually linked to soil salinity in floodplains. This was accredited to accumulation of salt in the rootzone (Van Hoorn & van Alphen, 2006; Munns & Tester, 2008). It is important to determine to what extent annual deposition of sediments by retreating floods serve as natural mechanisms for soil fertility renewal under FRC.

Floodplain soils are generally light to heavy textured: loamy sand to silt loam in the Illinois floodplain (Darmody & Marlin, 2002); medium to heavy textured (43% clay) in the West Africa floodplain soils (Buri et al., 1999); and silty loam to silty clay loam (> 88% silt and clay content) in the Amazon floodplain (Koschorreck & Darwich, 2003). Soil pH is generally alkaline 5.4 to 5.9 in 1 :2.5 soil to water solution in the West Africa floodplain (Buri et al., 1999); 5 to 6.5 in 1 M KCl in the Amazon floodplain (Koschorreck & Darwich, 2003); 7.9 in 1:1 soil to water solution in the Illinois floodplain (Darmody & Marlin, 2002), 5.47 in 0.01 M $CaCl_2$ in the Dommel floodplain (Bleeker & van Gestel, 2007), and the pH (1:1 soil water suspension) was 5.5-9.0 (Tsheboeng et al., 2013).

Generally, floodplain soils are rich in exchangeable bases and metallic elements. The high exchangeable bases can be attributed to relatively low leaching in floodplains because of the lower topographic position. Nutrient concentrations (ppm) were 156, 2281.5, 1049.1, and 300.3 for K, Ca, Mg and Na respectively in West Africa floodplains soils (Buri et al., 1999); 19.9 S, 12.0 P, 2612.3 Ca, 509.7 Mg, 114.0 K, 11.3 Na, 1.0 B, 115.7 Fe, 140.3 Mn, 4.9 Cu, 3.2 Zn, 295.3 Al in the Illinois floodplains (Darmody & Marlin, 2002); 0.586, 0.091, 8.49, 0.261, and 13.5 for Cd, Cu, Fe, Ni, and Zn respectively in the Dommel floodplains (Bleeker & van Gestel, 2007); and 500-1800 for Ca, 120-550 for K, 75-800 for Na, 75-400 for Mg, 7.5-90 for P in the Okavango Delta. Total soil organic C (%) was 1.29 in the Amazon floodplains (Koschorreck & Darwich, 2003); 1.39 (Darmody & Marlin, 2002); 1.1 in the West Africa floodplains (Buri et al., 1999); 3.39 in the Dommel floodplains (Bleeker & van Gestel, 2007). Percent total N was 0.098 in the West Africa floodplains (Buri et al., 1999) and 0.14 in the Amazon floodplains (Koschorreck & Darwich, 2003).

There is paucity of published literature on soil fertility status of cultivated floodplains in the mid-Zambezi Valley. Therefore, the objective of this study was to determine the fertility status of the mid-Zambezi Valley floodplain soils. It was envisaged that information on soil fertility status would provide a basis for selection of options for sustainable management of floodplain soils. Maize (*Zea mays* L.), the staple and most cultivated food crop in the floodplains was chosen as a reference crop for determination of fertilizer recommendations in order to relate the fertility status of the soils to crop nutrient requirements.

3.2 Materials and Methods

3.2.1 Description of the study area

The study was conducted in Muzarabani Communal Area (16.12^{o}S; 31.15^{o}E, altitude 334 m a.s.l.) in Muzarabani district, northern Zimbabwe (Figure 3.1). The major river in the area is Musengezi, a tributary of the Zambezi River. The area receives most of its rainfall between December and March and the mean annual rainfall is 650 mm. The mean annual temperature is 25 ^{o}C and the area is frost free (Pwiti, 1996). Therefore, temperature is not a limiting factor to crop growth for the summer crops such as maize in the area, though grown during the winter period. Soil type ranges from fine-grained loamy sands to sandy clays (Anderson et al., 1993). According to the FAO/UNESCO soil classification, the soils are classified as Calcaric Cambisols, Eutric Vertisols, Vertic Cambisols, Chromic Cambisols, Calcic/Chromic Luvisols (Anderson et al., 1993). These soils generally have high agricultural potential. The vegetation is of dry savanna, dominated by *Colophospermum mopane* Kirk ex Benth. and species of *Combretum*, *Sterculia* and *Vachellia* (previously *Acacia*). The naturalised *Ziziphus mauritiana* Lam., is also common. Dominant grass species include spear grass *Heteropogon contortus* (L.) Beauv. ex Roem. and Schult and some *Digitaria* species. The major upland rainfed crops grown are: maize, cotton (*Gossypium hirsutum* L.) sorghum (*Sorghum bicolor* L. Moench), and pearl millet (*Pennisetum glaucum* L. R. Br.

Seasonal floods, which mostly occur between January and February, are a frequent phenomenon in this area. In addition to the low-lying nature of the area, its location between the Kariba dam, upstream and

Cahora Bassa dam, downstream, predisposes the area to human-engineered flooding (Mavhura et al., 2013) and farmers use the residual moisture and the alluvial soils for crop production.

3.2.2 Experimental design

3.2.2.1 Site selection and description

Three research sites, two along Zhoubvunda River, and one on Mukumbura River, tributaries of Musengezi River were selected (Figure 3.1). Fields that experience flooding, where FRC was practised almost yearly were selected after consultation with the owners. Five farmers' fields were chosen, but for the purposes of this study, these were considered as three sites because fields that were a continuum on the same side of the river were regarded as one. The three sites are hereafter identified as Zhoubvunda 1 (16.18^{o}S, 31.19^{o}E, 363 m a.s.l.); Zhoubvunda 2 (16.17^{o}S, 31.18^{o}E, 352 m a.s.l.) and Mukumbura (16.01^{o}S, 31.19^{o}E, 328 m a.s.l.).

According to the farmers, FRC at Zhoubvunda sites dates back to the 1960s. Land area under cropping was smaller than the current field boundaries, which have been in existence since early 1980s. At Mukumbura, FRC reportedly began in the year 2000. The major crop grown at all the sites was maize and the other crops included cowpeas [(*Vigna unguiculata* (L.) Walp.)], sugar beans (*Phaseolus vulgaris* L.), watermelon [(*Citrullus lanatus* (Thunb.) Matsum. and Nakai], pumpkins (*Curcubita* spp.) and sweet potatoes (*Ipomoea batatas* L.). Farmers maintained *Z. mauritiana* trees in their fields. Field edges were bound by live fences. Land was cleared using slashes and axes followed by burning of the vegetative material.

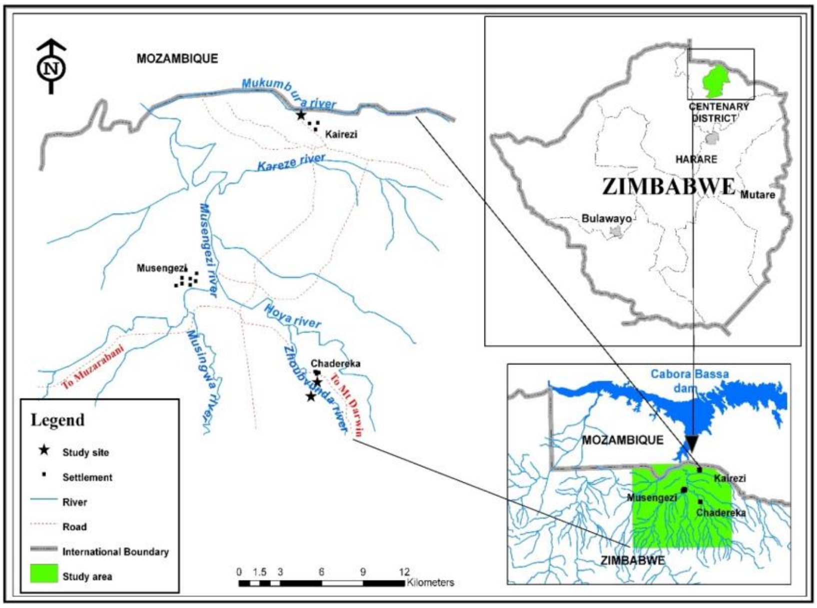


Figure 3.1: Map of the study area in the Zambezi Valley floodplain in Muzarabani Communal Area Zimbabwe

3.2.2.2 Soil sampling

Soil samples were collected between June and July 2015, during the FRC season in Muzarabani district only, due to financial considerations. In order to capture the full range of soil types and hydrological conditions (Rinklebe et al., 2007), the selected fields were stratified according to hydromorphological regimes, resulting in sampling points at distances: 30, 64, 123, 186, and 225 m from the river edge at Mukumbura; 36, 107, and 161 m, from the edge of the river at Zhoubvunda 1; and 42, 93, 120 and 170 m, from the edge of river at Zhoubvunda 2. Sampling points were replicated twice in each stratum. The replicates were approximately equidistant from the edge of the river and are hereafter referred to as measuring positions.

Soil samples for chemical analysis and textural determination were taken from profile pits at 0.20 m depth increments up to 0.60 m. For soil texture, a single composite sample per site was made from subsamples collected at each of the depths. Separate soil samples were taken using 100 cm^3 cores at the same depths for bulk density determination. Although differences in the topography of floodplains are usually slight, they result in important hydrological and pedological differences (Pinay et al., 2002; Rinklebe et al., 2007); therefore, relative elevations of measuring positions were measured using Leica Runner 20 Automatic level (Leica Geosystems, Switzerland).

3.2.2.3 Laboratory analyses

Soil bulk density was determined for 72 samples that were oven-dried for 48 hours at 105 ^oC. Soil texture was analysed using the hydrometer method (Bouyoucos, 1962). Organic matter content was estimated by the loss on ignition (LOI) method at 550 ^oC for 12 hours in a muffle furnace (Heiri et al., 2001; Ziadi & Tran, 2008). Prior to ignition and chemical analyses, soil samples were crushed to pass through 0.425 mm sieve and mixed to ensure homogeneity. Soil organic carbon (SOC) was estimated by dividing organic matter content by a factor of 1.724 (Jiménez & García, 1982).

Potassium, Calcium (Ca), Mg, Sodium (Na), Cu, Zn, Manganese (Mn), Boron (B), Molybdenum (Mo), Nickel (Ni), Cobalt (Co) and Iron (Fe) were extracted using the Mehlich 3 method (Ziadi & Tran, 2008); and analysed using the Inductively Coupled Plasma (ICP- SPECTRO ARCOS CETAC AUTO SAMPLER ASX52-AMETEK, Germany).

Nitrogen was analysed using the Kjeldahl procedure (Rutherford et al., 2008). Digestion was done in the Foss Tecator Dessicator at 420 ^oC for 1 hour in fume hood. Soil pH (1: 5 ratio, soil to 0.01 M $CaCl_2$ solution) was measured using the Adwa 1020 pH and Temperature meter (Romania), at 25 ^oC.

For the three sites, fertilizer recommendations for maize production based on soil analysis were conducted by the Zimbabwe government's Department of Research and Specialist Services.

3.2.2.4 Data analyses

Data from physical and chemical analyses were subjected to One Way Analysis of Variance (ANOVA) using IBM SPSS Version 21.0 (2013), at 5 % level of significance. Posthoc tests were done using Tukey's b test. Pearson's correlation coefficient was used to determine the relationship between distance from the edge of river and relative elevations; and selected soil characteristics: total N, bulk density, pH and SOC.

3.3 Results

Mean bulk density (g cm^{-3}) range was narrow for Zhoubvunda 1 but wider for Zhoubvunda 2 and Mukumbura. Mean soil bulk densities did not differ ($P>0.05$) with measuring position from the edge of the river for Zhoubvunda 1, but the furthest measuring position from the river bank had a lower bulk density ($P<0.05$) than the rest for Zhoubvunda 2 (Table 3.1). Bulk densities were similar ($P>0.05$) across depths, except at Zhoubvunda 1 where the 0.00-0.20 m depth had a higher ($P<0.05$) bulk density than the lower depths at position 3 (not shown). At Mukumbura, bulk densities generally showed a declining ($P<0.05$) trend as distance from the river increased (Table 3.2). For measuring positions 1 and 2, bulk densities were similar ($P>0.05$) across soil depths. Measuring positions 3 and 5 generally showed declining trends ($P<0.05$) and there was no trend at measuring position 4 (not shown). Bulk density was positively related to relative elevation, ($P<0.05$) at Zhoubvunda 2 and Mukumbura. The soils were in the moderately course to medium texture categories (Table 3.1).

Table 3. 1: Particle size distribution, texture and bulk density (mean standard deviation) of Zambezi Valley floodplain soils in Muzarabani Communal Lands, Zimbabwe

Site	**Distance from river (m)**	**^{a}Relative elevation (m)**	**^{b}Bulk density (g cm^{-3})**	**Sand (%)**			**Silt (%)**	**Clay (%)**	**Texture**
				Fine	**Medium**	**Coarse**			
Zhoubvunda 1	36	0.000	1.22 (0.08)^a	42	7	8	34	8	fine sandy loam
	107	–0.075	1.21 (0.10)^a						
	161	0.125	1.21 (0.07)^a						
Zhoubvunda 2	42	0.000	1.19 (0.05)^a	45	4	1	42	9	loam
	93	0.025	1.23 (0.10)^a						
	120	–0.030	1.22 (0.07)^a						
	170	–0.580	1.08 (0.08)^b						
Mukumbura	30	0.000	1.43 (0.03)^a	73	16	2	5	4	fine sand
	64	–0.205	1.36 (0.09)^a	43	13	2	35	7	fine sandy loam
	123	–0.415	1.31 (0.09)^b						
	186	–0.695	1.32 (0.09)^b						
	225	–0.840	1.18 (0.07)^c						

[a] The closest measuring position to river was taken as the benchmark at 0.000 m relative elevation.

[b] Means without common superscripts within a site are significantly different (Tukey's b: $P < 0.05$).

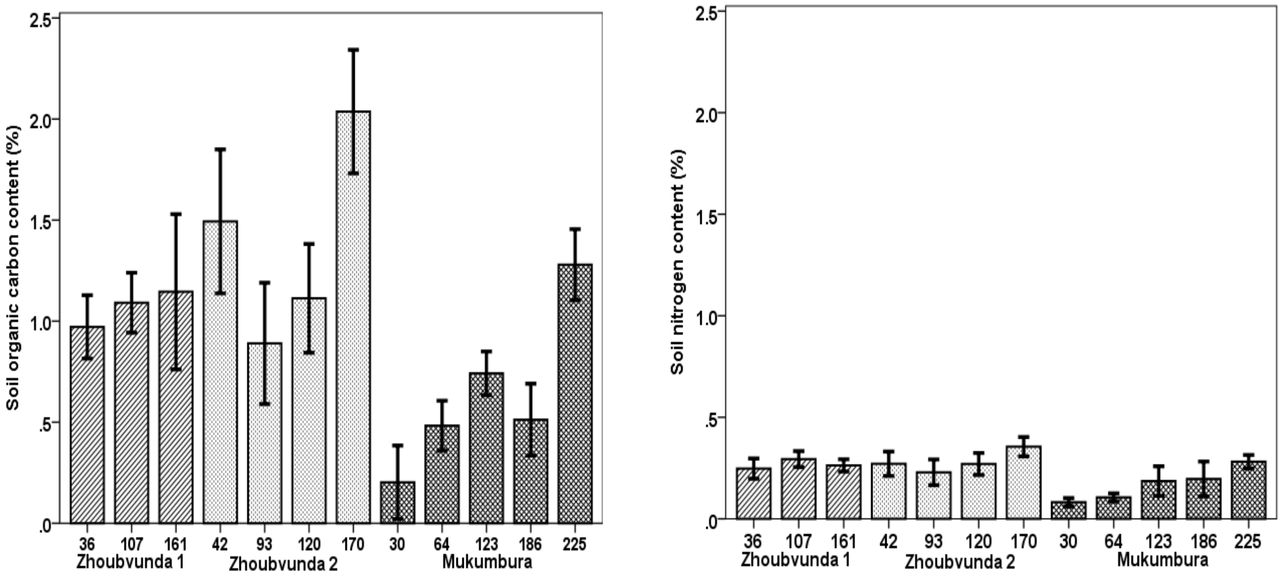
Mean SOC at Zhoubvunda 1 was lower ($P<0.05$) closest to the river than the other measuring positions, which were similar ($P>0.05$) (Figure 3. 2). At Zhoubvunda 2, there were variations ($P<0.05$) in SOC with distance from the river. The SOC nearest to the river was lower than that at all the other measuring positions, at Mukumbura. There were no consistent trends ($P<0.05$) in variations of SOC with depth at each measuring position.

Pearson's correlation coefficient confirmed that: SOC was positively related to distance from the river. This relation was significant ($P<0.05$) at Zhoubvunda 1 and Mukumbura. Soil organic carbon was negatively related to relative elevation at Zhoubvunda 2 and Mukumbura. This relation was significant ($P<0.05$) at Mukumbura (Table 3.2). Pearson's correlation coefficient also showed that: percent total N was negatively related to relative elevation ($P<0.05$) at Zhoubvunda 2 and Mukumbura. Percent total N was positively related to distance from the river at all sites but this relationship was only significant ($P<0.05$) at Mukumbura (Table 3.2). Combined over the three sites, bulk density was positively related to relative elevation ($P<0.05$) and total N was negatively related to relative elevation.

Table 3. 2: Correlation between distance from the river and relative elevation, and soil organic carbon, percent total nitrogen, bulk density and pH for Muzarabani floodplain soils in Northern Zimbabwe

Variables		**Zhoubvunda 1**		**Zhoubvunda 2**		**Mukumbura**		**Overall**	
		r	P	r	P	r	P	r	P
Distance from the river (m)	% total N	0.315	0.398	0.737	0.132	0.970	0.003	0.469	0.124
	Bulk density (g cm^{-3})	–0.903	0.142	–0.647	0.177	–0.904	0.018	0.005	0.966
	pH	–0.982	0.060	0.222	0.389	–0.683	0.102	-0.228	0.477
	Organic carbon (%)	0.994	0.036	0.468	0.266	0.815	0.046	0.353	0.261
Relative elevation (m)	% total N	–0.614	0.315	–0.977	0.011	–0.962	0.004	-0.693	0.013
	Bulk density (g cm^{-3})	–0.143	0.454	0.970	0.015	0.902	0.018	0.638	0.025
	pH	–0.701	0.253	0.384	0.308	0.693	0.097	0.474	0.120
	Organic carbon (%)	0.459	0.348	–0.880	0.060	–0.810	0.048	-0.529	0.077

There was an increasing trend ($P<0.05$) in percent total N at at Mukumbura, with distance from the river (Figure 3.2).



a

b

Figure 3.2: Organic carbon (a) and total nitrogen (b) contents in the Zambezi Valley floodplain soils in Muzarabani Communal Area, Zimbabwe. Error bars represent standard deviations. For each site, numbers represent measuring distances (measuring positions) in metres from the edge of river.

Soil pH ranged from 7.70-8.60 across sites. There was no variation ($P>0.05$) in pH with distance from the river at all sites except for Mukumbura, where the furthest point had a higher pH than the all other measuring positions. At all measuring positions, there were no differences ($P>0.05$) in pH among depths (not shown).

At Zhoubvunda 1, K concentration was lower closest to the river than the other two positions; while K concentration was lowest ($P<0.05$) at the point nearest to the river and highest ($P<0.05$) at the furthest point from the river (Table 3.3) at Mukumbura. Calcium concentration depicted a narrow range from

3835.16 ppm at Zhoubvunda 1 to 3875.69 ppm at Mukumbura (Table 3.3). At Zhoubvunda, a general increasing trend ($P<0.05$) with increasing distance from the river was observed at Mukumbura for Mg concentration (Table 3.3). Sodium concentration showed an increasing trend ($P<0.05$) with increasing distance from the river at Zhoubvunda sites; but the opposite was observed at Mukumbura. Exchangeable sodium percentages (SD) were 5.90(1.03) at Zhoubvunda 1, 7.32(1.51) at Zhoubvunda 2 and 4.14(1.75) at Mukumbura.

There was no trend in Fe concentration at Zhoubvunda 1; at Zhoubvunda 2, Fe concentration was higher ($P<0.05$) closer to the river than at all the other positions (Table 3.3). At Mukumbura, Fe concentration was highest ($P<0.05$) closest to the river and lowest furthest from the river. Lower Mn ($P<0.05$) concentration was observed closest to the river than all the other measuring positions at Mukumbura. At Zhoubvunda 1, Mn concentrations were similar at all measuring positions and varied without a trend at Zhoubvunda 2.

At Zhoubvunda sites, Cu concentrations were similar ($P>0.05$) at all measuring positions. At the Mukumbura site, all other measuring positions had similar Cu concentrations except for the furthest position from the river, which had a lower ($P>0.05$) concentration (Table 3.3). Zinc concentration depicted a narrow range across sites (8.46-10.11 ppm) (Table 3.3). Accordingly, Zn concentrations were similar for all measuring positions at all sites. Similarly, Boron concentrations were uniform ($P>0.05$) at 0. 50 ppm at all sites, and this was above detection limit (0.01 ppm) for the ICP machine used.

Cobalt concentration was lower ($P<0.05$) at the furthest position from the river at Zhoubvunda 1 than at the other two measuring positions whilst they were similar ($P>0.05$) at all positions at Zhoubvunda 2, but there was no trend ($P>0.05$) in Co concentrations at Mukumbura. There were no clear trends in Ni concentration at all the sites. Molybdenum concentrations were similar at Zhoubvunda 1, but there were no trends at the other two sites (Table 3.3).

Recommended maize fertilizer application rates for Mukumbura were 300 kg ha^{-1} for NPK basal fertilizer (7:6:6), 50-100 kg ha^{-1} Single super phosphate [$Ca(H_2PO_4)_2 + 2CaSO_4$], 50 kg ha^{-1} muriate of potash (KCl) and 425 kg ha^{-1} NH_4NO_3. These rates are equivalent to 168, 23-27, 44, 11-21, and 30-36 kg ha^{-1} N, P, K, Ca and S respectively. Fertilizer application rates for Zhoubvunda sites were 250 kg ha^{-1} NPK basal fertilizer (7:6:6) and 400 kg ha^{-1} $NH_4NO_3^-$, which is equivalent to 159, 15, 15, 15-24 kg ha^{-1} N, P, K, and S respectively. These fertilizer recommendations are for 6-10 t ha^{-1} maize yield.

Table 3. 3: Chemical characteristics (mean (standard deviation)) of Zambezi Valley floodplain soils in Muzarabani Communal Lands, northern Zimbabwe

Distance from river (m)	**pH**	**K**	**Ca**	**Mg**	**Na**	**Fe**	**Mn**	**Cu**	**Zn**	**Co**	**Ni**	**B**	**Mo**
					Mean concentration (Standard deviation) (ppm)								
Zhoubvunda Site 1													
36	8.12 (0.18)^{a}	561.05 (68.71)^{a}	3835.16 (1.04)^{a}	1569.14 (91.54)^{a}	958.94 (46.50$^{)a}$	166.39 (19.45)^{a}	169.34 (19.14)^{a}	12.57 (0.69)^{a}	9.90 (0.49)^{a}	3.26 (0.52)^{a}	7.88 (0.39)^{a}	0.50 (0.00)^{a}	1.00 (0.11)^{a}
107	7.95 (0.40)^{a}	379.18 (74.76)^{b}	3841.77 (12.13)^{a}	1244.68 (91.00)^{b}	1083.46 (41.79)^{b}	297.03 (82.57)^{b}	148.98 (23.66)^{a}	13.11 (0.29$^{)a}$	9.69 (0.50)^{a}	3.11 (0.53)^{a}	8.62 (0.48)^{b}	0.50 (0.00)^{a}	0.93 (0.10)^{a}
161	7.70 (0.36)^{a}	442.56 (56.33)^{b}	3837.64 (4.48)^{a}	1505.56 (80.40)^{a}	1096.81 (49.80)^{b}	155.09 (13.26)^{b}	150.77 (16.17)^{a}	13.00 (0.32)^{a}	9.96 (0.61)^{a}	2.38 (0.38)^{b}	8.24 (0.59)^{ab}	0.50 (0.00)^{a}	0.94 (0.11)^{a}
Zhoubvunda Site 2													
42	8.01 (0.14)^{a}	347.02 (23.66)^{a}	3851.60 (15.17)^{a}	1185.23 (213.97)^{a}	1248.30 (41.48)^{a}	269.64 (71.98)^{a}	145.86 (22.00)^{a}	13.20 (0.35)^{a}	10.11 (0.33)^{a}	2.61 (0.39)^{a}	8.68 (0.30)^{a}	0.50 (0.00)^{a}	0.89 (0.11)^{ab}
93	8.12 (0.07)^{a}	615.05 (98.26)^{a}	3837.80 (6.35)^{a}	1948.75 (184.31)^{b}	1198.05 (22.41)^{ab}	147.03 (19.50)^{b}	193.38 (28.15)^{b}	12.62 (0.70)^{a}	10.11 (0.45)^{a}	2.98 (0.67)^{a}	7.69 (0.55)^{b}	0.50 (0.00)^{a}	0.96 (0.04)^{b}
120	8.13 (0.19)^{a}	360.37 (48.62)^{a}	3839.29 (10.32)^{a}	1391.29 (187.34)^{a}	1306.73 (89.45)^{b}	195.53 (55.68)^{b}	138.32 (12.80)^{a}	12.38 (0.77)^{a}	9.77 (0.31)^{a}	2.55 (0.11)^{a}	8.87 (0.14)^{a}	0.50 (0.00)^{a}	0.78 (0.10)^{a}
170	8.04 (0.16)^{a}	364.22 (23.70)^{a}	3844.04 (12.36)^{a}	1298.65 (105.92)^{a}	1422.16 (43.87)^{c}	152.78 (23.78)^{b}	142.00 (12.59)^{a}	12.60 (0.75)^{a}	9.97 (0.47)^{a}	2.73 (0.30)^{a}	8.73 (0.27)^{a}	0.50 (0.00)^{a}	0.91 (0.08)^{ab}
Mukumbura Site													
30	8.60 (0.22)^{a}	210.55 (29.22)^{a}	3850.25 (12.44)^{a}	1185.76 (317.94)^{a}	790.08 (61.60)^{a}	1072.59 (478.88)^{a}	82.21 (32.29)^{a}	12.55 (0.52)^{a}	9.39 (0.40)^{a}	0.97 (0.59)^{a}	8.49 (0.37)^{ab}	0.50 (0.00)^{a}	1.16 (0.11)^{a}
64	8.38 (0.11)^{a}	291.66 (31.12)^{b}	3856.54 (4.71)^{ab}	1567.97 (127.41)^{b}	808.56 (104.03)^{a}	616.51 (76.98)^{b}	132.48 (21.82)^{b}	13.13 (0.27)^{a}	8.46 (1.79)^{a}	1.64 (0.10)^{b}	8.76 (0.13)^{bc}	0.50 (0.00)^{a}	1.05 (0.08)^{a}
123	8.59 (0.05)^{a}	333.56 (38.30)^{b}	3867.85 (6.69)^{bc}	2430.39 (315.64)^{c}	605.15 (110.86)^{b}	197.15 (66.87)^{c}	158.46 (23.38)^{b}	12.49 (1.01)^{a}	9.96 (0.17)^{a}	1.81 (0.14)^{b}	8.21 (0.40)^{a}	0.50 (0.00)^{a}	1.29 (0.14)^{ab}
186	8.45 (0.18)^{a}	334.88 (63.70)^{b}	3862.00 (7.47)^{b}	2015.57 (183.01)^{d}	568.00 (37.02)^{bc}	317.33 (136.07)^{bc}	133.23 (11.14)^{b}	12.99 (0.76)^{a}	9.24 (0.83)^{a}	1.76 (0.23)^{b}	8.47 (0.32)^{ab}	0.50 (0.00)^{a}	1.49 (0.23)^{bc}
225	8.09 (0.18)^{b}	397.97 (33.17)^{c}	3875.69 (1.06)^{c}	2891.12 (104.31)^{e}	479.84 (25.11)^{c}	129.59 (23.93)^{c}	135.31 (17.78)^{b}	10.55 (0.87)^{b}	9.94 (0.21)^{a}	1.39 (0.49)^{ab}	9.10 (0.36)^{c}	0.50 (0.00)^{a}	1.70 (0.22)^{c}

Means without common superscripts within a column at each site are significantly different (Tukey’s b: $P < 0.05$)

3.4 Discussion

Excluding distances less than 64 m from the river at Mukumbura, which were affected by deposition of sand, bulk density values observed in this study were consistent with values obtained in other cultivated floodplains (Hossain et al., 2002; Koschorreck & Darwich, 2003). The bulk densities were lower than those observed in Zimbabwe’s communal areas on sandy loam soils (Zingore et al., 2007; Nyakudya et al., 2014), which were however similar to the bulk density of the sandy deposition zone at Mukumbura, closest to the river. The relatively low bulk densities observed in the Zambezi Valley floodplains implies that crops can explore a larger soil volume due to easy root penetration and there is better soil aeration. In addition, land preparation is relatively easy and less costly (Hossain et al., 2002) and weeding with the hand hoe is less strenuous. Evidence of horizontal zonation was observed at two of the three sites, Zhoubvunda 2 and Mukumbura, where bulk densities at furthest distances from the river were lower than the rest. Lower bulk densities at furthest points from the rivers can be attributed to higher SOC (Figure 3.2) and less sand deposition at these points. Based on bulk density, the floodplain soils at the three sites provided good edaphic conditions.

Mean SOC values for Zhoubvunda compare favourably to Amazon floodplain (Koschorreck & Darwich, 2003); and the Illinois River floodplain (Darmody & Marlin, 2002). Mukumbura had lower SOC values that correspond to West Africa floodplains (Buri et al., 1999). However, if the outlier effect caused by sand deposition closer to the river is removed, the SOC becomes relatively high. Thus, the Zambezi Valley floodplains have more SOC than the West Africa floodplains. Soil organic carbon in the Zambezi Valley floodplain was similar to clay soil home-fields (Rusinamhodzi et al., 2013). However, SOC in the Zambezi Valley floodplain soils was lower than that found on floodplain soils of Dommel River in the Netherlands (Bleeker & van Gestel, 2007). This can be attributed to the location of the Dommel river floodplain in the temperate region where oxidation of organic matter is lower than in the tropics, where Zambezi Valley floodplain is located.

The pH (0.01 M $CaCl_2$) observed in the Zambezi Valley floodplain tallies with pH (1:1 distilled water) reported by Darmody & Marlin (2002) on Illinois river floodplain and Tsheboeng et al. (2014) in the Okavango Delta. However, the Zambezi Valley floodplain soils’ pH values exceeded the pH (soil to water ratio, 1:2.5) on West Africa floodplains (Buri et al., 1999); pH 0.01 $CaCl_2$, on Dommel River floodplain soils (Bleeker & van Gestel, 2007). Similarly, the Zambezi Valley floodplain soils’ pH was higher than those from Zimbabwe’s communal areas (Rusinamhodzi et al., 2013; Nyakudya et al., 2014). The high pH observed in the Zambezi Valley floodplains was linked to the high concentration of bases. Cooper and Fenner (1981) stated that in Zimbabwe most crops grow well at pH > 5.0.

However, at pH levels above 7.0 measured in the Zambezi Valley floodplains, there is likely to be P, Zn, Cu, Mn and Fe deficiency due to precipitation.

If the outlier effect of sandy soil closest to the river at Mukumbura site is removed: percent N in Zambezi Valley floodplain sites would be higher than: in the Amazon floodplain (Koschorreck & Darwich, 2003); the maximum values in West Africa floodplains (Buri et al., 1999), sandy soils and clays soil of communal lands in Zimbabwe (Rusinamhodzi et al., 2013) and sandy soils in Ruaca and Vunduzi villages in Central Mozambique (Rusinamhodzi et al., 2012). High total N levels in the Zambezi Valley floodplains can be attributed to the relatively high SOC levels.

Zambezi Valley floodplain soils exhibited at least double the reported concentrations for K, Mg, Na, Cu, and Zn and; similar concentrations for Ca, Fe, Mn and, B when compared with Illinois River floodplain soils for an equivalent depth up to 0.6 m (Darmody & Marlin, 2002). Except for K, the basic cation concentrations in the Zambezi Valley floodplains were at least 2.5 times more than those observed in West African floodplains, concentrations (Buri et al., 1999). Concentrations of basic cations in the in the Zambezi Valley were higher than those measured in the primary floodplains of Okavango Delta, following low and high floods for Ca, K, Mg and Na (Tsheboeng et al., 2014).

Potassium concentrations in Zambezi Valley floodplain soils exceeded those reported for the more weathered soils from Chinamhora Communal Area in Zimbabwe, but were on the higher side of concentrations of the less weathered soils of Mhondoro Communal Area in Zimbabwe (Nyamangara et al., 2000). A similar trend was observed for Ca in comparison with the same soils, but Mg concentrations were more than three times higher than those reported for the two Zimbabwean Communal Areas. The Zambezi Valley floodplain soils were well above the threshold concentrations for deficiency for K, and Mg (Nyamangara et al., 2000). The relatively high concentration of bases in floodplain soils is due to deposition of bases in the rootzone by nutrient-rich capillary rise water (Chimweta & Nyakudya, 2019). When compared with floodplain soils elsewhere, and soils from Communal Areas in Zimbabwe and other countries in southern Africa, Zambezi Valley floodplain soils are relatively more fertile. This implies that the Zambezi Valley floodplain soils have a relatively higher productivity potential. In the predominantly low-input smallholder farming systems of SSA, a viable nutrient management option is the adoption of cropping systems that have a legume component that uses relatively large concentration of bases. Examples of such legumes include sugar beans (*Phaseolus vulgaris* L.), cowpea [*Vigna unguiculata* L. (Walp)], groundnuts (*Arachis hypogaea* L.).

The existence of high concentrations of bases, which increases the likelihood of occurrence of saline soils in some fields, was linked to deposits of salts in the rootzone by capillary rise. Therefore, plants that have some degree of tolerance to salinity (Grieve et al., 2012) such as cowpeas, and squash (*Curcubita pepo* (L) should be included in FRC systems. However, the exchangeable sodium percentage values were below 10-15, the critical level at which soil structure damage occurs in light to medium textured soils (Van Hoorn & van Alphen, 2006), which are in the Zambezi Valley floodplains.

Most nutrients are attached to fine grained sediments as well as to organic matter and accumulate in topographically lower areas, for example, depressions, furrow and low-lying terraces (Rinklebe et al., 2007). Pearson's correlation coefficients confirmed that edaphic conditions improved with distance from the river (Table 3.2). According to Pinay et al. (2002), silt and clay percent was below the threshold for significant denitrification. The soils in the Zambezi Valley floodplains are therefore not highly susceptible to denitrification. However, it could be influenced by capillary rise in the floodplains.

Recommended fertilizer application rates by the Zimbabwe government's Department of Research and Specialist Services were based on rainfed cropping and these may not be applicable to FRC due to differences in the dominant soil processes between the upland rainfed and floodplain ecosystems. For example, in the rainfed uplands leaching and eluviation leading to nutrient losses are dominant whilst capillary rise, which is dominant in the floodplains, brings nutrients into the crop rootzone. Timing and placement of fertilizer recommended for rainfed cropping may not be appropriate for FRC. For example, as the water table recedes, the capillary rise may not reach the soil surface in adequate amounts to dissolve topdressing fertilizer. In floodplains, dissolution of the topdressing fertilizer can be enhanced through subsurface placement as is done with compound fertilizer and implementing practices that result in a long duration of flooding and low flow rates, which enhance groundwater recharge through increased infiltration. These practices include maintaining vegetation within the crop growing areas and live hedges, construction of cropping dykes and partial closing of waterways that are located in the fields.

3.5 Conclusions

Zambezi Valley floodplain soils are relatively fertile. Sodium hazard was relatively low as evidenced by the low exchangeable sodium percentage, less than nine (9). Edaphic conditions improved with increasing distance from the river and decreasing relative elevations, thus edaphic conditions are not necessarily better closer to the river. Although the soils are relatively fertile, inorganic fertilizer application may be considered at lower than recommended rates in order to correct nutrient deficiencies while avoiding negative effects of nutrient enrichment in the fragile floodplain ecosystem. A high concentration of bases increases the likelihood of occurrence of saline soils therefore there is need to determine soil salinity dynamics in the floodplains.

CHAPTER 4: MAIZE YIELD RESPONSE TO CROP ESTABLISHMENT METHOD, CULTIVAR AND FERTILIZER APPLICATION UNDER FLOOD-RECESSION CROPPING IN THE MID-ZAMBEZI VALLEY

Abstract

Water deficit in the rootzone and poor soil fertility are major constraints to dryland crop production in sub-Saharan Africa. Flood-recession cropping (FRC) has potential to improve food security through utilisation of capillary water and fertile alluvial soils. However, agronomic practices in African floodplain cropping systems are underdeveloped, thereby reducing their potential contribution to food security. The objectives of this study were to determine effect of crop establishment method, cultivar and fertilizer regime on maize yield in FRC. Field experiments were conducted at three sites in the floodplains of tributaries of Musengezi River in the Zambezi Valley in northern Zimbabwe. A preliminary survey was conducted to establish floodplain farmers' yields. In experiment 1, a 4*4 factorial in a randomized complete block design (RCBD) tested the effect of application rate of NPK basal fertilizer [7: 6: 6, (6-8% S)] banded below the seed and N top-dressing fertilizer (Ammonium nitrate 34.5% N) side dressed on the soil surface, all applied at 0, 75, 150 and 225 kg ha^{-1}, on maize grain yield of a short season maize cultivar, SC 513. In experiment 2, a 3* 4* 4 factorial arranged in split-split plot design with maize cultivar maturity class (early -SC513, medium -SC 627 and late -SC 727 maturing cultivars) as the main-plot factor, NPK basal fertilizer application rate (0, 75, 150 and 225 kg ha^{-1}) as the sub-plot factor and N top-dressing fertilizer application rate (0, 75, 150 and 225 kg ha^{-1}) as the sub-sub plot factor, in 2017 and 2018. In experiment 3, two crop establishment methods were compared (furrow only and furrow + holing-out) in a CRD. Data were analysed using Genstat 18th Edition. Analysis of variance (ANOVA) was used to test treatment effects on yields and means were separated using standard error of the difference when the F-test was significant at $P<0.05$. Pearson linear correlation was used to test relationships between fertilizer application rate and maize yield. Comparisons between yields from farmers' fields and experimental fields, yields from crop establishment methods were conducted using Student's t-Test. Mean maize yield from farmers' fields was 3.23 t ha^{-1} and yield from SC513 without fertilizer was 6.42 t ha^{-1}. There were yield benefits ($P<0.05$) changing from early and medium to late-maturing cultivar when NPK basal fertilizer was applied at ≤150 t ha^{-1}. Averaged across application rates of NPK basal and N top-dressing fertilizers, maize grain yield increased ($P<0.05$) in the order SC513=SC627<SC727 at Zhoubvunda 1 in the 2017 and 2018 seasons and SC513<SC627<SC727 at Mukumbura in the 2017 season. The steepest yield increases were observed when NPK basal fertilizer was increased from 0 to 75 kg ha^{-1}. Yield benefits of N top-dressing fertilizer were only significant at 0 kg ha^{-1} NPK basal fertilizer. Similar to grain yield, stover yield for the early maturing cultivar, SC513, was remarkably high; ranged from 6.8 to 9.10 t ha^{-1}. Furrow + holing-out improved maize emergence by 22-42% and grain yield by ≥1.6 t ha^{-1}. Furrow + holing out; planting late-maturing cultivar SC727; ≤150 kg ha^{-1} NPK basal fertilizer and; no N top-dressing were recommended.

Key words: Floodplain; Maize harvest index; Microdosing; Salinity; Tillage

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4.1 Introduction

Floodplains are among the most productive ecosystems in the world (Scudder, 1989; Adams, 1993; Pwiti, 1996; Lynch & Brown, 2000; Koschorreck & Darwich, 2003; Rinklebe et al., 2007; Sidibé et al., 2016; Balana et al., 2019) and flood-based farming systems (FBFS) provide viable options for improving food security for resource-constrained smallholder farmers (Kashe et al., 2015; Kool et al., 2018; Kolawole & Kashe, 2019). Africa has large floodplain areas, for example, floodplains in the Congo, Senegal, Niger and Zambezi rivers basins occupy approximately 30 million hectares (CGIAR, 2015). These floodplains are usually endowed with abundant water resources and fertile alluvial soils that eliminate the major crop production constraints in smallholder farming systems, namely, inadequate, and poorly distributed rainfall (Steiner & Rockström, 2003) and poor soil fertility (Sanchez, 2002). An example of a low-cost FBFS that is appropriate for resource-constrained smallholder farmers is flood-recession cropping (FRC), where farming communities along floodplains plant crops after seasonal floods recede (Postel, 2000; Chidanti, 2011; Motsumi et al., 2012; Kashe et al., 2015; Sidibé et al., 2016; Balana et al., 2019; Comptour et al., 2020).

Unlike rainfed cropping where decisions are based on rainfall forecasts, under FRC farmers make cropping decisions post-flooding, hence, management practices can be manipulated to sustain crops predictably better and lead to higher and more stable crop yields. Kashe et al. (2015) reported yields between 2.4 and 3.4 t ha^{-1} without fertilizer application for the early maturing maize (*Zea mays* L.) cultivar, SC403, under FRC (*molapo* farming) in the Okavango Delta, and Nederveen and Steenbergen (2011) obtained between 1.6 and 2.2 t ha^{-1} in farmers' fields in Ethiopia. Sidibé et al. (2016) also reported that under ideal crop management, sorghum [*Sorghum bicolor* (L.) Moench] yields can reach 2.5 t ha^{-1}. These yields are significantly higher than the yields of the major staple food crops in smallholder farming systems in Sub-Saharan Africa that oscillate around 1 t ha^{-1} (Rockström et al., 2003; Shiferaw et al., 2011, Kurwakumire et al., 2014; Nyakudya et al., 2014; VIB, 2017). Although the reported FRC yields are much higher than the rainfed crop yields, they are still low considering that floodplains are among the high potential ecosystems. The yield can increase 2 to 3-fold in floodplains, through selection of appropriate water management techniques, crop establishment methods; crops, cultivars, and plant spacing (Scudder, 1989, Vanderpost, 2009; Sidibé et al., 2016; Kashe et al., 2015).

In comparison to Asian and American floodplains, African floodplains are underutilized and their governance not properly structured (Buri et al., 1999; Fox & Ledgerwood, 1999; Darmody & Marlin, 2002; Tsheboeng et al., 2014). This can be partly attributed to inadequate information on African floodplains, hence the need for research that informs policy and practice. In Zimbabwe, FRC is not formally recognised. As a result, there is no formal research and extension support, despite FRC's decades of existence (Pwiti, 1996). Agronomic practices that are currently used in FRC in Zimbabwe are therefore based on a mixture of recommendations from upland areas and the lived-in experiences of farmers learned over decades using this farming system. Upland rainfed farming recommendations may not be appropriate due to differences in dominant soil processes between the two ecotopes that result in differences in soil water and nutrient dynamics. Leaching, eluviation and soil water erosion, which result in nutrient loss from topsoil in upland areas may not be as dominant in floodplains. In contrast, in floodplains, nutrient accumulation in top layers of the soil may occur due to deposition of nutrient-rich silt and capillary rise (Chapter 3, Section 3.1). While capillary water can introduce mineral nutrients from deeper soil layers, accumulation of salt in the rootzone may expose plants to high concentrations of salts that reduces crop yield (Van Hoorn & van Alphen, 2006; Munns & Tester, 2008).

This study focused on maize, the staple food crop for more than 200 million people in Sub-Saharan Africa (Macauley & Ramadjita 2015) that is planted under FRC across the continent (Turpie et al., 2006; Chidanti-Malunga, 2011; Sidibé et al., 2016; Balana et al., 2019). In southern Africa, maize is the main flood-recession crop (Vanderpost, 2009; Chidanti-Malunga, 2011). Balana et al. (2019) cited shortage of improved seeds as one of the production constraints under FRC. Preliminary studies in the mid-Zambezi Valley showed that most of the flood-recession maize growing households (95.7%) planted retained seed and only 8.5% planted certified seed that included SC403, SC513 and PAN43, and SC627 belonging to very early, early, medium maturity categories respectively. The only published research on flood-recession maize is on performance of a very early maturing and low-yielding cultivar (SC403) (Kashe *et al*., 2015). There is need to evaluate yield performance medium and late maturing cultivars in order to provide information that assists farmers in selecting cultivars that meet their production objectives.

Flood-recession cropping farmers rarely use fertilizers because they perceive the soils to be fertile (Vanderpost, 2009; Kolawole & Kashe, 2019). However, Traore et al. (2016) showed that addition of organic manure and inorganic fertilizer improved sorghum yield compared to non-application of fertilizers with additional yield between 0.490 and 1,666 t ha^{-1} in Yelimane Mali. Improved yield under fertilizer application suggest that microdosing with inorganic fertilizers could provide maize yield benefits in floodplains, without impacting negatively on the environment.

Tillage is used for water management under FRC. When there is no excess moisture, farmers plant on the flat in deep pits or furrows reinforced with planting pits to reach a depth with adequate moisture for successful crop emergence and establishment (Chidanti-Malunga, 2011; Chimweta et al., 2021). In wetter seasons or floodplains that are inundated for longer durations, ridges or crop dykes are constructed to create a well aerated zone above the floodwater and enable early planting of crops (Chidanti-Malunga, 2011; Kpadonou et al., 2012; Comptour et al., 2020). Hirtherto, published research on tillage has concentrated on explaining FRC crop establishment methods without determining their yield benefits.

The objective of this study was to test the effect of crop establishment method, maize cultivar, and inorganic fertilizer application rate on the yield of flood-recession maize. This study presented and discussed results of 3-year agronomic experiments involving three maize cultivars of different maturity categories, two crop establishment methods and inorganic fertilizers levels based on recommendations from Department of Research and Specialist Services. Hypotheses were: (i) different crop establishment methods result in differences in maize crop emergence and yield, (ii) maize yield can be increased significantly through selection of high yielding late maturing cultivars over early maturing cultivars and (iii) conventional fertilizer recommendations based on calibrations done on rainfed farming systems lead to over application of nutrients in FRC.

4.2 Materials and Methods

4.2.1 Study area

The study was conducted at the same sites as chapter three (Chapter 3). The mean annual rainfall is less than 650 mm with 60-80% chance of exceeding 500 mm (Manatsa et al., 2020). The area is frost-free with a mean maximum temperature of 28-30^{o}C (Manatsa et al., 2020). The low-lying and relatively flat terrain predisposes the area to flooding from rainfall and backflow from Cahora Bassa Dam (Mavhura et al., 2013). Flooding usually occurs mainly between January and February and at least three flood events with a cumulative floodwater residence period of nine or more days are adequate for FRC (N. Chadereka, personal communication, May 31, 2016). Farmers grow crops in the floodplains, taking advantage of fertile alluvial soils and residual moisture from March to September.

Major crops grown under the flood-recession system include maize, cowpeas [*Vigna unguiculata* L. (Walp)], okra [*Abelmoschus esculentus* (L.) Moench], sugar beans (*Phaseolus vulgaris* L.), tomatoes (*Lycopersicon esculentum* Mill.), and sweet potatoes (*Ipomoea batatas* L.) (Chapter 2).

4.2.2 Experimental sites selection and soil characterisation

Farmers who participated in the field experiments were selected from a list of flood-recession maize farmers provided by AGRITEX. Host farmers were then randomly selected from list of farmers with fields that had adequate area for the experiments and were willing to participate in the study. Three experimental sites were selected in the floodplains of tributaries of Musengezi River: Zhoubvunda 1 (16.18^{o}S, 31.19^{o}E, 363 m a.s.l.); Zhoubvunda 2 (16.17^{o}S, 31.18^{o}E, 352 m a.s.l.) and Mukumbura (16.01^{o}S, 31.19^{o}E, 328 m a.s.l.).

Prior to conducting the field experiments, soil samples were collected from the experimental sites and analysed at the Department of Research and Specialist Services (DR&SS) in 2015. Results from farmers' yields without fertilizer application (Chapter 2) and the soil analysis reported in Chapter 3 (Table 4.1) formed the basis of the fertilizer application rates that were tested in this experiment. Lower rates than recommended were purposively used, taking into consideration the sensitivity/fragility of floodplains. Soil analysis showed that, Zhoubvunda 1 and Mukumbura had fine sandy loams and Zhoubvunda 2 had loam soils. Soil bulk density (g cm^{-3}) was relatively low at all sites 1.21 to 1.22 for Zhoubvunda 1; 1.08 to 1.23 for Zhoubvunda 2 and 1.18 to 1.43 for Mukumbura (Chapter 3, Section 3) Soil pH (0.01M $CaCl_2$) ranged from 7.7 to 8.12 at Zhoubvunda 1, 8.01 to 8.12 at Zhoubvunda 2 and 8.09 to 8.60 at Mukumbura (Chimweta et al., 2018).

Table 4. 1: Maize fertilizer recommendations for mid-Zambezi Valley floodplain soils from analysis conducted by the Zimbabwe Department of Research and Specialist Services

Site	**Fertilizer recommendation kg ha^{-1}**			
	NPK [(7:6:6, 6-8% S]	Single Super Phosphate (12%P:21%Ca:12%S)	Muriate of Potash (52%K:48%Cl)	Ammonium Nitrate (34.5%N)
Zhoubvunda 1	250			400
Zhoubvunda 2	250			400
Mukumbura	300	50-100	50	425

Source: (Chimweta et al., 2018); Chapter 3).

4.2.3 Determination of baseline yield from selected farmers' fields

During the first season (2016), maize yield was determined from selected farmers' fields: four fields close to Zhoubvunda sites and two fields close to Mukumbura. The farmers were selected randomly from a list of maize growing farmers within a kilometre of the experimental sites. Two of the fields were planted to retained seed; three fields to SC513 and one field to SC403.

4.2.4 Experiment 1: Effect of NPK basal fertilizer and N top-dressing fertilizer on the yield of flood-recession maize

Experiment 1 was set up as a 4*4 factorial arranged as a randomised complete block design with rate of application of a NPK basal fertilizer [7:6:6, (6-8% S)] banded below seed before planting at 0, 75, 150 and 225 kg ha^{-1} and rate of application of N top-dressing fertilizer [ammonium nitrate (34.5% N)] side dressed on the soil surface at 0, 75, 150 and 225 kg ha^{-1} as factors tested in the study, replicated three times per site. Relative ground surface elevation which affected timing of flood-recession was used as the blocking factor. Each block measured 61.2 m × 8.0 m including buffers and area of each experimental plot was 6.0 m × 3.6 m. An early maturing maize cultivar, SC513 (Seed-Co) with a yield potential of 10 t ha^{-1} and mean plant height of 2.8 m was planted. The experiment was repeated at three sites, namely Zhoubvunda 1, Zhoubvunda 2 and Mukumbura in 2016 and at Zhoubvunda 1 in 2018.

The land was prepared by making furrows spaced at 0.90 m using an ox-drawn mouldboard plough. To reach moist soil to facilitate germination, ploughing was repeated three times inside each furrow to a depth of ≈0.175 m. Planting holes measuring ≈0.125 m deep were dug inside the furrow at 0.60 m intervals. Therefore, the total planting depth was approximately 0.30 m. Basal NPK fertilizer was banded below the seed in each planting station and covered with a thin layer of soil to avoid direct seed-fertilizer contact. Planting was done on: 12 March and 16 April in 2016 at Zhoubvunda 1; 16 April in 2016 and 10 April in 2018 at Zhoubvunda 2 and; 29 and 30 March in 2016, at Mukumbura. Five maize seeds were planted per station and thinned to three plants per station at one week after crop emergence (WACE).

4.2.5 Experiment 2: Effect of cultivar, NPK basal fertilizer and N top-dressing fertilizer on yield of flood-recession maize

A 3* 4* 4 factorial experiment arranged in split-split plot design with maize cultivar maturity class as the main plot factor (early maturing cultivar,SC513; medium maturing cultivar, SC627; and late maturing cultivar, SC727), NPK basal fertilizer banded below seed, applied before planting at 0, 75, 150 and 225 kg ha^{-1} as sub-plot factor and N top-dressing fertilizer [ammonium nitrate (34.5% N)] side dressed on the soil surface, applied at 0, 75, 150 and 225 kg ha^{-1} as sub-sub plot factor was conducted at two sites Zhoubvunda 1 and Mukumbura in 2017 and Zhoubvunda 1 in 2018. Land preparation, planting and plant spacing were similar to experiment 1. Planting was done on: 8, 10 and 17 April in 2017 and, 8 and 9 April in 2018 at Zhoubvunda 1; 9 and 11 April, and 17 May in 2017; 11 to 13 April in 2018 at Mukumbura.

4.2.6 Experiment 3: Effect of crop establishment method on maize emergence and yield

The experiment was set up in Completely Randomized Design, replicated three times at Zhoubvunda 1 and Mukumbura in 2016 and 2017, and Zhoubvunda 1 in 2018. Each main plot measured 9.0 m × 8.4 m. Two crop establishment methods were compared namely furrow + holing out (as described in experiment 1) and furrow only. Furrow only referred to making furrows in the same way as in the other treatment without holing out. Furrows were spaced at 0.90 m intervals. Seed-Co early maturing maize cultivar, SC513, was planted within two hours of preparation of planting stations to minimize soil moisture loss. Planting dates were: 12 March at Zhoubvunda 1 and 30 March at Mukumbura in 2016; 10 April at Zhoubvunda 1 and 11 April at Mukumbura in 2017; and, 9 April at Zhoubvunda 1 in 2018. Three seeds were planted per station after placement of NPK basal fertilizer at 150 kg ha^{-1}.

4.2.7 Management of experimental plots (Experiments 1, 2 and 3)

One week after crop emergence, maize was thinned to three plants per station in experiments 1 and 2. The crop was hoe-weeded at 3 and 6 WACE. In line with farmers' practice, during the first weeding, planting holes were filled with previously holed-out dry soil to ground level thus creating a mulching effect that conserves soil moisture. Nitrogen top-dressing fertilizer was split into three equal 75 kg ha^{-1} applications at 28, 35 and 42 days after planting.

Pests were controlled by hand-picking and application of chemical pesticides. Fall armyworm was new in the country; there were no recommended pesticides therefore market available pesticides were experimented with. In 2016, Carbaryl 85% WP and trichlorfon were used to control fall armyworm [(*Spodoptera frugiperda* (J. E. Smith)] and African maize stalkborer [*Busseola fusca* (Fuller, 1901)]. Fall armyworm was the major pest in the succeeding seasons (Chimweta et al., 2019). In 2017, fall armyworm was controlled using a combination of Lambda-Cyhalothrin 50 g L^{-1}, Carbaryl 85% WP and Dichlorvos 100%. In 2018 Acephate was used as the sole pesticide.

4.2.8 Data collection

4.2.8.1 Rainfall and floods data

Rainfall was measured using a rain gauge at Chadereka District Development Fund centre (16.17^{o}S, 31.20^{o}E, 356 m a.s.l.) within 1 km of Zhoubvunda sites. Farmers ranked the height and duration of flooding in the floodplain where FRC experiments were conducted.

4.2.8.2 Soil texture and bulk density

In 2017 and 2018, soil samples were collected using an Edelman screw auger at 0.20-m depth intervals up to 0.80 m after harvesting maize in September. Soil samples were collected from three random positions per site and three sub-samples were collected at each depth. For determination of soil texture, composite samples were made from the sub-samples at each depth. Soil texture was determined using the hydrometer method (Bouyoucos, 1962) and bulk density using the core method (Blake, 1986; Andraski, 1991; Dumroese et al., 1999).

4.2.8.3 Measurements

4.2.8.3.1 Experiments 1 and 2

Maize plant height was measured from the base of plant to the first tassel branch on five randomly selected plants per plot using a graduated rod at 10 WACE. The plants were tagged for determination of root collar diameter (RCD) using a Vernier calliper after air drying for six weeks after harvesting. Maize was harvested from 1.8 m × 1.8 m net plots between the second week of August and first week of September. Maize grain was air-dried for three days and the moisture content was measured using a grain Draminski GMM mini (Poland) moisture meter and yield was adjusted to 12.5% moisture content and expressed per hectare before statistical analysis. Stover was air-dried for six weeks and weighed using a digital scale. Harvest index was calculated as mass of grain divided by mass of total aboveground biomass (grain plus stover).

4.2.8.3.2 Experiment 3

Percent emergence was determined 3 WACE from three rows with 10 planting stations each in 6.0 m × 2.7 m net plots. Maize was harvested for grain and stover yield determination in August in all the three seasons, after reaching physiological maturity.

4.2.9 Statistical analyses

Analysis of Variance (ANOVA) was carried out in GenStat 18th Edition (VSN, 2016) to test the effects of cultivar, NPK basal fertilizer, N top-dressing fertilizer, crop establishment method and their interaction on maize grain and stover yield. Linear (Pearson) correlation was carried out to determine relationships among maize grain yield, maize stover yield, maize plant height and RCD. A single sample t-Test was used to compare independent farmers' grain and stover yields, and HI to overall mean yield for SC513 under experiments 1 and 2 across the experimental sites and seasons.

4.3 Results

4.3.1 Rainfall and floods

Seasonal rainfall totals were 668 mm in the 2015-2016 season: 855.7 mm in 2016-2017 season and 471.2 mm in the 2017-18 season (Figure 4.1). It was notable that in the 2017-18 season, the first half of the season; November, December and January received little rainfall whilst February and March recorded abundant rainfall (Figure 4.1). At Mukumbura, the farmer who was allocated a rain gauge, did not record the rainfall consistently, therefore the records were unreliable, and they were discarded.

Farmers ranked the height and duration of flooding in the order coincident with total seasonal rainfall, 2016-17>2015-16>2017-18. Zhoubvunda 1 and 2 flooded at least twice for all the three seasons. In the highest floods season, 2016-17, Zhoubvunda sites flooded five times, with the flood events coinciding with heavy rainfall between 52 and 84 mm in 24 hours. Mukumbura flooded twice in 2016, thrice in 2017 and; once in 2018.

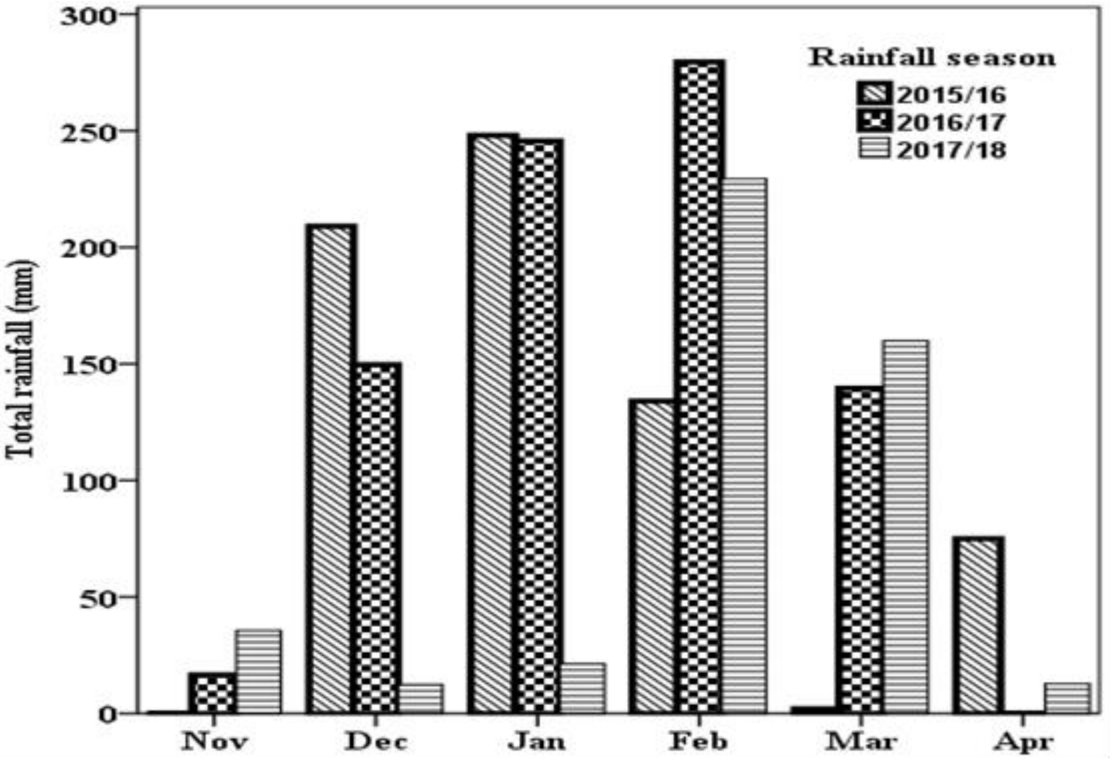


Figure 4.1: Monthly rainfall 2015/16-2017/18 season at Chadereka District Development Fund Centre (16.17^{o}S, 31.20^{o}E, 356 m a.s.l.), near Zhoubvunda floodplain in the mid-Zambezi Valley

4.3.2 Soil texture and bulk density

In the 2017 and 2018 FRC seasons, soil texture and bulk densities were: fine to medium sandy loam and 1.14 to 1.23 g cm^{-3}; fine sandy loam to silty clay loam and 1.11 to 1.21 g cm^{-3}; and, fine sandy loam and 1.20 to 1.33 g cm^{-3} at Zhoubvunda 1, Zhoubvunda 2 and Mukumbura, respectively.

4.3.3 Grain and stover yield

4.3.3.1 Maize grain yield under normal farmer practices

Average FRC maize grain and stover yield under normal farmers' practice in the mid-Zambezi Valley was 3.23 ± 0.54 t ha^{-1} and 3.43 ± 0.59 t ha^{-1}, respectively.

4.3.3.2 Experiment 1

4.3.3.2.1 Maize grain yield

Remarkably high maize grain yield was recorded for the early maturing cultivar SC513 in participatory action research trials under FRC in this study (Figure 4.2). Without fertilizer application, maize grain yield was above 6 t ha^{-1}(Figure 4.2). These maize grain yields were at least twice higher than those recorded under normal farmers' practice under FRC in the mid-Zambezi Valley in this study.

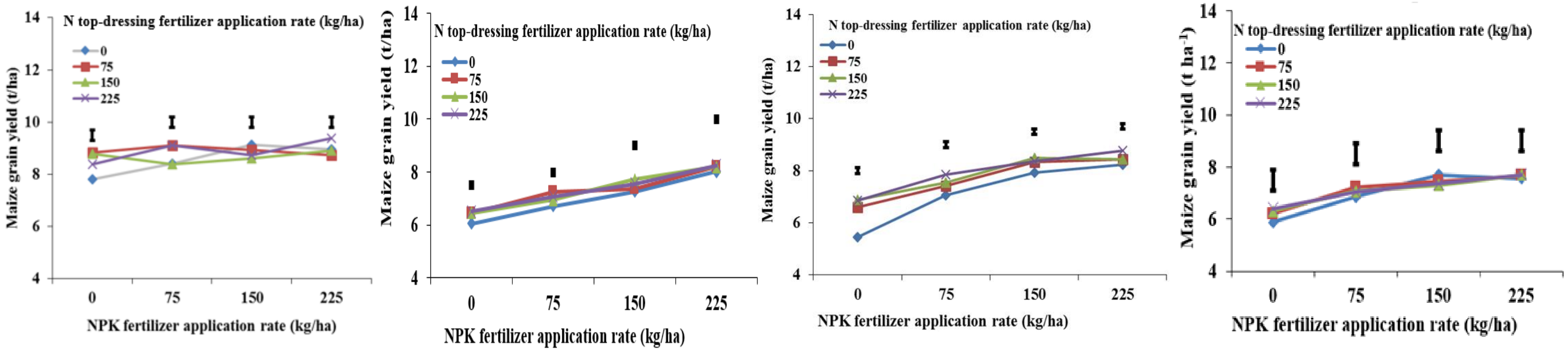
Averaged across N top-dressing fertilizer application rate, maize grain yield increased ($P<0.001$) by 10% when NPK basal fertilizer application rate was increased from the unfertilized control to 75 kg ha^{-1} at Zhoubvunda 1 in the 2016 season and increasing application rate above 75 kg ha^{-1} of NPK basal fertilizer did not increase maize grain yield (Figure 4.2). Maize grain yield increased ($P<0.001$) by 28.2% with increase in NPK basal fertilizer application rate from the unfertilized control to 225 kg ha^{-1}, averaged across N top-dressing fertilizer application rates, at Zhoubvunda 2 in the 2016 FRC season (Figure 4.2). Maize grain yield increased ($P<0.001$) by 28.4% and 20.2% on increasing NPK basal fertilizer application rate from the unfertilized control to 150 kg ha^{-1} at Mukumbura in the 2016 season and at Zhoubvunda 2 in the 2018 season, respectively, averaged across N top-dressing fertilizer application rates (Figure 4.2).

There was no effect ($P>0.05$) of N top-dressing fertilizer application rate on maize grain yield at Zhoubvunda 2 in the 2018 season. Application of 75 kg ha^{-1} N top-dressing fertilizer increased ($P<0.01$) maize grain yield by miniscule 3.8% and 4.3% compared to the unfertilized control, at Zhoubvunda 1 and Zhoubvunda 2 in the 2016 FRC season, averaged across NPK basal fertilizer application rates (Figure 4.2). Maize grain yield reached an asymptote at N top-dressing fertilizer application rate of 75 kg ha^{-1} and did not increase with increase in N top-dressing fertilizer application rate, at these two sites. Maize grain increased ($P<0.001$) by a modest 7.4% with increase in N top-dressing fertilizer application rate from the unfertilized control to 225 kg ha^{-1}, averaged across NPK basal fertilizer application rates, at Mukumbura in the 2016 season (Figure 4.2).

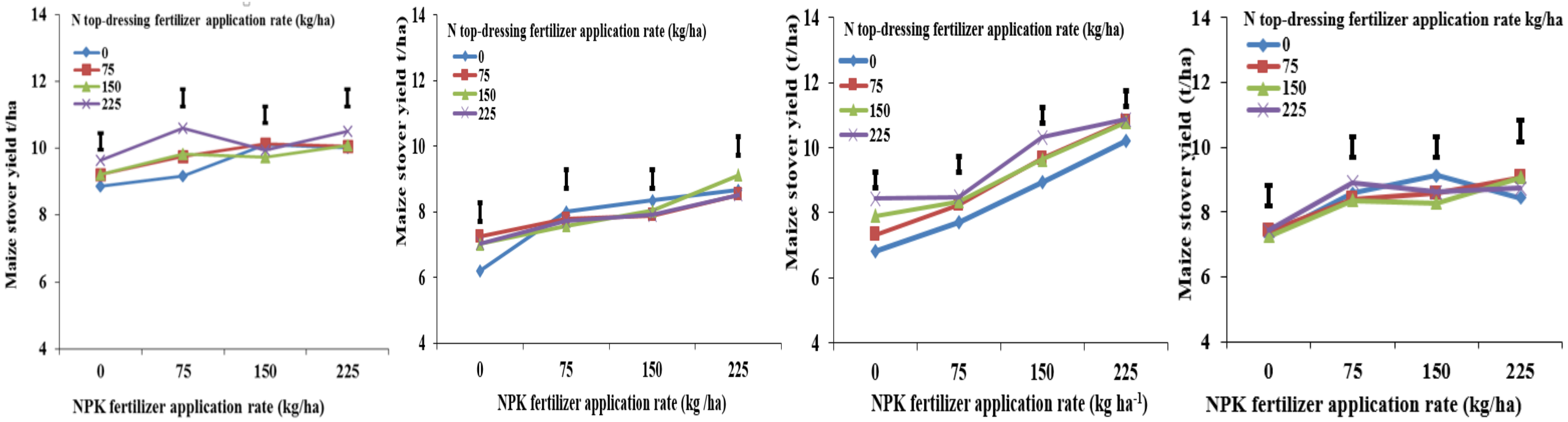
However, the effects of NPK basal fertilizer and N top-dressing fertilizer application rates on maize grain yield were confounded in the significant NPK basal fertilizer application rate * N top-dressing fertilizer application rate interaction at Zhoubvunda 1 ($P<0.001$), Zhoubvunda 2 ($P<0.05$) and Mukumbura ($P<0.001$) in the 2016 season (Figure 4.2). The interaction shows that there was co-dependence in the influence of NPK basal fertilizer application rate and N top-dressing fertilizer application rate on maize grain yield of the early maturing cultivar SC513 grown under FRC in the mid-Zambezi Valley. The interaction generally shows that application of N top-dressing fertilizer produced the greatest maize grain yield benefits when no NPK basal fertilizer was applied and these benefits plateaued at 75 and 150 kg ha^{-1} of NPK basal fertilizer rates, dependent on site and season, and were generally absent at the highest application rate of NPK basal fertilizer, 225 kg ha^{-1} at all sites (Figure 4.2).

4.3.3.2.2 Stover yield

Similar to grain yield, stover yield for the early maturing cultivar, SC513, was remarkably high; more than twice the yield from normal FRC farmers' practice. Without fertilizer application, stover yields were ranged from 6.8 to 9.10 t ha^{-1} (Figure 4.2). The effects of NPK basal fertilizer and N top-dressing fertilizer application rates on maize stover yield were confounded in the significant NPK basal fertilizer application rate * N top-dressing fertilizer application rate interaction at Zhoubvunda 1 ($P<0.05$) and Zhoubvunda 2 ($P<0.001$) (Figure 4.2). The interaction shows that there was a significantly higher stover yield recorded when 225 kg ha^{-1} of the N top-dressing fertilizer was applied to the unfertilized control and 75 kg ha^{-1} of NPK basal fertilizer application rate at Zhoubvunda 1 in the 2016 season. At fertilizer application rates higher than 75 kg ha^{-1}, application rate of N-top dressing fertilizer had no effect on maize stover yield at Zhoubvunda 1 in the 2016 season (Figure 4.2). Application of N top dressing fertilizer was only beneficial in increasing stover yield compared to the control when no NPK basal fertilizer was applied; this stover yield benefit disappeared whenever NPK basal fertilizer was applied at Zhoubvunda 2 in the 2016 season (Figure 4.2).



2016 Zhoubvunda 1 **2016 Zhoubvunda 2** **2016 Mukumbura** **2018 Zhoubvunda 2**



2016 Zhoubvunda 1 **2016 Zhoubvunda 2** **2016 Mukumbura** **2018 Zhoubvunda 2**

Figure 4.2: Interaction between NPK basal fertilizer [7:6:6, (6-8% S)] and N top-dressing fertilizer [ammonium nitrate (34.5%)] on grain and stover yield of an early maturing cultivar, SC513 at Zhoubvunda 1, Zhoubvunda 2 and Mukumbura in 2016 and Zhoubvunda 2 in 2018, under flood-recession cropping in the mid-Zambezi Valley, in Experiment 1

4.3.3.2.3 Harvest index

In the 2016 season, averaged across N top-dressing fertilizer rate, NPK basal fertilizer application rate had no effect ($P>0.05$) on HI at Zhoubvunda 1, but it had a significant effect ($P<0.001$) on HI at Zhoubvunda 2 and Mukumbura (Table 4.2). Averaged across NPK basal fertilizer application rate, N top-dressing fertilizer application rate did not have an effect ($P>0.05$) on HI at all sites in the 2016 season (Table 4.2), but in 2018 the rate of application of N top-dressing fertilizer had a significant effect on HI ($P<0.05$) at Zhoubvunda 2. The effects of NPK basal fertilizer and N top-dressing fertilizer application rate on HI were confounded in the significant NPK basal fertilizer application rate * N top-dressing fertilizer application rate interaction at Zhoubvunda 1 ($P<0.05$), Zhoubvunda 2 ($P<0.001$) and Mukumbura ($P<0.05$) (Table 4.2).

Table 4. 2: Effect of rate of application of NPK basal fertilizer [7:6:6, (6-8% S)] and N top-dressing fertilizer [ammonium nitrate, (34.5%N)] on flood-recession maize harvest index for the early maturing cultivar, SC513 in the mid-Zambezi Valley during the 2016 and 2018 seasons for Experiment 1

	Zhoubvunda 1	**Zhoubvunda 2**		**Mukumbura**
	2016	**2016**	**2018**	**2016**
NPK basal fertilizer application rate (kg ha^{-1})				
0	0.4778^{a}	0.4814^{a}	0.457^{ab}	0.4581^{a}
75	0.4711^{a}	0.4738^{b}	0.451^{a}	0.4768^{b}
150	0.4702^{a}	0.4818^{a}	0.463^{b}	0.4620^{a}
225	0.4696^{a}	0.4841^{a}	0.464^{b}	0.44^{c}
P value	0.218	0.004	0.014	<0.001
± s.e.d	0.0043	0.0027	0.004	0.004
N-top-dressing fertilizer application rate (kg ha^{-1})				
0	0.4736^{a}	0.4741^{a}	0.455^{ab}	0.4625^{a}
75	0.4765^{a}	0.4817^{a}	0.460^{a}	0.4600^{a}
150	0.4718^{a}	0.4804^{a}	0.462^{ab}	0.4625^{a}
225	0.4669^{a}	0.4849^{a}	0.458^{b}	0.4575^{a}
P value	0.166	0.003	0.419	0.302
± s.e.d	0.0043	0.0027	0.004	0.004
NPK basal fertilizer * N top-dressing fertilizer				
P-value	0.041	<0.001	0.501	0.004
± s.e.d	0.0085	0.0054	0.0134	0.0070
CV%	2.2	1.4	2.2	2.0

Values in the same column with a common superscript are not significantly different ($P > 0.05$)

4.3.3.2.4 Maize height and root collar diameter

Maize height ranged from 2.23 m to 2.83 m and RCD ranged from 1.25 cm to 2.30 cm (Appendix 5).

4.3.3.3 Experiment 2

4.3.3.3.1 Maize grain

Like results recorded in experiment 1, maize grain and stover yields recorded in action research trials under farmer and researcher management, without fertilizer application, were twice or more times greater than those that were recorded in this study under normal farmers' practice in the mid-Zambezi Valley in FRC (Figure 4.3). Averaged across application rates of NPK basal and N top-dressing fertilizers, maize grain yield increased ($P<0.05$) in the order SC513=SC627<SC727 at Zhoubvunda 1 in the 2017 and 2018 seasons and SC513<SC627<SC727 at Mukumbura in the 2017 season (Figure 4.3). Averaged across maize cultivars and N top-dressing fertilizer application rate, maize grain yield increased ($P<0.001$) by 18.6%, 22.7% and 20.5% with increase in NPK basal fertilizer application rate from the control to 225 kg ha^{-1} at Zhoubvunda 1 in the 2017 and 2018 seasons and at Mukumbura in the 2017 season, respectively (Figure 4.3). Averaged across maize cultivars and NPK basal fertilizer application rates, maize grain yield increased ($P<0.001$) by 2.3% and 2.8% with increase in N top-dressing fertilizer from 0 to 75 kg ha^{-1}, with no further increase as the N top-dressing fertilizer was increased above 75 kg ha^{-1}, at Zhoubvunda 1 in the 2017 and 2018 season, respectively (Figure 4.3). The exception was at Mukumbura where an increase in the rate of application of N top-dressing fertilizer from the unfertilized control to 225 kg ha^{-1}, increased ($P<0.001$) maize grain yield by 10.9% (Table 4.3).

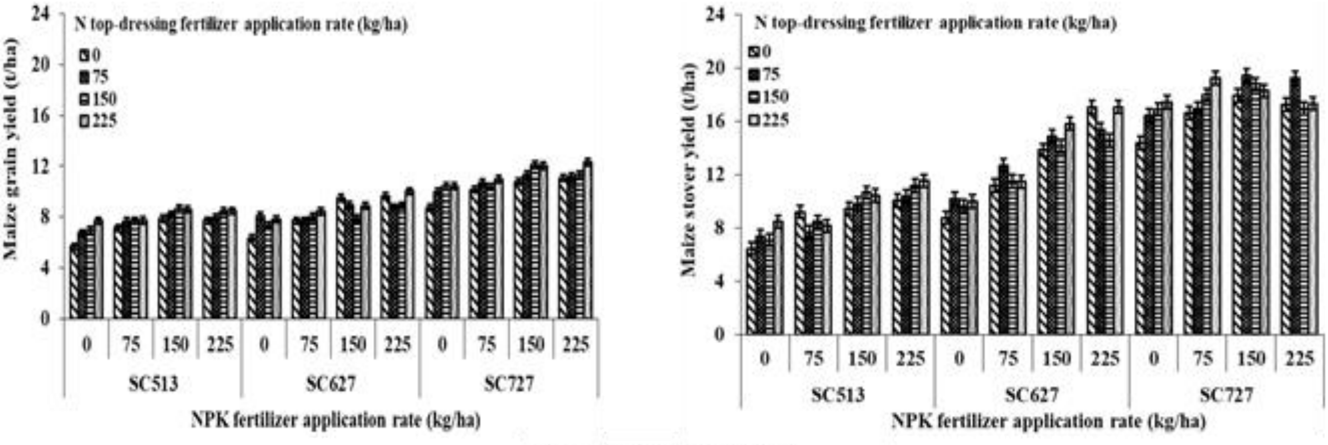
However, the effects of maize cultivar, NPK and N top-dressing fertilizer application rate were confounded within a significant maize cultivar * NPK basal fertilizer application rate * N top-dressing fertilizer application rate interaction ($P<0.001$) on maize grain yield at the two sites and seasons (Figure 4.3). The interaction shows that the effects of maize cultivar, NPK basal fertilizer application rate and N top-dressing fertilizer application rate on maize grain yield were interdependent as illustrated in Figure 4.3. The three-way interaction shows that, although maize grain yield increased with increase in length of season to reach maturity for the cultivar, application of NPK basal fertilizer had higher impact on increasing maize grain yield in the early (SC513) and medium (SC627) maturing cultivars compared to late maturing (SC727) cultivar. In addition, application of NPK basal fertilizer significantly increased maize grain yield for the early maturing maize cultivar SC513, at low fertilizer application rates, from the control to 75 kg ha^{-1} of NPK basal fertilizer and for the medium and late maturing cultivars, maize grain yield generally plateaued at a higher NPK basal fertilizer application of 150 kg ha^{-1} (Figure 4.3). The results also show that benefits of N top-dressing fertilizer application were highest in increasing maize grain yield when no NPK basal fertilizer was applied, and the size of these yield gains increased with increased length of growing season for the maize cultivar in the order SC513<SC627<SC727 (Figure 4.3).

4.3.3.3.2 Stover yield

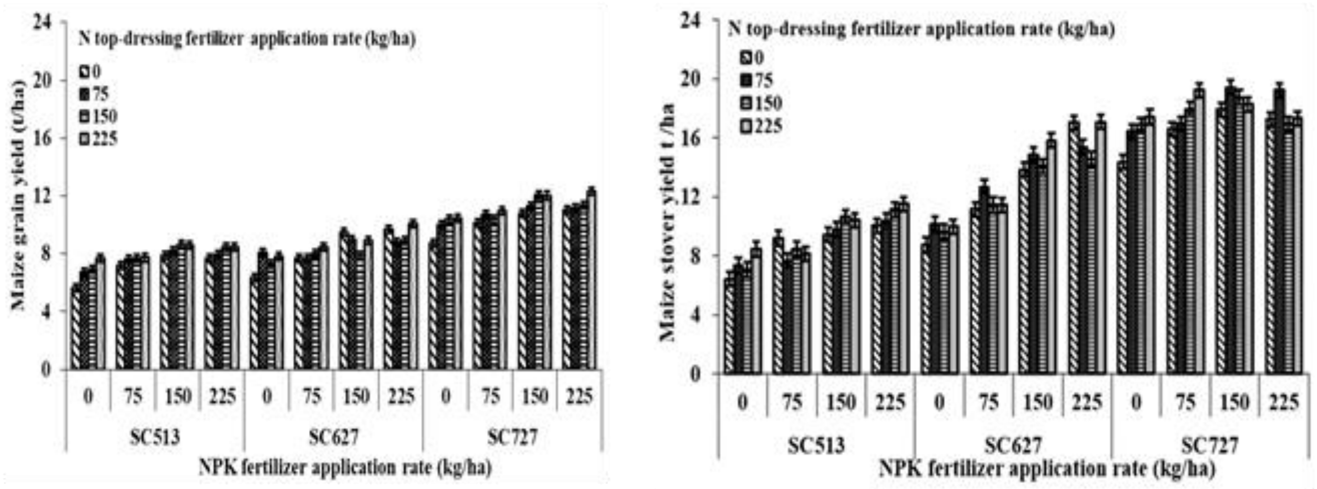
Averaged across application rates of NPK basal and N top-dressing fertilizers, maize stover yields differed ($P<0.05$) in the order SC513<SC627=SC727 at Zhoubvunda 1 in 2017 and SC513<SC627<SC727 at Mukumbura in 2017, and 2018 at Zhoubvunda 1 (Figure 4.3). Averaged across maize cultivar and N top-dressing fertilizer application rate, stover yield increased with increasing NPK basal fertilizer application rate from 0-75, 75-150, 150-225 kg ha^{-1} by: 6.5%, 7.3% and 11.7% at Zhoubvunda 1; 13.5%, 14.8% and 2.6% at Mukumbura in the 2017 season; and 12.6%, 6.1% and 5.3% at Zhoubvunda 1, in the 2018 season respectively.

When averaged across maize cultivar and NPK basal fertilizer application rate, maize stover yield increased by 6.8% and 3.9%. at Zhoubvunda 1 in 2017 and 2018 FRC seasons respectively, and 8.5% at Mukumbura in the 2018 season, when N top-dressing fertilizer was increased from the control to 225 kg ha^{-1} (Figure 4.3).

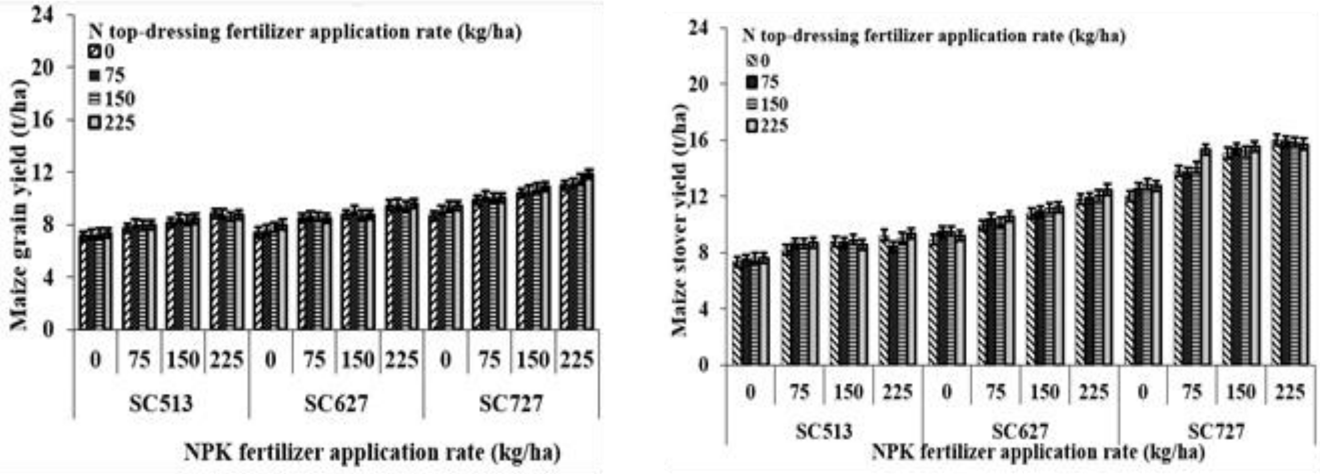
In the 2017 season at Zhoubvunda 1 and Mukumbura, and the 2018 season at Zhoubvunda 1, there was cultivar * NPK basal fertilizer * N top-dressing fertilizer interaction ($P<0.001$) for stover yield (Figure 4.3). The interaction shows that, although maize stover yield increased with increase in length of season to reach maturity for the maize cultivar, application of NPK basal fertilizer had higher contribution on increasing maize stover yield in the late maturing cultivar SC727, than in the medium and early maturing cultivars. In 2017, although application of N top-dressing fertilizer significantly increased maize stover yield in the unfertilized control for all cultivars; for the late maturing cultivar, SC727, significant stover yield increases were observed at 75 kg ha^{-1} N top-dressing fertilizer at NPK basal fertilizer application rates ≥ 150 kg ha^{-1} (Figure 4.3).



Zhoubvunda 1 2017



Mukumbura 2017



Zhoubvunda 1 2018

Figure 4.3: Effect of cultivar, NPK basal fertilizer [7:6:6, (6-8% S)] and N top-dressing fertilizer [ammonium nitrate, (34.5%N)] interaction on grain and stover yield of flood-recession maize at Zhoubvunda 1 and Mukumbura in the mid-Zambezi Valley during the 2017 and Zhoubvunda 1 in 2018 seasons, Experiment 2

4.3.3.3.3 Harvest index

Averaged across NPK basal and N top-dressing fertilizer rates, cultivars' HI differed ($P<0.001$) in the order SC727=SC627<SC513, at Zhoubvunda 1 and Mukumbura in 2017 and in the order SC727<SC627<SC513 in 2018 at Zhoubvunda 1 (Table 4.3). In the 2017 FRC season, averaged across cultivar and N top-dressing fertilizer application rates, effect of NPK basal fertilizer application rate on HI varied without a trend at Zhoubvunda 1, and HI decreased with increasing NPK basal fertilizer application rate up to 150 kg ha^{-1} at Mukumbura. At Zhoubvunda 1 in the 2018 season, NPK basal fertilizer rate did not have an effect ($P>0.05$) on HI (Table 4.3). Averaged across cultivar and NPK basal fertilizer application rate, effect of N top-dressing fertilizer rate varied without a trend at Zhoubvunda 1 in the 2017 season ($P<0.001$) and in the 2018 season ($P<0.05$) whilst at Mukumbura, effect of N top-dressing fertilizer rate on HI was significant ($P<0.05$) at NPK fertilizer application rate >150 kg ha^{-1}.

Similar to maize grain and stover yield, the effects of maize cultivar, NPK and N top-dressing fertilizer application rate were confounded within a significant maize cultivar*NPK basal fertilizer application rate*N top-dressing fertilizer application rate interaction ($P<0.001$) on HI at Zhoubvunda 1 and Mukumbura in 2017 and Zhoubvunda 1 in the 2018 season (Table 4.3).

Table 4. 3: Effect of cultivar, NPK basal fertilizer [7:6:6, (6-8% S)] and N top-dressing fertilizer [ammonium nitrate, (34.5%N)] interaction on flood-recession maize harvest index in the mid-Zambezi Valley during the 2017 and 2018 seasons in Experiment 2

	Zhoubvunda 1		**Mukumbura**
	2017	**2018**	**2017**
Maize Cultivar			
SC 513	0.4565^{a}	0.489^{a}	0.4597^{a}
SC 627	0.3226^{b}	0.449^{b}	0.3958^{b}
SC 727	0.3335^{b}	0.416^{c}	0.3824^{b}
P value	0.006	<0.001	0.005
± s.e.d	0.0202	0.006	0.0039
NPK basal fertilizer application rate (kg ha^{-1})			
0	0.3740^{ac}	0.457^{a}	0.4303^{a}
75	0.3895^{ab}	0.450^{a}	0.4183^{b}
150	0.3796^{ac}	0.449^{a}	0.4039^{c}
225	0.3671^{c}	0.451^{a}	0.3980^{c}
P value	0.0690	0.335	0.012
± s.e.d	0.0080	0.005	0.0076
N top-dressing fertilizer application rate (kg ha^{-1})			
0	0.3800^{a}	0.451^{a}	0.4097^{a}
75	0.3755^{b}	0.458^{b}	0.4107^{ac}
150	0.3839^{c}	0.451^{a}	0.4146^{bc}
225	0.3709^{d}	0.450^{a}	0.4155^{b}
P value	<0.001	0.003	0.012
± s.e.d	0.0017	0.001	0.0020
Cultivar * NPK basal fertilizer interaction			
P value	0.2320	0.410	0.019
± s.e.d	0.2350	0.009	0.0121
Cultivar * N top-dressing fertilizer interaction			
P value	<0.001	0.002	<0.001
± s.e.d	0.0204	0.006	0.0049
NPK basal fertilizer *N top-dressing fertilizer interaction			
P value	<0.001	<0.001	<0.001
± s.e.d	0.0085	0.005	0.0084
Cultivar * NPK basal fertilizer *N top-dressing fertilizer interaction			
P value	<0.001	<0.001	<0.001
± s.e.d	0.0240	0.001	0.0130
CV %	1.9	1.3	1.6

Values in the same column with a common superscript are not significantly different ($P > 0.05$)

4.3.3.3.4 Maize height and root collar diameter

Maize height ranged from 2.35 to 2.70 m for SC513, 2.51 to 3.07 m for SC627 and 2.74 to 3.08 m for SC727 (Appendix 6). Root collar diameter ranged from 1.92 to 2.11 cm for SC513, 1.52 to 2.14 cm for SC627 and 1.56 to 2.18 for SC727.

4.3.3.4 Experiment 3

In all years (2016-2018) at Zhoubvunda 1 and Mukumbura, furrow plus holing out performed better than furrow only ($P<0.05$), with higher crop emergence percent between 22 and 42%, and substantial grain and stover yield increases > 20% at Zhoubvunda 1 and > 30% at Mukumbura (Table 4.4). Harvest index showed similar results, except in 2017 at Mukumbura, where there was no significant difference ($P>0.05$).

Table 4. 4: Effect of crop establishment method on percent emergence, grain and stover yield and harvest index of flood-recession maize in the Zambezi Valley, Northern Zimbabwe

Crop establishment method	**Zhoubvunda 1**				**Mukumbura**			
	Emergence (%)	**Grain yield (t ha^{-1})**	**Stover yield (t ha$^{-1)}$**	**Harvest Index**	**Emergence (%)**	**Grain yield (t ha^{-1})**	**Stover yield (t ha^{-1})**	**Harvest Index**
2016 Season								
Furrow only	54.07	6.265	7.307	0.4616	57.15	5.195	7.197	0.4193
Furrow + holing out	68.89	7.986	8.205	0.4932	74.96	6.830	8.075	0.4582
P value	0.035	<0.001	<0.001	0.013	<0.001	0.001	0.019	<0.001
t	-2.3	13.70	18.10	8.91	-5.01	-8.14	3.83	-13.2
F	2.03	11.87	6.58	7.86	1.86	4	4	4
DF	16	4	4	4	16	5.34	1.87	1.09
± s.e.d	6.45	0.126	0.0496	0.00355	3.555	-1.635	0.2300	0.00295
2017 Season								
Furrow only	55.93	7.251	8.456	0.4616	61.75	7.440	8.010	0.4817
Furrow + holing out	79.63	8.949	9.283	0.4909	75.53	9.823	10.082	0.4939
P value	<0.001	<0.001	0.001	0.015	0.001	<0.001	0.015	0.064
t	-6.02	10.62	7.88	4.06	-3.95	-7.95	-4.10	-0.56
F	2.40	1.66	2.45	1.39	1.07	2.21	3.52	1.82
DF	16	4	4	4	16	4	4	4
± s.e.d	3.937	0.160	0.105	0.0072	3.645	0.3	0.505	0.0217
2018 Season								
Furrow only	38.15	5.824	6.596	0.4690				
Furrow + holing out	54.07	7.441	7.632	0.4936				
P value	<0.001	<0.001	0.003	<0.001				
t	-4.14	17.89	6.73	4.28				
F	1.80	1.93	15.08	1.56				
DF	16	4	4	4				
± s.e.d	3.845	0.0904	0.154	0.00575				

4.3.4 Correlation between fertilizer rate and maize yield

4.3.4.1 Experiments 1 and 2

When data were combined for all seasons (2016-2018), there were significant positive relationships ($P<0.05$) between rate of application of NPK basal fertilizer and grain and stover yield of the early maturing cultivar SC513 and medium maturing cultivar SC627, however, for the late maturing cultivar SC727, the relationship was not significant ($P>0.05$) (Table 4.5). There were no significant relationships ($P>0.05$) between rate of application of N top-dressing fertilizer and maize grain and stover yield for all cultivars.

Table 4. 5: Relationship between fertilizer rate and maize yield under flood-recession cropping in the mid-Zambezi Valley

Maize Cultivar	Statistic	[2]NPK basal fertilizer versus Grain yield	NPK basal fertilizer versus Stover yield	[3]N top-dressing fertilizer versus Grain yield	N top-dressing fertilizer versus Stover yield
SC513	r[1]	0.687	0.706	0.266	0.172
	P value	<0.001	<0.001	0.235	0.229
SC627	r	0.760	0.651	0.120	0.177
	P value	0.004	0.022	0.711	0.582
SC727	r	0.530	0.531	0.243	0.212
	P value	0.077	0.076	0.446	0.507

[1]r represents the Pearson's correlation coefficient; [2] NPK basal fertilizer [7:6:6, (6-8% S)]; [3]N top-dressing fertilizer [ammonium nitrate (34.5%)]

4. 4 Discussion

Mean maize grain yield (3.23 t ha^{-1}) from normal FRC farmers' fields was considerably higher than 1 t ha^{-1} usually reported for rainfed maize in smallholder farming systems (Smale et al., 2011; Nyakudya et al., 2014). Mean FRC grain and stover yield from the early maturing cultivar SC513 in Experiment 1, under researcher and farmer management in action research trials without fertilizer application, was 6.416 t ha^{-1} and 7.257 t ha^{-1}, respectively; double those from normal FRC farmers' fields. These results suggest that smallholder farmers practicing FRC in the mid-Zambezi Valley have potential to double maize grain yield by deploying improved maize hybrids and increasing the intensity of agronomic, pest and disease management to similar levels as researcher and farmer managed trials in this study, without fertilizer application. These high yields obtained under FRC without fertilizer application in this study, confirm that soil fertility replenishment through alluvial deposition and groundwater recharge (Chimweta et al., 2018; Laisi, 2016; Adams, 1993) ensured adequate supply of mineral nutrients and residual moisture to the growing maize crop. However, the nutrient-rich water (Chimweta & Nyakudya, 2019) may also lead to salinization of the rootzone during capillary rise of water; this has potential to reduce maize grain yield (Doorenbos & Kassam, 1979). Given the concentrations of the basic cations in the study area (Chimweta et al., 2018), there is high threat of salinity.

The yields from typical farmers' fields were comparable to yields obtained by FRC farmers in the Okavango Delta, 2.4 to 3.4 t ha^{-1}, for a very early maturing maize cultivar (SC403) without applying fertilizers (Kashe et al., 2015). Normal farmers' fields yield may have been lower due to non-adherence to strict agronomic practices as observed in experimental plots management. In the Amazon River floodplain, Gonçalves et al. (2010) obtained 5.612 t ha^{-1}, which is comparable to the yield for SC513 without fertilizers in this study. Under rainfed cropping in Zimbabwe, such high yields are usually attained in fertilized, researcher-managed experiments in smallholder farming systems, for example, Mugwira et al. (2002) reported yields > 5.70 t ha^{-1} for the late maturing cultivar SR52 and Nyakudya et al. (2014) recorded up to 4.63 t ha^{-1} for SC513.

There were maize yield benefits of changing from early to late maturing cultivars (7.7-8.1 t ha^{-1} for SC513, 7.5-8.7 t ha^{-1} for SC627, and 8.4-10.9 t ha^{-1} for SC727) (Table 4.3). Under rainfed cropping, these medium and late maturing cultivars are recommended for high rainfall areas (Mashingaidze, 2006), therefore, their superior performance confirms that the Zambezi Valley floodplains are high potential areas despite their location in a semi-arid agro-ecological region. However, although the late maturing and higher yielding cultivar (SC727) consistently performed better than the medium (SC627) and early maturing (SC513) cultivars, the lower HI for the later maturing cultivars suggests that there are environmental conditions that favoured vegetative growth over grain filling for these cultivars. Soil salinity and soil moisture content are examples of environmental factors that have a more severe effect on grain yield than total dry matter of maize (Katerji et al., 1996; Mashingaidze, 2006). Effects of soil salinity were visible during late growth stages of SC727 (Appendix 7). The early maturing cultivars escape salinity due to their shorter growth cycles. Measurement of soil moisture and salinity changes in flood-recession maize fields during the growing season may provide information on their potential effect on maize.

The three way interaction, maize cultivar*NPK basal fertilizer application rate*N top-dressing fertilizer rate on grain yield suggests that although in general farmers can derive more benefit from applying NPK basal fertilizer than N top-dressing fertilizer: they should not exceed 75 and 150 kg ha^{-1} NPK basal fertilizer for the early maturing cultivar and the later maturing cultivars respectively. The results are in line with fertilizer demands for the different cultivar maturity categories, where the later maturing higher yielding cultivars generally require more fertilizers than the early maturing and lower yielding cultivars (Mashingaidze, 2006). Furthermore, the interactions suggest that farmers can benefit more from applying N top-dressing fertilizer at 0 kg ha^{-1} NPK basal fertilizer and the benefit is more in the later maturing cultivars that require more fertilizer.

Tailing off of maize grain yield increase at ≤150 kg ha^{-1} NPK basal fertilizer application rate and the largely negligible effect of N top-dressing fertilizer implies that fertilizer recommendations between 200 and 250 kg ha^{-1} NPK basal fertilizer, and 300 and 425 kg ha^{-1} for N top-dressing fertilizer (Chapter 3) lead to over application of plant mineral nutrients, which adversely affect the environment. The negative environmental effects include nutrient enrichment of water enrichment and salinization of the rootzone. The NPK basal fertilizer thresholds for maize grain increase observed in this study are favourable to the resource-constrained farmers, who on average applied 50 kg ha^{-1} of fertilizer (Mashingaidze, 2006). The differences in response to fertilizer between Zhoubvunda 1 and Mukumbura can be attributed to better edaphic conditions at the former, for example, lower pH, higher SOC level and nutrient reserves (Chapter 3).

In support of farmers' preferred method of crop establishment (Chapter 2, Section 2.3.4), grain and stover yields were higher in plots with furrow plus holing out crop establishment method than furrow only (Table 4.4). This can be attributed to moisture benefits that resulted in higher emergence percentage under furrow plus holing out than furrow only (Chidanti-Malunga, 2011). Although, there are additional labour costs associated with furrow plus holing out, it may be worthwhile to incur these costs given the substantial yield increase ≥1.6 t ha^{-1}. The emergence percentages in furrow plus holing out were comparable to crop emergence percentages (54.5 to 72.8%) reported under rainfed cropping in semi-arid Zimbabwe by Nyakudya (2014).

4.5 Conclusions and Recommendations

The furrow plus holing out crop establishment method improved percent emergence by between 22 and 42% and increased maize grain yield by between 22 and 23%, compared to furrow only. The late maturing cultivar, SC727, out-yielded the medium and early maturing cultivars, but it had a low HI. Overall, the greatest increase in maize grain yield was obtained when NPK basal fertilizer was increased from 0 to 75 kg ha^{-1} for SC513 and 150 kg ha^{-1} for the later maturing cultivars. Application of N top-dressing fertilizer was more beneficial at 0 kg ha^{-1} NPK basal fertilizer and the yield benefit was greater in the later maturing cultivars, compared to the early maturing cultivar.

Recommendations to the farmers were to: (i) practice furrow plus holing out where resources are available; (ii) plant the late maturing and higher yielding cultivar SC727; and (iii) apply NPK basal fertilizer at ≤150 kg ha^{-1}, depending on cultivar, their resource endowment and objectives. Further studies should be conducted to (i) measure nutrient accumulation in top layers of the soil which may occur due to deposition of nutrient-rich silt and capillary rise (ii) assess effect of topdressing fertilizer placement method on crop yield under FRC (iii) ascertain the environmental factors that reduced the HI of later maturing cultivars (iv) determine performance of intermediate crop establishment methods with less number of runs in the furrow and (v) determine the effect of covering planting holes with soil on maize root development and yield.

CHAPTER 5: SOIL MOISTURE CONTENT AND SALINITY DYNAMICS: IMPLICATIONS FOR FLOOD-RECESSION MAIZE IN THE MID-ZAMBEZI VALLEY FLOODPLAINS

Abstract

Maize is moderately sensitive to soil salinity and it is susceptible to both waterlogging and drought. Therefore, changes in soil moisture and salinity that typify most floodplain ecosystems can significantly affect maize yield. The objectives were to determine soil moisture content and salinity during the flood-recession cropping season and explore the effect of soil salinity on maize production. Soil moisture content was measured using the gravimetric and Time Domain Reflectometry methods. Soil electrical conductivity (EC), was measured using a pH and conductivity meter and converted to saturated soil electrical conductivity (ECe) using a dilution factor. Maize root samples were collected, oven-dried and weighed. Soil moisture content, soil ECe and maize root mass were subjected to ANOVA. Soil moisture content and ECe graphic trends and bivariate correlations were performed. Soil profile moisture content was lowest in 0.0-0.2-m layer and decreased with season progression, but remained within the available water capacity range except for one site in a low floods season. Saturated soil EC was highest in the 0.0-0.2-m depth. Saturated soil EC exceeded 1.7 dS m^{-1}, the threshold for maize yield decrease, and reached levels that can reduce yield by 10 to 50%. Most roots, 84±4%, were in the top 0.2-m. The flood-recession season length was long enough to support a cultivar that took ≈100 days to mature. It was concluded that soil moisture deficit was not a limiting factor to maize production in this study maize. However, soil salinity could be a limiting factor to production of medium maturing and late maturing maize cultivars, which mature later than 100 days. Therefore, the implications of salinity are on reducing yield and determining factor for season length. Mulching, nutrient stewardship to reduce salt accumulation in the rootzone, and planting early maturing cultivars that escape salinity were recommended.

Key words: Maize roots distribution; Salt tolerance; Season length; Soil electrical conductivity

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5.1 Introduction

Maize (*Zea mays* L.) is the most important crop worldwide in terms of grain production (Steduto et al, 2012). It is a staple food crop for over 200 million people in Sub-Saharan Africa (SSA) (Macauley & Ramadjita, 2015). However, rainfed maize yields in smallholder farming systems of SSA have remained low, oscillating around 1 t ha^{-1} (Rockström et al., 2003; Nyakudya et al., 2014; AGRA, 2017), thereby perpetuating food insecurity. The major biophysical constraints to improving maize yields are inadequate and poorly distributed rainfall (Steiner & Rockström, 2003) and poor soil fertility (Postel, 2000; Sanchez, 2002; Motsumi et al., 2012). Floodplains are usually endowed with water resources and fertile alluvial soils, which make them the most productive ecosystems in the world (Adams, 1993; Pwiti, 1996; Lynch & Brown, 2000; Koschorreck & Darwich, 2003; Rinklebe et al., 2007; Balana et al., 2019), that provide solutions to the crop production constraints in smallholder rainfed farming systems. Floodplains along major rivers in Africa occupy approximately 30 million hectares of land and contribute significantly to the continent's agroeconomy (CGIAR, 2015). For example, the economic value of flood-recession cropping (FRC) in the Zambezi basin was estimated at US$50 million (Schuyt, 2005). Flood-recession cropping is the growing of crops using subsurface water after flood levels recede in areas that experience flooding such as river floodplains, wetlands and lake margins.

Maize is grown in floodplains across SSA (Chidanti-Malunga, 2011; Kashe et al., 2015; Sidibé et al., 2016; Kool et al., 2018; Balana et al., 2019; Comptour et al., 2020), and it is the major crop grown under flood-recession cropping (FRC) in Southern Africa (Chidanti-Malunga, 2011; Kashe et al., 2015). This farming system can be a viable option for improving food security through increasing and stabilising crop yields. Maize yields achieved from farmers' fields without fertilizer application exceed rainfed crop yields: Nederveen and Steenbergen (2011) reported 1.6 to 2.2 t ha^{-1} over seven years in Boru, Ethiopia; Kashe et al. (2015) obtained 2.4 to 3.4 t ha^{-1} in the Okavango Delta, compared to 0.162 t ha^{-1} under rainfed cropping; and Chimweta et al. (2021) reported 3.2 t ha^{-1} compared to 0.2 to 0.4 t ha^{-1} under rainfed cropping in the mid-Zambezi Valley. Whilst maize yields achieved under FRC are higher than those under rainfed production, they still remain relatively low considering that flooplains are high potential ecosystems, suggesting that in addition to agronomic practices, there could be other yield limiting factors in these ecotopes. Potential maize yield exceed 8 t ha^{-1} for most cultivars (SEEDCO, 2004). Flood and salt-tolerant crops that grow successfully under limited periods of waterlogging or drought-associated salt stress are ideal for flood-based farming systems including FRC (Verhoeven & Setter, 2010). Unfortunately, maize is susceptible to both waterlogging and drought

(Mashingaidze, 2006) and moderately sensitive to salinity (Shalhevet, 1994) suggesting that soil salinity and moisture content are likely to be among the yield limiting factors.

In floodplains, FRC occurs during the dry season when there is no downward flow and water usually moves upwards by capillary rise. The water is taken up by plant roots or evaporates at the surface and salts accumulate in the rootzone or in the top soil layer (Van Hoorn & van Alphen, 2006). Therefore, there is risk of plant exposure to high salinity (salt content) in soil within the season. The risk of cumulative increase in salinity in the rootzone from one season to the other is low because seasonal flooding contributes to desalinization of floodplains (de León-Lorenzana et al., 2017). Therefore, intraseason soil salinity build-up is the major concern. Crop growth responds to salinity in two phases: a continuous osmotic phase that inhibits plant water uptake and an ionic phase when the accumulation of specific ions in the plant leads to ion toxicity or ion imbalance (Munns & Tester, 2008). In saline soils, when the soil gets drier, the salt concentration increases with increased negative effect on crop yield. The tolerance of maize to salinity decreases in the order: germination; ear and grain filling; and seedling stage (Maas et al., 1983). Salinity has a more severe effect on the grain yield than total dry matter (Katerji et al., 1996). Grain yield is reported to decrease as saturated electrical conductivity (ECe) (dS m^{-1}) increases: 0% at 1.7, 10% at 2.5, 25% at 3.8, 50% at 5.9 and 100% at 10 (Doorenbos and Kassam, 1979).

Soil water available for plant uptake falls between the lower limit, permanent wilting point (WP) and upper limit saturation capacity (SC) (Feng et al., 2012). Under rainfed or irrigated cropping, when the soil water is above field capacity (FC) water drains by gravity, but in floodplains the soil moisture content may be maintained at SC because of shallow water tables. Under FRC, there is a danger of aeration stress due to waterlogging at planting and during the early vegetative stage. Severe waterlogging causes oxygen deficiency, which inhibits root respiration and the rate of photosynthesis (Beckman et al., 1992). Tian et al. (2019) established that the effect of waterlogging stress on the dry matter accumulation of maize decreased in the order: seedling (V3), jointing (V6) and tasseling (VT) stages. As the season progresses moisture depletion may lead to water stress that affects the maize reproductive stages silking (R1) and kernel development (R2 to R3) stages.

For sustainable cropping based on crops that are susceptible to salt and water stress there is need to develop strategies for alleviating water and salinity stress. However, there is paucity of information on soil moisture content and salinity dynamics under FRC. This information is required for selection and development of appropriate maize agronomic practices and selection of cultivars that fit into the FRC season length.

In Chapter 3, high concentrations of bases that increased the likelihood of occurrence of saline soils were observed. In Chapter 4, visible signs of maize damage by salinity and low harvest indices on the late maturing cultivar (SC727) were observed. The fact that salinity affected the late maturing more than the early maturing cultivars suggest that salinity may affect FRC maize season length, hence the need for proper cultivar selection. This prompted the need to determine soil salinity dynamics in the floodplains.

The objectives of this study were to (i) determine FRC maize season length and (ii) explore the potential effect of soil salinity and moisture content on maize yield. Soil moisture content and electrical conductivity, and maize root distribution were measured in river floodplains. Considering soil moisture content only, the season was assumed to have ended when the rootzone moisture content fell below WP. The hypotheses were: (i) rootzone soil salinity is a limiting factor to FRC maize season length, and (ii) soil moisture content is not a limiting factor to FRC maize season length in the mid-Zambezi Valley in northern Zimbabwe.

5.2 Materials and Methods

5.2.1 Description of the study area

The study was conducted at the same site as for experiments in Chapter 4. Based on farmers' assessment, the ranking of recent seasons from high to low floods was: 2017>2016>2018. Temperature is not a limiting factor to maize production in the area because the low temperatures that limit maize in the Highveld are not experienced in the Zambezi Valley.

5.2.2 Experimental setting

The study was part of maize cultivar and fertilizer levels experiments that were conducted in farmers' floodplain fields (Chapter 4 Section 2.5). The experiments were conducted at three sites over three seasons and replicated three times per site. The blocking factor (criterion for demarcating blocks) was relative elevation of ground surface, which affected timing of flood-recession. In 2016, one maize cultivar SC513 was planted and from 2017 to 2018 two additional maize cultivars SC627 and SC727 were planted. Days to maturity for these cultivars at 1300 m a.s.l. were 137; 144 and 160 for SC513, SC627 and SC727 respectively (Seed-Co 2018). Over the three seasons planting dates fell between the second week of March and the third week of May. Details of experimental design and management of experimental plots are described in Chapter 4, Section 1.6.

5.2.3 Data collection

5.2.3.1 Soil data

5.2.3.1.1 Dynamic parameters

In 2016, soil moisture content was measured using the gravimetric method. Soil samples for moisture determination were collected weekly at 0.2-m intervals up to 0.6 m depth from three representative sampling points in each block at each site. Measurements were conducted within rows, between two planting stations. Collection of soil samples started at or within 3 weeks after crop emergence (WACE) and ended in August, at or within two weeks before harvesting. The soil samples were kept in soil moisture tins, weighed within 12 hours of collection and oven dried for 48 hours at 105 ^{o}C. The mass of water was calculated by subtracting the mass of dry soil from the mass of the wet soil. Gravimetric moisture content was then calculated as mass of water divided by mass of oven-dried soil multiplied by 100%. The gravimetric moisture content was converted to volumetric water content by multiplying it by soil bulk density.

At Zhoubvunda 1 in 2017 and 2018and Mukumbura in 2017, soil moisture content was measured fortnightly at 0.2-m intervals in 44 mm tecanat access tubes using the TRIME-PICO IPH-44 31238 (Germany). Soil moisture was measured twice at each depth up to 0.6 m in 2017 and up to 0.8 m in 2018. For Zhoubvunda 2, the gravimetric method was used because soils at this site had a tendency to crack and this created air pockets that affect TRIME-PICO IPH-44 31238 measurements.

The total number of access tubes (measuring points) was 12 at Zhoubvunda 1 and eight at Mukumbura, in 2017. In 2018 the total number of access tubes was 18 for Zhoubvunda 1. Concurrently, soil samples for ECe measurement in the laboratory were collected within 0.5 m of the access tubes using an Edelman screw auger at the same depths as samples for moisture content measurement. In order to avoid the possible effect of NPK basal fertilizer [7:6:6, (6-8% S)] on soil EC; samples for both moisture content and salinity were taken randomly in plots that had 0 kg ha^{-1} NPK basal fertilizer. Soil samples for measurement of gravimetric moisture content were collected at three representative points per site within 0.5 m of access tubes for calibrating TRIME-PICO IPH soil moisture content. TRIME-PICO IPH soil moisture content ($TDR_{\Theta v}$) was converted to oven-dry calibrated moisture content on a volume basis before analysis, $\Theta v_{(\text{oven dry calibrated})}$, using regression equations:

$\Theta v_{(\text{oven dry calibrated})} = 1.030 * TDR_{\Theta v} + 0.896$; ($R^2 = 0.703$; $P<0.001$) [Equation 1]

$\Theta v_{(\text{oven dry calibrated})} = 1.295 * TDR_{\Theta v} - 0.174$; ($R^2 = 0.827$; $P<0.001$) [Equation 2]

Where Equation 1 applied to Zhoubvunda 1; and Equation 2 applied to Mukumbura. The R^2 values are above an acceptable value of 0.69 (Wiyo et al., 2000).

Soil salinity, is commonly expressed by electrical conductivity (EC), which is easier and cheaper to measure. Soil EC is calculated by dividing the salt concentration in milliequivalents per litre by a number between 10 and 12 (van Hoorn & van Alphen, 2006). In this study, soil electrical conductivity on a 1:5 soil to deionized water scale was measured using the combined pH and conductivity meter (ADWA 3000 EC/TDS, Romania) at 25 ^{o}C. Saturated soil electrical conductivity was then calculated using a dilution factor (Smith & Doran, 1996).

5.2.3.1.2 Constant parameters

Soil samples for bulk density and texture determination were collected after harvesting at the same depth intervals for soil moisture content and ECe. Soil bulk density was determined using the core method and soil texture using the hydrometer method (Bouyoucos, 1962). Soil texture was used to estimate saturation capacity, FC and WP from the soil profile file of FAO's AquaCrop Model Version 6.1 (2018) (Fereres et al., 2008; Raes et al., 2018). The difference between FC and WP represents available water capacity.

5.2.3.2 Crop data

Maize root samples were collected from representative planting stations with three plants per station. The total number of sampling points over the three seasons was 40: twelve in 2016; eight in 2017 and sixteen in 2018. Soil containing the maize roots were excavated from rectangular pits (Schuurman & Goedewaagen, 1971) measuring 0.8 m length × 0.6 m width × 0.6-0.8 m depth. The target planting station for root extraction was positioned in the middle of the pit. Root sampling was done up to 0.6 m depth because the effective rooting depth (ERD) for maize is about 0.6 m (Wiyo et al., 2000; Chikowo et al., 2003; Mhizha, 2010; Baizin & Stroosnijder, 2012; Nyakudya et al., 2014). Effective rooting depth is the soil depth where most of the root water uptake takes place, even though some crops may have a few roots beyond that depth.

Soil containing root samples was excavated at 0.2-m depth intervals up to 0.8 m depth. The excavated soil was put in plastic bowels and saturated with water for at least 45 minutes. Water was added whilst stirring the soil-water mixture until roots came into suspension. Suspended roots were extracted using a nest of sieves measuring 2 mm, 0.85 mm, and 425 µm, and placed into trays. Water was added as necessary to bring more roots into suspension, and extraction continued until there were no suspended roots. The soil-water suspension was then passed through sieves in order to collect the roots that remained at the bottom of the container. Extracted roots and debris, which was mainly other organic matter were then separated using running tap water under a nest of sieves. The roots were oven-dried for 48 hours at 70 ºC and weighed.

During the third season (2018), days to 20%, 50% and 80% tasselling and silking of maize were determined by counting the number of tasselling and silking plants at 3-day intervals starting at 7 to 7.5 WACE. For each cultivar 14 lines with 13 planting stations were used to collect the tasselling and silking data. Collection of maize yield data were presented in Chapter 4 section 2.1.

5.2.4 Data analysis

Soil moisture content, ECe and maize roots data were subjected to analysis of variance, and graphic trends analysis in the IBM Statistical Package for Social Sciences Version 21.0. The independent variables were soil depth and Julian day. Field capacity and WP were plotted on the soil moisture content trends graphs. Bivariate correlation of soil moisture content and ECe were performed using the Pearson correlation coefficient. Days to maturity of the three maize cultivars were calculated based on the standard reduction of 4 days for every 100 m decrease in elevation using calibration curves (Seed-Co Manual 2011).

5.3 Results

5.3.1 Soil physical properties

Soils ranged from sandy loams (SaL) to silty clay loams (SiCL) with relatively low bulk densities between 1.08 and 1.36 g cm^{-3} (Table 5.1). Estimated available water capacity ranged from 12% at Zhoubvunda 1 and Mukumbura where there were sandy loams, to 21% in silty clay loams at Zhoubvunda 2 (Table 5.1).

Table 5. 1: Measured and estimated values for selected physical parameters of mid-Zambezi Valley floodplain soil

Site	**Season**	**Depth (m)**	**Bulk density (g cm^{-3})**	**Soil texture**	**Estimated water constants (%)**		
					Saturation capacity	**Field capacity**	**Permanent Wilting point**
Zhoubvunda 1	2016	0.0-0.2	1.23±0.10	fSaL	41	22	10
		0.2-0.4	1.25±0.07	fSaL	41	22	10
		0.4.0.6	1.16±0.00	fSaL	41	22	10
		0.6-0.8	-	mSaL	41	22	10
	2017	0.0-0.2	1.14±0.09	fSaL	41	22	10
		0.2-0.4	1.14±0.08	fSaL	41	22	10
		0.4.0.6	1.18±0.09	fSaL	41	22	10
		0.6-0.8	1.18±0.12	fSaL	41	22	10
	2018	0.0-0.2	1.22±0.08	fSaL	41	22	10
		0.2-0.4	1.16±0.04	fSaL	41	22	10
		0.4.0.6	1.17±0.12	fSaL	41	22	10
		0.6-0.8	1.23±0.10	mSaL	41	22	10
Zhoubvunda 2	2016	0.0-0.2	1.20±0.12	SiCL	52	44	23
		0.2-0.4	1.21±0.06	fSaL	41	22	10
		0.4.0.6	1.13±0.07	fSaL	41	22	10
		0.6-0.8	1.08±0.08	-	-	-	-
	2018	0.0-0.2	1.11±0.90	SiCL	52	44	23
		0.2-0.4	1.21±0.86	SiCL	52	44	23
		0.4.0.6	1.11±0.07	SiCL	52	44	23
		0.6-0.8	1.17±0.83	-			
Mukumbura	2016	0.0-0.2	1.36±0.10	fSaL	41	22	10
		0.2-0.4	1.34±0.09	fSaL	41	22	10
		0.4.0.6	1.26±0.12	fSaL	41	22	10
	2017	0.0-0.2	1.33±0.10	fSaL	41	22	10
		0.2-0.4	1.20±0.10	fSaL	41	22	10
		0.4.0.6	1.30±0.12	fSaL	41	22	10
		0.6-0.8	1.24±0.04	fSaL	41	22	10

5.3.2 Soil moisture content

Mean soil profile moisture content showed a declining trend with season progression in all seasons at all sites ($P<0.001$) (Table 5.2). Similarly, in all seasons at all sites, soil moisture content decreased as the season progressed within individual depths ($P<0.05$); (Figure 5.1), Although overall a decline was observed, there were periods where moisture content did not show significant differences as the season progressed in 2016 and 2017 (Figure 5. 1).

In 2016, at Zhoubvunda 1, mean soil moisture content was lower in the 0.0-0.2 m layer than the deeper depths ($P<0.05$); at Zhoubvunda 2 the mean soil moisture content was similar at shallower depths, which were lower than the 0.4-0.6 m depth; and all depths had similar moisture content at

Mukumbura. In 2017 at Mukumbura, mean soil moisture content was higher at depth 0.4-0.6 m than at shallower depths ($P<0.001$). At Zhoubvunda 1, moisture content increased with increasing soil depth ($P<0.001$) in both 2017 and 2018 (Table 5.3). A similar trend was observed at Zhoubvunda 2 in 2018.

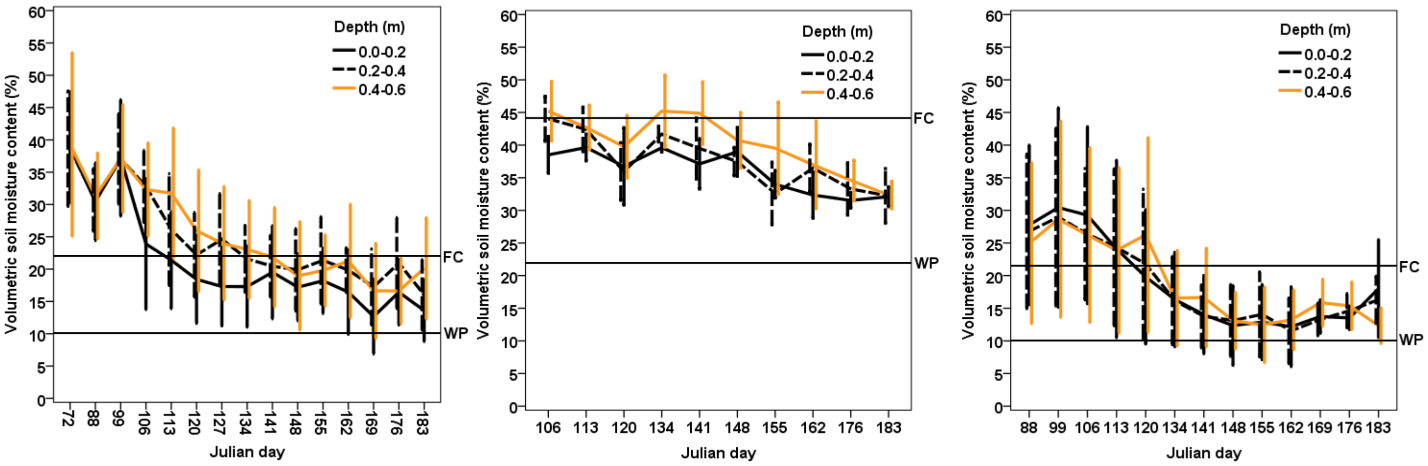
With reference to variations in soil moisture content with depth at individual Julian days: in 2016, soil moisture content was similar across depths at all sites except for Julian days 106, 113, 120 and 183 at Zhoubvunda 1 where depth 0.4-0.6 had higher soil moisture content than the 0.0-0.2-m depth. In 2017 at Mukumbura throughout the season and Zhoubvunda 1 on days 108 and 118, soil moisture content was higher in the 0.4-0.6 m depth than shallower depths ($P<0.05$). In 2018, except for Julian day 126, soil moisture content increased with increasing depth ($P<0.05$). However, the differences in soil moisture content between soil depths decreased as the season progressed. In 2017 interaction between Julian day and soil depth was observed for soil moisture content only at Mukumbura (DF = 16; F = 20.091; P = 0.000).

In the 0.0-0.2-m depth, soil moisture content exceeded FC up to Julian day: 106 in 2016, 133 in 2017, and 141 in 2018 at Zhoubvunda 1; 126 in 2018 at Zhoubvunda 2; 113 in 2016, and 161 in 2017 and at Mukumbura (Figure 5.1). From 2016 through to 2018 seasons, soil moisture content only fell below or equalled WP between days 181 and 231 at Zhoubvunda 2 in 2018. Significant interactions between soil depth and Julian day were observed in 2018 at Zhoubvunda 1 (DF = 21; F = 2.094; P = 0.003); and at Zhoubvunda 2 (DF = 21; F =4.390; P = 0.000).

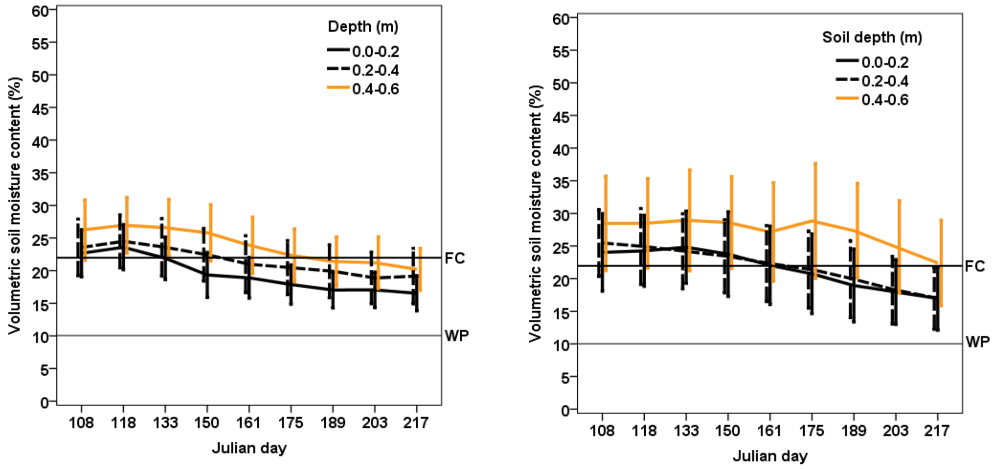
Table 5. 2: Soil moisture content trends during 2016 to 2018 flood-recession cropping seasons in the mid-Zambezi Valley in northern Zimbabwe

Julian day			**Soil moisture content (%)^{1,2}**						
			Zhoubvunda 1			**Zhoubvunda 2**		**Mukumbura**	
2016	**2017**	**2018**	**2016**	**2017**	**2018**	**2016**	**2018**	**2016**	**2017**
72	**108**	**126**	38.94±10.44^{a}	24.15±4.4^{a}	29.01±8.97^{a}		48.13±3.64^{a}		25.98±6.40^{a}
88	**118**	**141**	30.83±5.64^{b}	25.01±4.18^{b}	25.06±10.79^{b}		38.37±9.17^{b}	26.50±11.69^{ac}	25.88±6.31^{a}
99	**133**	**153**	37.13±7.81^{a}	24.01±4.47^{a}	21.07±10.36^{c}		36.25±7.44^{b}	29.35±14.09^{a}	25.97±6.72^{a}
106	**150**	**168**	29.67±8.63^{bc}	22.52±4.74^{c}	20.66±10.90^{c}	42.58±4.44^{a}	32.947.01^{b}	27.27±12.02^{ad}	25.26±6.79^{ab}
113	**161**	**181**	26.42±9.49^{c}	21.33±4.48^{d}	19.64±10.37^{cd}	41.58±3.00^{a}	27.816.58^{bd}	24.11±12.25^{cd}	23.83±6.89^{bc}
120	**175**	**196**	22.19±8.02^{dg}	20.22±4.18^{e}	18.37±10.47^{d}	37.48±4.73^{bc}	29.63±5.56^{b}	22.61±12.18^{d}	23.65±7.92^{c}
127	**189**	**217**	21.98±7.85^{dg}	19.43±3.99^{f}	17.45±10.11^{d}		24.13±3.15^{c}		22.05±7.31^{d}
134	**203**	**231**	20.65±6.63^{dfg}	19.05±3.97^{fg}	17.43±11.45^{d}	42.16±3.76^{a}	27.13±4.56^{d}	16.34±6.81^{b}	20.35±6.62^{e}
141	**217**		20.60±6.47^{dhk}	18.63±3.77^{g}		40.50±5.18^{ac}		14.81±6.11^{b}	18.78±6.00^{f}
148			18.68±6.60^{gijkl}			39.06±3.35^{acd}		12.86±5.14^{b}	
155			19.78±5.73^{dikl}			35.37±5.42^{bde}		13.13±5.81^{b}	
162			19.18±6.69^{di}			35.27±4.75^{bde}		12.32±5.10^{b}	
169			15.52±6.46^{ejl}					14.29±2.97^{b}	
176			18.00±5.95^{kl}			33.14±2.93^{e}		14.50±2.73^{b}	
183			16.57±6.51^{l}			32.22±2.46^{e}		15.55±5.33^{b}	
DF			14	8	7	9	7	12	8
F			27.182	74.208	196.773	0.015	72.764	11.719	50.086
P			0.000	0.000	0.000	0.000	0.000	0.000	0.000

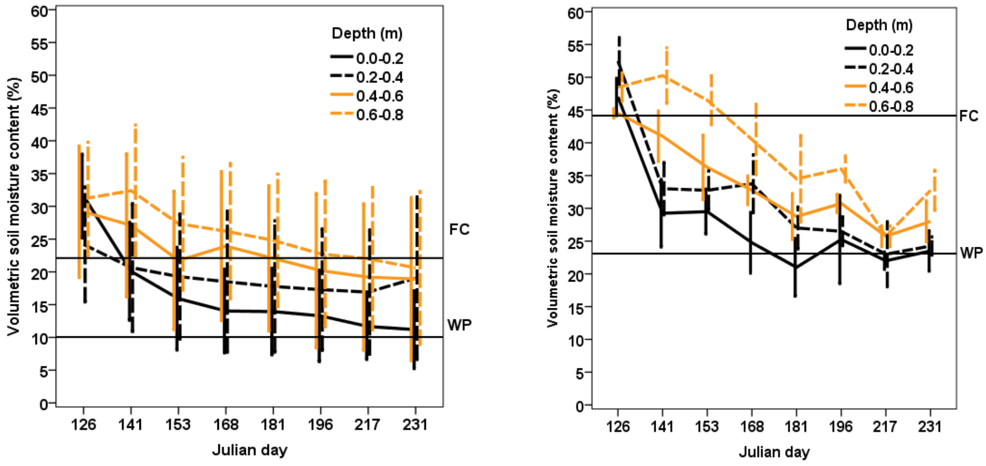
^{1}Number after ± represent standard deviations; ^{2}Values in the same column with a common superscript are not significantly different (P > 0.05).



(a) 2016 Zhoubvunda 1 (b) 2016 Zhoubvunda 2 (c) 2016 Mukumbura



(d) 2017 Zhoubvunda 1 (e) 2017 Mukumbura



(f) 2018 Zhoubvunda 1 (g) 2018 Zhoubvunda 2

Figure 5.1: Volumetric soil moisture content measured during 2016-2018 flood-recession cropping seasons, in the mid-Zambezi Valley in northern Zimbabwe

Table 5.3: Mean seasonal (2016-2018) volumetric moisture content and saturated electrical conductivity in cultivated floodplain soils in the mid-Zambezi Valley, northern Zimbabwe[1,2]

Soil depth (m)	**Volumetric soil moisture content (%)**							**Saturated electrical conductivity (dSm^{-1})**			
	Zhoubvunda 1			**Zhoubvunda 2**		**Mukumbura**		**Zhoubvunda 1**		**Zhoubvunda 2**	**Mukumbura**
	2016	**2017**	**2018**	**2016**	**2018**	**2016**	**2017**	**2017**	**2018**	**2018**	**2017**
0.0-0.2	21.26 ± 10.12^{a}	19.30 ± 3.97^{a}	16.46 ± 9.07^{a}	36.05 ± 4.08^{a}	25.79 ± 6.51^{a}	19.11 ± 11.26^{a}	21.49 ± 6.30^{a}	3.60 ± 1.83^{a}	1.72 ± 0.31^{a}	1.74 ± 0.57^{a}	2.15 ± 0.32^{a}
0.2-0.4	24.63 ± 9.09^{b}	21.41 ± 4.59^{b}	19.20 ± 10.18^{b}	37.56 ± 5.14^{a}	29.43 ± 6.86^{b}	18.87 ± 10.15^{a}	21.87 ± 6.19^{a}	1.82 ± 1.03^{b}	0.89 ± 0.17^{b}	0.82 ± 0.20^{b}	1.33 ± 0.23^{b}
0.4-0.6	25.34 ± 10.66^{b}	23.74 ± 4.77^{c}	22.79 ± 11.59^{c}	40.19 ± 5.93^{b}	32.33 ± 6.12^{c}	19.25 ± 10.99^{a}	27.23 ± 7.61^{b}	1.24 ± 0.29^{c}	0.83 ± 0.11^{b}	0.83 ± 0.18^{b}	1.18 ± 0.17^{c}
0.6-0.8			25.91 ± 11.01^{d}					1.15 ± 0.33^{c}	0.75 ± 0.11^{c}	0.81 ± 0.21^{b}	1.15 ± 0.16^{c}
0.8-1.0								1.12 ± 0.32^{c}			
DF	2	2	3	2	3	2	2	4	3	3	3
F	11.847	186.574	51.206	8.188	74.275	0.041	180.332	122.728	402.226	84.446	576.328
P	0.000	0.000	0.000	0.933	0.000	0.959	0.000	0.000	0.000	0.000	0.000

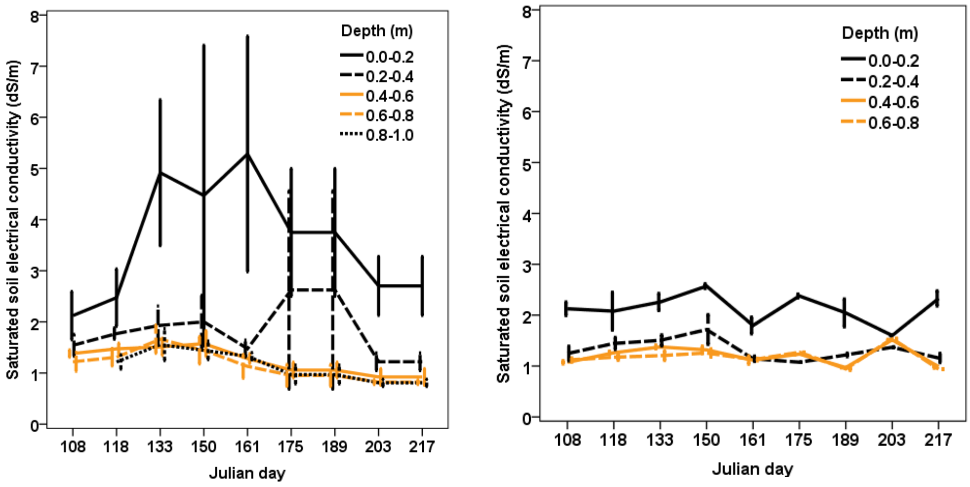
[1] Number after ± represent standard deviations; [2] Values in the same column with a common superscript are not significantly different ($P>0.05$).

5.3.3 Soil electrical conductivity

In 2017, ECe was highest ($P<0.05$) in the 0.0-0.2-m depth at both sites (Zhoubvunda 1 and Mukumbura): DF = 4; F = 122.728; $P<0.001$ at Zhoubvunda 1 and DF = 3; F = 576.328; $P< 0.001$ at Mukumbura (Figure 3). The seasonal ECe mean (d Sm^{-1}) in increasing soil depth was: 3.60>1.82>1.24≈1.15≈1.12 at Zhoubvunda 1 and 2.15>1.33>1.18≈1.15 at Mukumbura (Table 5.3). Starting from the seasonal peak to the level at the end of season, Ece decreased by 51% at Zhoubvunda 1 and and 11% at Mukumbura in the 0.0-0.2-m depth.

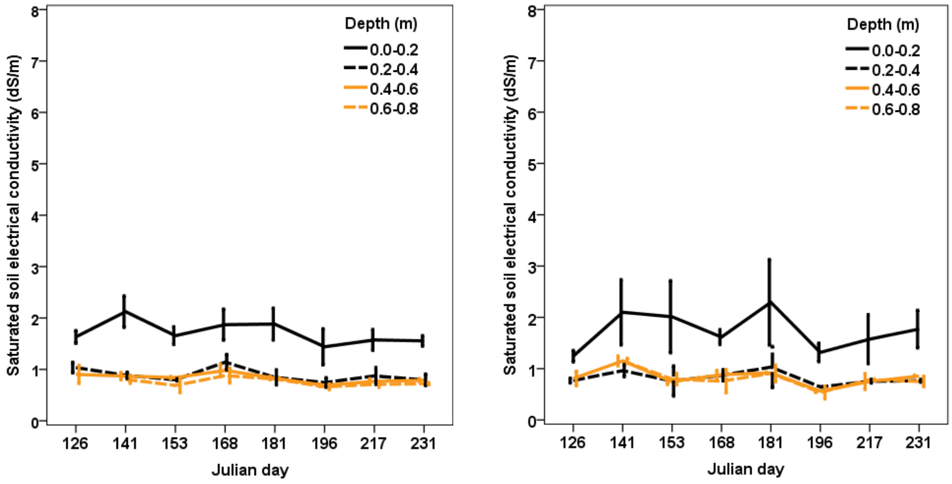
In 2018, ECe was higher ($P<0.05$) in the 0.0-0.2-m depth than all other depths at Zhoubvunda 1 (DF = 3; F = 402.226; $P<0.000$) and Zhoubvunda 2 (DF = 3; F = 84.446; $P<0.000$) (Figure 5.2, Table5.3). Mean soil profile ECe varied without a trend with season progression in all seasons at all sites ($P<0.001$) (Table 5.4). In the 0.0-0.2-m depth, Ece decreased by 30% from the seasonal peak to the level at the end of season at Zhoubvunda 1 and by 28% at Zhoubvunda 2.

In 2018, significant interaction between soil depth and Julian day was observed (DF = 20; F = 7.47; P = 0.000) at Zhoubvunda 1. At this site, similar to mean soil profile ECe, there were variations without trends within each depth ($P\leq0.001$). At Julian days 126, 141, 181, 196 and 231 the 0.0-0.2 m depth had a higher ECe than the rest of the depths, which had similar ECe. At all the other Julian days the 0.0-0.2 m depth had higher ECe than all depths, which varied without a trend.



(a) 2017 Zhoubvunda 1

(b) 2017 Mukumbura



(c) 2018 Zhoubvunda 1

(d) 2018 Zhoubvunda 2

Figure 5.2: Saturated soil EC measured during 2016-2018 flood-recession cropping seasons, in the mid-Zambezi Valley in northern Zimbabwe

Table 5. 4: Saturated soil electrical conductivity trends during 2017 to 2018 flood-recession cropping seasons in the mid-Zambezi Valley in northern Zimbabwe [1, 2]

Measurement	**Julian day**		**Saturated electrical conductivity (dSm^{-1})**			
			Zhoubvunda 1		**Zhoubvunda 2**	**Mukumbura**
	2017	**2018**	**2017**	**2018**	**2018**	**2017**
1	**108**	**126**	1.57 ± 0.44^{ac}	1.19 ± 0.35^{ad}	0.94 ± 0.24^{ac}	1.39 ± 0.45^{a}
2	**118**	**141**	1.65 ± 0.53^{a}	1.17 ± 0.58^{ac}	1.34 ± 0.55^{b}	1.49 ± 0.41^{b}
3	**133**	**153**	2.31 ± 1.48^{b}	1.00 ± 0.41^{b}	1.08 ± 0.66^{a}	1.59 ± 0.42^{ce}
4	**150**	**168**	2.32±1.90b	1.22 ± 0.44^{d}	1.03 ± 0.38^{a}	1.72 ± 0.56^{d}
5	**161**	**181**	2.16 ± 1.95^{bd}	1.09 ± 0.49^{c}	1.29 ± 0.73^{b}	1.30 ± 0.31^{fg}
6	**175**	**196**	1.87 ± 1.51^{ad}	0.88 ± 0.37^{e}	0.76 ± 0.35^{c}	1.49 ± 0.54^{b}
7	**189**	**217**	1.87 ± 1.51^{ad}	0.98 ± 0.38^{b}	0.97 ± 0.43^{a}	1.29 ± 0.47^{g}
8	**203**	**231**	1.30±0.78c	0.97 ± 0.36^{be}	1.04 ± 0.47^{a}	1.51 ± 0.09^{be}
9	**217**		1.30 ± 0.78^{c}			1.35 ± 0.59^{ag}
DF			8	7	7	8
F			9.117	13.002	7.352	29.252
P			0.000	0.000	0.000	0.000

[1] Number after ± represent standard deviations; [2] Values in the same column with a common superscript are not significantly different ($P > 0.05$).

5.3.4 Correlations between soil moisture content and saturated electrical conductivity

There was no significant correlation ($P>0.05$) between soil moisture content and ECe within the uppermost soil depths, 0.0-0.2 m and 0.2-0.4 m (Table 5.5). Positive correlations between soil moisture content and ECe were only observed in 2017 at Zhoubvunda 1 at depths 0.4-0.6 m ($P< 0.001$, $r = 0.958$) and 0.6-0.8 m ($p = 0.05$, $r = 0.666$) but there were no significant correlations when data were combined over sites and seasons at each depth. Correlation between soil moisture content and ECe within the entire measured profile depth (whole profile), 0.0-0.8 m depicted mixed results; it showed significant negative relationships at Zhoubvunda 1 in 2017 ($P < 0.05$, $r = -0.410$) and 2018 season ($P < 0.05$, -0.413) but it was not significant ($P > 0.05$) at the other two sites. Combined over all sites and seasons, correlation of whole profile soil moisture content and ECe showed a significant negative relationship ($P < 0.05$, $r = -0.285$).

Table 5. 5: Correlation between soil moisture content and saturated electrical conductivity in floodplain soils cropped to maize in the mid-Zambezi Valley in northern Zimbabwe

Depth (m)	**Statistic[1]**	**All sites**	**Site**			
			Zhoubvunda 1		**Zhoubvunda 2**	**Mukumbura**
		2017-2018	**2017**	**2018**	**2018**	**2017**
0.0-0.2	N	34	9	8	8	9
	P	0.328	0.747	0.673	0.250	0.439
	r	-0.173	-0.126	0.177	-0.461	0.296
0.2-0.4	N	34	9	8	8	9
	P	0.249	0.836	0.250	0.948	0.278
	r	-0.203	0.081	0.461	0.028	0.406
0.4-0.6	N	34	9	8	8	9
	P	0.896	0.000	0.069	0.392	0.581
	r	0.023	0.958	0.670	0.352	0.214
0.6-0.8	N	32	9	7	7	9
	P	0.535	0.050	0.303	0.213	0.597
	r	-0.114	0.666	0.456	0.538	0.205
0.0-0.8 (Whole profile)	N	134	36	31	31	36
	P	0.001	0.013	0.021	0.113	0.073
	r	-0.285	-0.410	-0.413	-0.290	-0.303

[1] r represents Pearson's correlation coefficient

5.3.5 Maize root distribution in soil profile

Most roots (mean ±standard deviation), 84±4 %, were in the top 0.2-m soil depth (P<0.001) (Table 5.6). Root weights at lower depths were not different from each other (P>0.05).

Table 5. 6: Maize root distribution in the mid-Zambezi Valley floodplain soils in northern Zimbabwe for 2016 to 2018

Depth (m)	**Maize root mass (g per plant)[1,2]**						
	2016			**2017**		**2018**	
	Zhoubvunda 1	**Zhoubvunda 2**	**Mukumbura**	**Zhoubvunda 1**	**Mukumbura**	**Zhoubvunda 1**	**Zhoubvunda 2**
0.0-0.2	6.47 ± 1.61^{a}	8.64 ± 3.00^{a}	6.64 ± 1.45^{a}	7.44 ± 0.88^{a}	8.08 ± 1.78^{a}	7.42 ± 3.32^{a}	7.36 ± 1.48^{a}
0.2-0.4	0.62 ± 0.16^{b}	1.48 ± 0.49^{b}	0.68 ± 0.31^{b}	0.74 ± 0.18^{b}	0.64 ± 0.53^{b}	1.20 ± 0.53^{b}	1.08 ± 0.54^{b}
0.4-0.6	0.28 ± 0.11^{b}	1.30 ± 0.51^{b}	0.42 ± 0.21^{b}	0.43 ± 0.17^{b}	0.35 ± 0.29^{b}	0.44 ± 0.16^{b}	0.41 ± 0.21^{b}
DF	2	2	2	2	2	2	2
F	55.270	22.128	66.106	224.011	65.318	38.813	104.401
P	0.000	0.000	0.000	0.000	0.000	0.000	0.000

[1] Number after ± represent standard deviations

[2] Values in the same column with a common superscript are not significantly different ($P > 0.05$)

5.3.6 Days to maturity of maize cultivars

The late maturing cultivar, SC727, reached 20%, 50% and 80% tasselling and silking ±7 days later, whilst the medium maturing cultivar SC627 reached these stages 2 days later than the early maturing cultivar, SC513 (Appendix 8).

Estimated days from planting to maturity were 99 for SC513, 108 for SC627, 114 for SC727 at Zhoubvunda and they were a day less for each cultivar at Mukumbura. Based on estimated maturity dates (Appendix 9), in all seasons, all maize cultivars matured when soil moisture content was above WP at all depths but the early maturing cultivar, SC513 matured when soil moisture content was close to WP in the 0.0-0.4 m depth at Zhoubvunda 2 in 2018 (Figure 5.1).

5.4 Discussion

Soil moisture content decreased as the season progressed (Figure 5.1), this may be attributed to increasing cumulative evapotranspiration that lowered the water table thereby decreasing capillary rise water reaching the rootzone. Most maize roots occurred in the 0.0-0.2-m depth, therefore, moisture depletion in this depth was more than in the 0.4-0.6 m depth except for Mukumbura in 2016 (Table 5.6; Figure 5.1). However, the >10% of roots found in the lower subsoil could be quite significant in water abstraction by the plant therefore contributing to some level of drought resilience by the maize and support the adjustment of planting depth to salinity. Soil moisture content exceeded FC for different durations from the start of measurements ≤3 WACE, except at Zhoubvunda 2 in 2016, implying that maize was subjected to varying levels of aeration stress during these periods (Figure 5.1). Although, there was a declining trend in soil moisture content, it remained between FC and WP from the middle to the end of the maize growing period. This period covered the maize growth stages that are particularly susceptible to drought: pollination (R1 stage) and grainfilling (R4 stage) (Mashingaidze, 2006); therefore, in general soil moisture deficit was not a limiting factor to maize production in this study (Appendix 7, Figure 5.1).

Mean seasonal ECe in the 0.0-0.2-m depth, between 1.72 and 3.60 dS m^{-1}, over the two seasons at all sites (Table 5.3), exceeded 1.7 dS m^{-1}, the threshold for maize yield reduction (Doorenbos & Kassam, 1979). As the season progressed, salts were deposited in the rootzone through capillary action, therefore there was intra-season cumulative increase in soil salinity. Indeed evidence of salinity damage was observed at all sites in all seasons, for example, see Appendix 7. At Zhoubvunda 1, ECe reached levels that can reduce maize yield by between 10 and 50% (Table 5.3, Figure 5.2). At this site, high ECe values coincided with the mid-season growth stages (V14 to R2), Julian days 133 to 175.

This was linked to the period of relatively high evapotranspiration that left more salts deposited in the upper soil layer. Decline in salinity towards the end of the season may be attributed to absorption of some salts by the maize plants (Harvey, 1985). The fact that there is no significant correlation between soil moisture content and ECe within the uppermost soil depths (0.0-0.2 m and 0.2-0.4 m) where most plants roots were observed (Tables 5.5 and 5.6) supports the assertion that some of the salts were taken up by plants as season progressed. If this was not the case, the ECe would be expected to increase with decrease in soil moisture content as the season progressed.

Mean harvest indices obtained in (Chapter 4, Section 4.3; Chimweta et al., 2021): 0.47, 0.39 and 0.38 for the early maturing cultivar, SC513; medium maturing cultivar, SC627; and late maturing cultivar SC727 respectively suggest that the early maturing cultivar was better at escaping the seasonal cumulative effect of salinity (Munns & Tester, 2008). The results from this study corroborate the assertion that salinity affect maize grain yield than more than stover yield (Katerji et al., 1996). The implication of the results of this study is that maize cultivars that mature in approximately 100 days can be grown in the mid-Zambezi floodplains with minimal detrimental effect of salinity stress.

In order to reduce the negative effects of salinity within the maize growing season, good soil and water management is required to maintain a favourable salt balance within the rootzone. Soil and water management options include mulching, which reduces soil water loss by evaporation, thereby decreasing capillary rise and salt accumulation in the rootzone, and application of the 4R-principle of nutrient stewardship (*right* source, *right* place, *right* rate, and *right* time) in order to minimize contribution of fertilizers to salt accumulation (Zingore & Johnston, 2013; Johnston & Bruulsema, 2014). Bezborodov et al. (2010) reported that salinity in non-mulched treatments was 20% higher than in mulched treaments in the upper 0.15 m depth. Chimweta et al. (2018) reported high levels of Ca (> 3800 ppm) in the mid-Zambezi Valley floodplain soils. Therefore, in the mid-Zambezi Valley floodplains, fertilizers that contain calcium and sulphate should be avoided or used sparingly where necessary.

There is need for selection of suitable crops (Ashraf & Saeed, 2006; Rengasamy, 2010). Options based on crop selection include planting early maturing cultivars that escape saline conditions for example the early-maturing maize cultivar SC513 should be selected over the late maturing SC727, and replacing salt-sensitive with salt-tolerant crops (Qadir & Oster, 2004). Among salt-tolerant crops that are grown in the Zambezi Valley are cotton (*Gossypium hirsutum* L.) and sugarcane (*Saccharum officinarum* L.). Cowpea is moderately tolerant to salinity (Maas, 1986) therefore, it should be recommended over salt-sensitive crops. Genetic engineering for production of salt-tolerant transgenic maize may provide a viable option for sustainable production in the future. Given that, ECe decreased with increasing soil depth, there is need to explore the performance of deep-rooting crops that extract, water and nutrients from depths with lower ECe.

It was hypothesized that the increase in salinity that was recorded as the season progressed under FRC in the mid-Zambezi Valley would be dissipated by seasonal floods that occur in the succeeding rainy season, allowing FRC farmers to plant new crops without high salt concentrations in the soil. Periodic annual flooding to leach out salts, is therefore an essential element of sustainable utilization of floodplains under FRC. However, increasing levels of aridity and higher frequency of drought caused by climate change (Postel, 2000; Fauchereau, 2003; Brown & Funk, 2008; Chidanti-Malunga, 2011; Gosling & Arnell, 2016; Mafongoya & Alayu, 2017; Manatsa et al., 2020), construction of dams and diversion of water upstream (Tsikata, 2006) have potential to threaten the natural cycle of flooding that purges floodplains of salts that are deposited in surface soils during the very hot dry season that is characteristic of river basins where FRC is practiced.

5.5 Conclusions and Recommendations

Results from this study reveal that maize FRC season length was long enough to support an early maturing cultivar that took approximately 100 days from planting to maturity. Soil salinity could be a limiting factor to production of medium maturing and late maturing maize cultivars, which mature later than 100 days. Because soil salinity has a more severe effect on the grain yield than total dry matter, it will result in low harvest indices for medium maturing and late maturing maize cultivars. Overall, soil moisture content was not a limiting factor to maize FRC season length.

Mulching, application of the 4R-principle of nutrient stewardship to reduce salt accumulation in the rootzone and planting early maturing cultivars that escape saline conditions and salt-tolerant crops was recommended from this study. Further research is required to: screen maize cultivars for salt tolerance and quantify salts that are absorbed by plants; explore the performance of deep-rooting crops that extract water and nutrients from depths with lower ECe; and determine the long-term impact of climate change on floodplain soil salinity and its implications on the sustainability of FRC.

CHAPTER 6: SYNTHESIS

6.1 Introduction

Floodplains are usually endowed with abundant water resources and fertile alluvial soils (Buri et al., 1999; Darmody & Marlin, 2002; Koschorreck & Darwich, 2003; Bleeker & van Gestel, 2007; Rinklebe et al., 2007; Tsheboeng et al., 2014) that minimise the effects of major rainfed crop production constraints: poor soil fertility, and inadequate and poorly distributed rainfall. Therefore, flood-based farming systems (FBFS) in these floodplains provide viable options for improving food security for resource-constrained smallholder farmers in semi-arid Sub-Saharan Africa (SSA) (Kashe et al., 2015; Sidibé et al., 2016; Kool et al., 2018; Balana et al., 2019; Kolawole & Kashe, 2019). However, despite being practised for decades (Pwiti, 1996; Namara et al., 2010; Russell et al., 2014; Laisi, 2016); these FBFS have largely been neglected and their potential to contribute to household food security has not been adequately quantified. This study focused on flood-recession cropping (FRC), the growing of crops post-inundation using residual soil moisture (Postel, 2000). The aim of this study was to explore sustainable options for optimising maize yield under FRC in the Zambezi Valley, northern Zimbabwe. The study focussed on maize, a staple food crop for more than 200 million people in SSA (Macauley & Ramadjita, 2015) that is grown under FRC across the continent (Turpie et al., 2006; Duvail & Hamerlynck, 2007; Chidanti-Malunga, 2011; Leauthaud et al., 2013; Sidibé et al., 2016; Balana et al., 2019; Comptour et al., 2020).

The study comprised of questionnaire surveys, focus group discussions (FGDs), field observations, characterisation of cultivated floodplain soil fertility, participatory experiments, and measurement of soil salinity and moisture content in farmers' fields. Due to the fact that FRC is scantly documented, a baseline questionnaire survey, FGDs and field observations were conducted to provide insight into FRC in the mid-Zambezi Valley. Participatory field experiments were conducted over three seasons at three sites to test the effect of crop establishment method, cultivar and NPK basal fertilizer [7:6:6, (6-8%S)] and N top-dressing fertilizer [ammonium nitrate, (34.5%N)] on maize yield. Seasonal rootzone soil moisture content and salinity were measured in experimental fields.

6.2 Socioeconomic Benefits of Flood-recession Cropping

Flood-recession cropping farmers' maize yield was more than five times the yield achieved from upland rainfed crop fields (0.2 to 0.4 t ha^{-1}), in the mid-Zambezi Valley. Kashe et al. (2015) obtained 2.4 to 3.4 t ha^{-1} in the Okavango Delta under experimental conditions compared to 0.162 t ha^{-1} under rainfed cropping. The relatively high FRC yields imply that this farming system has potential to improve household food security. This is particularly important given the cereal deficit experienced in the province (ZimVac, 2019). The high yield achieved by FRC farmers without applying fertilizers is an incentive for the resource constrained farmers to practise FRC, despite government's regulation that prohibits cultivation within 30 m of rivers or wetlands (Government of Zimbabwe, 2007). In addition to enhanced food security, the benefits from FRC include employment creation and improved household income, mostly achieved through growing of high value crops (Balana et al., 2019; Comptour et al., 2020). Although inadequate labour is cited among production challenges, from another perspective the high labour needs create employment and reduce seasonal rural-urban migration (Sidibé et al., 2016). The estimated floodplain area in the Zambezi Valley in northern Zimbabwe estimated at 750 583 ha, provides a big opportunity for FBFS including FRC (Appendix 1b). Given the high levels of productivity of the mid-Zambezi Valley floodplains and their potential contribution to food security, it may be worthwhile for policy makers to consider formally recognising FRC and other FBFS.

6.3 Fertility Status of the Mid-Zambezi Valley Floodplain Soils

Consistent with Chapter 2 results in which farmers did not mention fertility as a challenge, Chapter 3 results showed that the mid-Zambezi Valley floodplain soils were more fertile compared to other floodplains (Hossain et al., 2002; Koschorreck & Darwich, 2003). The relatively low soil bulk density (1.2 to 1.4 g cm^{-3}) is desirable because it is associated with low land preparation draught power requirements (Hossain et al., 2002), good soil aeration and ease root penetration. Soils of medium texture, loam to silty loam in the top horizon and loam to silty clay loam in the subsoil are best for maize production (Olson & Sander, 1988). The mid-Zambezi Valley floodplain soils ranged from sandy loams (SaL) to silty clay loams (SiCL), therefore they were close to the most ideal soils.

The mid-Zambezi Valley floodplains are mildly to strongly alkaline, with soil pH (0.01M $CaCl_2$), 7.70 to 8.60 favourable for most crops (Cooper & Fenner, 1981). These pH values are higher than those from Zimbabwe's communal areas (Rusinamhodzi et al., 2013; Nyakudya et al., 2014). However, the pH was in the range (7.5 to 8.4) in which Fe, P and Zn availability is reduced in calcerous soils (Olson and Sander, 1988). The pH was also in the range of pH of saline soils, suggesting that there could be danger of development of saline conditions during the FRC. However, despite their high base saturation, the exchangeable sodium percentage values of the Zambezi Valley floodplain soils were below 10, the critical value for sodium hazard (Van Hoorn & van Alphen, 2006). In addition, leaching caused by water percolating to the subsoil during the rainy season reduces accumulation of salts in the rootzone from one season to the next.

Soil organic carbon (SOC), 2.04% was in the range of SOC for soils of medium texture with high agricultural potential and it was comparable to Amazon floodplains (Koschorreck & Darwich, 2003) and Illinois River floodplain soils (Darmody & Marlin, 2002). However, floodplain soils of Dommel River in the Netherlands (Bleeker & van Gestel, 2007) had higher SOC than the mid-Zambezi Valley floodplain soils. The relatively low percent N (0.36%) suggested that there was no danger of N enrichment. However, the recommended N application rates from the Department of Research and Specialist Services, 159-168 kg ha^{-1}, may lead to N enrichment of floodplains and contaminate water resources. Inorganic N microdosing ≤ 25 kg N ha^{-1} (Twomlow et al., 2010) may be more appropriate.

6.4 Inorganic Fertilizer Application in Flood-Recession Cropping

In Chapter 2, it was reported that farmers perceived that the mid-Zambezi Valley floodplain soils were fertile and hence they barely used inorganic fertilizers. The soils were confirmed to be fertile in Chapter 3 where the measured nutrient levels exceeded thresholds for nutrient deficiency and bulk density and pH were ideal from an edaphological perspective. Fertilizer recommendations given in Chapter 3 were based on calibrations done for rainfed cropping with different nutrient dynamics from capillary fed floodplain soils. Maize yield performance from field experiments revealed that the current fertilizer recommendations developed under rainfed conditions overestimated fertilizer requirements in the mid-Zambezi Valley floodplain soils (Chapters 4).The results suggest that the focus should be on improving agronomic practices and selecting appropriate cultivars. For example, planting an early maturing and low yielding cultivar (SC513) and improving management increased grain yield from 3.23 t ha^{-1} in farmers' fields to greater than 6 t ha^{-1} under participatory action research.

Given relatively high yields achieved in farmers' fields (> 3 t ha^{-1}) using low yielding early maturing cultivars or retained seed without fertilizer application, and the potential negative environmental effects of fertilizers, it may be more sustainable to avoid fertilizer application except where nutrient deficiencies exist. The relatively high pH may lead to P, Fe and Zn deficiencies; hence microdosing with inorganic fertilizer (Twomlow et al., 2010) may be beneficial. In such cases, the 4-R principle of nutrient stewardship (*right rate*, *right place*, *right time*, *right source*) should be observed (Johnston & Bruulsema, 2014).

6.5 Large Maize Yield Gaps

In Chapter 2, it was established that farmers' flood-recession maize yields (1.7 t ha^{-1}), were more than five times higher than yields reported from rainfed upland fields (AGRITEX, 2005a, 2005b). In addition, there was a large yield gap between yields achieved in farmers' fields and yields achieved in experimental plots without fertilizer application (Chapter 4). The FRC farmers' maize yield of 1.7 t ha^{-1} was the final yield harvested as grain. After observing that most farmers sold substantial quantities of the maize as green mealies (Chapter 2), measurements were conducted and a yield of 3.23 t ha^{-1} was observed in undisturbed plots in farmers' fields. The yields achieved in farmers' fields resonated with range reported in the Okavango Delta (Kashe et al., 2015) and in Boru district in Ethiopia (Nederveen & Steenbergen, 2011). Although FRC yields in farmers' fields were higher than rainfed crop yields; they were less or equal to half of the yield achieved by the lowest performing cultivar (SC513) without application of fertilizer (Chapter 4). The large yield gap between FRC farmers' yields and that achieved in field experiments can be attributed to management related suboptimal performance and use of uncertified seed by farmers. These findings reinforce the assertion that yield can increase 2 to 3-fold in floodplains, through selection of appropriate water management techniques, crop establishment methods; cultivars, and plant spacing (Scudder, 1989, Vanderpost, 2009; Sidibé et al., 2016; Kashe et al., 2015). For example, field experiments in this study revealed that there were yield benefits of changing from early (SC513) to late maturing cultivar (SC727).

6.6 Crop Establishment Method and Implications for Productivity

In chapter 2, farmers indicated variation in their land preparation for crop establishment. The use of crop establishment method as a tool for optimising water use under FRC (Chidanti-Malunga, 2011; Kpadonou et al., 2012; Comptour et al., 2020) was confirmed in this study. The relatively deep planting stations are adaptive and unique to FRC (Chidanti-Malunga, 2011; Chapter 2). This study showed that the deep planting achieved in furrow + holing out outperformed furrow only, but it is not clear what happens at levels between these two extremes. The covering of the deep pits after maize emergence promoted development of roots on prop roots that are usually suspended above the soil surface (Appendix 3) (du Plessis, 2003). Development of more roots improves P uptake because it is very immobile in the soil. The deep planting of seeds enhances root access to soil moisture early in the season and later as capillary strength decreases due the lowering water table as the season progresses (Chimweta & Nyakudya, 2019). Burying of nodes at which prop roots develop may alter maize-microbial associations, and subsequently affect maize yield. The soil mulch created by covering planting stations after crop emergence break the soil-atmosphere capillary rise continuum and leads reduced evaporative water loss and salt accumulation in the rootzone.

6.7 Soil Salinity and Maize Cultivar Selection

In Chapter 4, it was reported that the early maturing cultivar, SC513, yielded up to 9 t ha^{-1} which was close to its potential yield, 10 t ha^{-1} (SEEDCO, 2004). However, the higher yielding cultivars (SC627 and SC727) performed below their potential, as reflected by their relatively low harvest indices that were less than 0.40. The low harvest indices confirm that there were other factors that reduced maize grain yield relative to stover yield. Two dynamic parameters namely soil salinity and moisture content that normally affect crop yields in floodplains were measured (Chapter 5) (Doorenbos and Kassam, 1979; Katerji et al., 1996). Results confirmed accumulation of salts in the soil as the season progressed to levels that can reduce maize yield by between 10 and 50%. The recommendation of considering early maturing cultivars that escape salinity is, however, in sharp contrast to the recommendation of adopting the late maturing cultivar, SC727, on the basis of higher yield alone (Chapter 4).

6.8 Environmental Sustainability of Flood-recession Cropping: "Prohibited" but Decades of Practice

Flood-recession cropping in the Zambezi Valley in northern Zimbabwe has persisted for decades (Pwiti, 1996) despite uncertainty with regards to land tenure of floodplain fields. Land tenure uncertainty in FBFS is not peculiar to the mid-Zambezi Valley; it has also been reported in the Okavango Delta (Kolawole & Kashe, 2019) and in the Volta Delta (Namara et al., 2010). Farmers' perseverance can be attributed to the huge incentive that is provided by natural replenishment of soil fertility by annual alluvial deposits and existence of reliable water source. In a survey in the Okavango Delta, Kolawole and Kashe (2019) found that 86% of the respondents cited soil fertility and favourable soil moisture in floodplains as major motivations to practice FRC.

However, there have been concerns that FBFS including FRC causes environmental degradation due to deforestation that leads to silting of water bodies (Mavhura, 2017). The increased incidence of droughts and floods as a result of climate change will have a negative effect on rainfed upland crop yields and farmers will resort to the productive but fragile floodplains. Creation of new markets for FRC products may also lead to pressure on floodplains (Comptour et al., 2020). There is evidence of environmental stewardship from FRC farmers, for example, farmers planted or maintained live hedges to slow floodwater, filter the coarse sediment and allow finer sediment deposition and reduce soil water erosion (Barrios, 1997; Chimweta et al., 2018). Considering the benefits that the vulnerable resource-constrained smallholder farmers obtain from FRC, and the potential savings the government can make from reduced food import costs, regulating usage and complementing farmers' environmental management initiatives could be better than the current 'prohibition', which in essence is equal to indifference due to failure by governments to enforce the existing regulations. Nederveen and Steenbergen (2011) emphasized that it is not exactly known where flood recession farming is practiced; this implies that control measures cannot be implemented effectively.

6.9 The Need for Farmer Training in Flood-recession Cropping

The general view that FRC is a neglected farming system (Nederveen & Steenbergen, 2011; Balana et al., 2019; Sidibé et al., 2016; Traore et al., 2016; Kool et al., 2018; Kolawole & Kashe, 2019) was confirmed in this study. The baseline survey revealed that at least a third of the farmers reported that they required training on FRC and extension support to improve productivity. Agronomic practices evolved from farmers' experimentation or lived in experiences (Chapter 2). The large yield gap between FRC farmers' yields and yields obtained in participatory experiments in farmers' fields can be partially attributed to science-based knowledge gaps which can be closed through farmer training.

6.10 Contribution to Science

This study was the first to provide a detailed account of fertility status of the mid-Zambezi Valley floodplain soils providing soil pH, bulk density, SOC, concentrations of thirteen essential plant nutrient elements, and ESP, a measure of the sodium hazard (Chapter 3). The other study in the region by Kashe et al. (2015) only considered five plant nutrient elements and soil pH.

Testing effects of crop establishment method, cultivar and inorganic fertilizer application on FRC maize yield were new in the mid-Zambezi Valley. This study is the first one to generate information on maize yield gaps between normal FRC farmers' fields and experimental fields managed by researchers and farmers. Previous studies in the region (Chidanti-Malunga, 2011) only described the crop establishment methods without testing them. Kashe et al. (2015) only determined yield level of a single very early maturing cultivar (SC403) without application of fertilizers.

Salinity stress limits productivity on at least 80 million hectares particularly under irrigation and FBFS (FAO, 2008). In FBFS waterlogging stress is also prevalent; therefore flood and salt-tolerant crops are ideal for these farming systems (Verhoeven & Setter, 2010). This study was the first to report on seasonal changes in soil salinity and moisture content and to describe their implications on maize production and yield. Information on estimation of flood-recession maize growing season length is provided. Hitherto, there was no published research on these two parameters in the region despite their potential effect on FRC.

6.11 Limitations of the Study

The experiments in this study were short term (≤ 3 years) and conducted at three sites only. Medium to long-term experiments that have more seasons with different flood levels would be more generalizable.

6.12 Institutional and Policy Implications

Given the maize yield benefits and socio-economic importance placed on FRC by smallholder farmers, policy makers should consider formally recognising FRC. Formal recognition of FRC is likely to have more positive impact on sustainable use of floodplains than the current ‘pseudo-prohibitive’ stance. For example, it will promote sharing of information about the farming system, and creating an enabling environment for non-governmental organisations (NGOs), business and industry to interact with the farmers. Once formally recognised, government should extend production incentives that are given for upland rainfed cropping to FBFS including FRC. In line with the government’s heritage based philosophy; FBFS and FRC in particular, should be incorporated into schools’, colleges’ and universities’ curricula.

6.13 Recommendations for Further Research

Further studies should focus on: (i) multiple site long-term maize cultivar- basal fertilizer levels experiments for development of cultivar-fertilizer recommendations in floodplain soils; (ii) effect of crop establishment method on maize root development and yield; (iii) screening maize cultivars for tolerance to salinity and; (v) perfoming cost-benefit analysis for all agronomic experiments.

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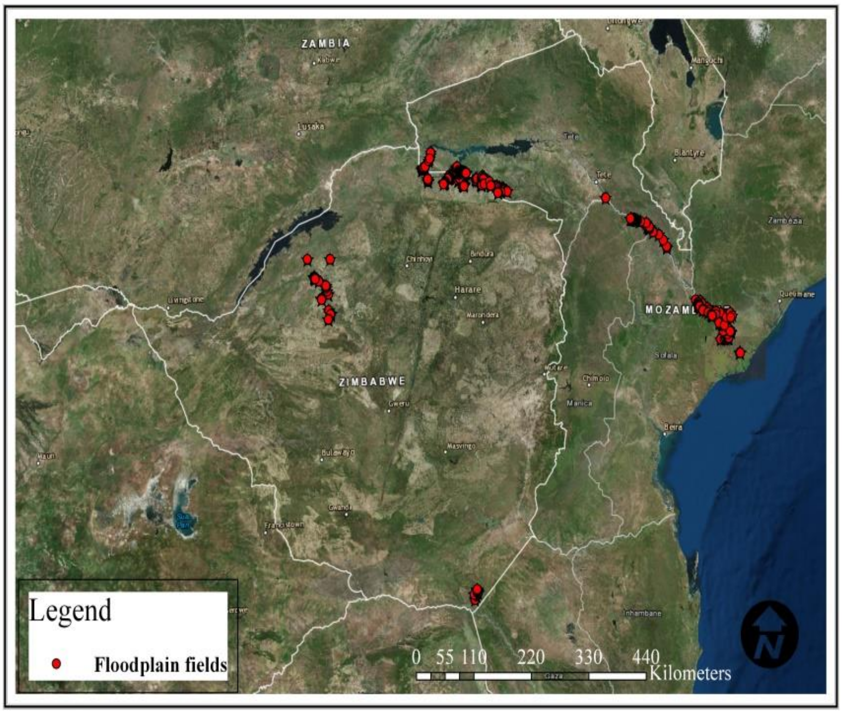
APPENDICES

Appendix 1: (a) Flood-recession cropping areas Zimbabwe and parts of Mozambique. (b) Area under floodplains in the mid to lower Zambezi Valley.



a

b

Appendix 2: Flood-recession cropping Questionnaire

BINDURA UNIVERSITY OF SCIENCE EDUCATION

FACULTY OF AGRICULTURE and ENVIRONMENTAL SCIENCE

Introduction

This questionnaire was designed to capture data for research purposes. It is envisaged that the research will lead to a better understanding of the riparian farming and subsequent recommendations for sustainable and improved crop productivity. Since practices may vary among different locations the research provides a platform for sharing information among communities in the riparian zones. Personal details of farmers interviewed during this study will be treated with utmost confidentiality. The questionnaire will be administered to the household head or the person who makes decisions about farming in the household. The objectives of this study are to:

(i) assess the socio-economic importance of FRC to smallholder farmers;
(ii) identify the major crop production challenges under FRC;
(iii) characterise agronomic practices with respect to maize production;
(iv) determine factors that affect selection of crop establishment method; and
(v) identify opportunities to improve productivity and farmers' livelihoods under FRC.

SECTION A: RESPONDENT'S PERSONAL DATA AND HOUSEHOLD CHARACTERISTICS

Name:____________________________ Sex 1 Male 2 Female Age:___________
Village: ____________________________Ward:____________________________
District: ____________________________Riparian zone: ____________________________

Household composition

	Age	**Sex**	**Remarks (e.g. school going, formally employed e.t.c.)**
1			
2			

A1. How many family members are involved in riparian farming activities? _____________

A2. What is the principal occupation of the household head? 1 formally employed 2 informally employed

A3. Are you a full time farmer? 1 Yes 2 No

A4. What is the average household annualincome (US$)?________________________

A5. What are your sources of income? (Rank in order of importance beginning with the most important).

Source	**Amount raised per year**	**Rank**
Riparian crops		
Conventional crops		
Gardens		
Salary/wages		
Pension		
Remittances		
Livestock		
Non-timber forest products		
Others		

SECTION B: FARMING EXPERIENCE, EDUCATION, AND TRAINING

B1. Do you practice both riparian and conventional cropping? 1 Yes 2 No

B2. When did you come to know about riparian farming? 1 Since childhood 2 After migrating to the area

B3. When did you start farming in the riparian zone (specify year):________________________

B4. How many times have you practiced riparian farming:________________________

B5. What is the distance of riparian main field from the edge of the river? ___________(m)

B6. Have you ever been trained on riparian crop production? 1Yes 2 No

B7. If yes, who provided the training? at what level were you been trained (you may tick more than 1)?

1 AGRITEX 2 NGOs 3 Input supplier 4 Contractors 5Other (specify) __________________

SECTION C: RESOURCE ENDOWMENT

C1. Area of riparian field :_______________

C2. Looking at the field you use for riparian farming, how do you consider it in terms of size?

1 Too small 2 Of the right size 3 Too big

C3. How much does it cost to rent riparian land? US$______________

C4. Number of cattle : ____________________ C4. Number of donkeys: ____________________

C5. Number draught animals: ________________

C6. Draught equipment used for riparian farming (*tick were applicable)*

	Type	Riparian
1	Hand Hoes	
2	Mouldboard plough	
3	Ripper	
4	Cultivator	
5	Ridger	
6	Other (specify)	

SECTION D1: GENERAL CROPPING

D1.1. Riparian crops grown in the main riparian in order of importance.

	Crop	Area	Output (50 kg bags)	Major markets	Period of marketing
1					

D1.2. What is the main purpose of the riparian crops you grow?

1 Home consumption 2 Sales 3 Stock feed 4 Other (specify)________

D1.3. Which farming system conventional or riparian is more labour intensive?

1 Riparian 2 Conventional 3 They are similar 4 Only practice riparian farming

SECTION D2: MAIZE CROPPING

D2.1.How many times do you weed your riparian maize crop?

Mechanical weeding	**Chemical weeding**

D2.2.Describe the method that you use for preparing planting stations for maize.

	Description of method	Reasons
1	e.g Holing out	
2		

D2.3.What planting pits dimensionsdo you use for riparian maize?

	Size (cm)
Depth	
Diameter	
Inter-row spacing	
In-row spacing	

D2.4.Which maize cultivars do you grow in the main riparian field in order of hectarage?

	Cultivar	Area
1		
2		

D2.5. Fertilizers application in the main riparian field

	Type of fertilizer	Amount applied	Frequency
Basal dressing			
Topdressing			

D2.6.Have your riparian crops been affected by any other natural hazards? 1 Yes 2 No

D2.7.If yes, describe the natural hazards.

	Hazard	Years experienced (e.g. 2004, 2008)	Specify where applicable
1	e.g Late flooding		
2			

SECTION E: INSTITUTIONAL SUPPORT

E.1.Where do you obtain advice on riparian farming?

Source of support	**Tick where applicable**	**Source of support**	**Tick where applicable**
None		Sales representatives	
Neighbours		Other (specify)	
Extension officers			

E.2.How often do extension officers visit your fields per month?__________

E.3.What is your opinion on the quality of service provided by extension officers who visited you?

0 No advice 1 Very poor 2 Poor 3 Satisfactory 4 Very good 5 Excellent

E.4.Do you belong to one or more farmers' organisations? 1 Yes 2 No

E.5.If yes, what support did you receive that assisted in riparian farming from these farmers' organisation

1____
2____
3____
4____

E.6How do you rate the yields from riparian farming to those from the conventional (conventional)?

1 Less 2 Equal 3 More

SECTION F: PRODUCTION, MARKETING AND INSTITUTIONAL CHALLENGES

F.1 Which production challenges do you face in riparian farming? (Write in order of importance)

Challenge	**Rank**	**Challenge**	**Rank**	**Challenge**	**Rank**	**Challenge**	**Rank**
Labour shortage		Land shortage		Theft		Lack of draught power	
Lack of equipment		Lack of capital		Pests		Poor rainfall distribution	
Lack of skills		Hail storm		Diseases		Excessive rainfall/floods	
High temperatures		Lack of skills		Weeds		Lack of water sources	
Land shortage		Hail storm		Droughts			
Poor soil fertility		High temperatures					

F.2 Which marketing challenges affect the marketing of yourriparian produce? (Write in order of importance)

Marketing challenge	**Rank**	**Marketing challenge**	**Rank**
Shortage of markets		Poor product quality	
Flooded market/poor prices		High transport cost	
Long distance to markets		Poor road network	

F.3 Which institutional challenges affect riparian crop production? (Write in order of importance)

Institutional challenge	**Rank**	**Institutional challenge**	**Rank**
EMA policies		Poor input supply	
Poor policing services		Poor transport services	
Inadequate policing services		Unavailability of credit institutions	
Poor extension services		High requirements of lending institutions	
Inadequate extension services		Lack of research institutions	

F.4 What do you think have to be done to increase riparian farmoutput
1____
2____

Any comments____

The End Thank you

Appendix 3: Development of roots on maize prop roots in the deep planting pit under flood-recession cropping in the Zambezi Valley, northern Zimbabwe

Appendix 4: Salinity tolerance of major crops grown by flood-recession farmers in the Zambezi Valley in northern Zimbabwe

Crop		**Salt tolerance parameters**				**Reference**
Common name	**Botanical name**	**Tolerance based on**	**Rating**	**Treshold rootzone ECe (dS/m)**	**Percent decrease per unit increase in rootzone ECe (dS/m)**	
Maize	*Zea mays* L.	Ear fresh weight	Moderately sensitive	1.7	12	Kaddah & Ghowail, 1964; Shalhevet, 1994;
Okra	*Abelmoschus esculentus* (L.) Moench	Pod yield	Moderately sensitive	_	_	Masih et al., 1978;
Cowpea	*Vigna unguiculata* L. (Walp)	Seed yield	Moderately tolerant	4.9	12	West & Francois, 1982; Shalhevet, , 1994;
Sweetpotato	*Ipomoea batatas* (L.) Lam	Fleshy root	Moderately sensitive	1.5	11	Shalhevet, 1994;
Sugar beans	*Phaseolus vulgaris* L.	Seed yield	Sensitive	1.0	19	Hoffman & Rawlins, 1970;
Tomato	*Lycopersicon esculentum* Mill.	Fruit yield	Moderately sensitive	2.5	9.9	Qadir & Oster 2004;
Watermelon	*Citrullus lanatus* (Thunb.) Matsum. and Nakai)	Fruit yield	Moderately sensitive	_	_	De Forges, 1970.

Source: Adapted from Maas and Grattan (1999)

Appendix 5: Effect of NPK basal [7:6:6, (6-8% S)] and N top-dressing [Ammonium nitrate (34.5%)] fertilizers on flood-recession maize plant height and root collar diameter (RCD) in the mid-Zambezi Valley during the 2016 season

	Zhoubvunda 1		**Zhoubvunda 2**		**Mukumbura**	
	Height (m)	**RCD (cm)**	**Height (m)**	**RCD (cm)**	**Height (m)**	**RCD (cm)**
NPK fertilizer application rate (kg ha^{-1})						
0	2.7210^{a}	1.8137^{a}	2.2330^{a}	1.2520^{a}	2.4107^{a}	1.5902^{a}
75	2.7785^{b}	2.0473^{b}	2.2640^{a}	1.5255^{b}	2.4882^{b}	1.8832^{b}
150	2.7998^{b}	2.1077^{c}	2.4125^{b}	1.8540^{c}	2.4295^{a}	2.0290^{c}
225	2.8332^{c}	2.2360^{d}	2.3450^{c}	2.0915^{d}	2.6117^{b}	2.2957^{d}
P value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
± s.e.d	0.01223	0.01203	0.02493	0.01698	0.01633	0.01229
N top-dressing fertilizer application rate (kg ha^{-1})						
0	2.7488^{a}	2.0260^{a}	2.2545^{a}	1.6390^{a}	2.4572^{a}	1.9432^{a}
75	2.7988^{b}	1.9847^{b}	2.3175^{b}	1.6670^{ab}	2.5787^{b}	1.9485^{a}
150	2.7932^{b}	2.0785^{c}	2.3420^{b}	1.6875^{b}	2.3675^{c}	1.9805^{b}
225	2.7917^{b}	2.1155^{d}	2.3405^{b}	1.7295^{c}	2.5367^{d}	1.9260^{a}
P value	<0.001	<0.001	0.002	<0.001	<0.001	<0.001
± s.e.d	0.01223	0.01203	0.02493	0.01698	0.01633	0.01229
NPK* N top-dressing fertilizer						
P-value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
± s.e.d	0.02446	0.02406	0.04986	0.03396	0.03265	0.02459
CV%	2.4	3.2	3.4	3.2	2.9	2.8

Numbers with common superscripts within a single column are not significantly different ($P > 0.05$).

Appendix 6: Effect of cultivar, NPK basal [7:6:6, (6-8% S)] and N top-dressing [Ammonium nitrate (34.5%)] fertilizers interaction on flood-recession maize plant height and root collar diameter (RCD) in the mid-Zambezi Valley during the 2017 and 2018 seasons

Maize Cultivar	**Zhoubvunda 1**				**Mukumbura**	
	2017		**2018**		**2017**	
	Height (m)	**RCD (cm)**	**Height (m)**	**RCD (cm)**	**Height (m)**	**RCD (cm)**
SC 513	2.6903^{a}	1.9233^{a}	2.7005^{a}	1.2547^{a}	2.3530^{a}	2.1068^{a}
SC 627	2.8554^{b}	2.2547^{b}	3.0719^{b}	1.5198^{b}	2.5333^{b}	2.1416^{b}
SC 727	3.0869^{c}	2.1835^{c}	3.1881^{c}	1.5644^{c}	2.7481^{c}	2.1278^{c}
P value	<0.001	<0.001	0.003	<0.001	<0.001	<0.001
± s.e.d	0.00644	0.01359	0.01851	0.00703	0.01226	0.00592
NPK fertilizer application rate (kg ha^{-1})						
0	2.8807^{a}	2.0686^{a}	2.9428^{a}	1.3386^{a}	2.5008^{a}	1.9679^{a}
75	2.8474^{b}	2.1043^{b}	3.0068^{bc}	1.4622^{b}	2.5156^{a}	2.0721^{b}
150	2.8529^{b}	2.1302^{b}	3.0253^{b}	1.5198^{c}	2.5979^{b}	2.1674^{c}
225	2.9292^{c}	2.1790^{c}	2.9725^{c}	1.4729^{b}	2.5650^{c}	2.2968^{d}
P value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
± s.e.d	0.00743	0.01570	0.01059	0.00812	0.01416	0.00683
Ammonium nitrate fertilizer application rate (kg ha^{-1})						
0	2.8616^{a}	2.1140^{ac}	2.9775^{ac}	1.4424^{a}	2.5810^{a}	2.0881^{a}
75	2.8820^{b}	2.1610^{b}	2.9656^{a}	1.4247^{b}	2.5231^{b}	2.1840^{b}
150	2.8629^{a}	2.0864^{a}	2.9865^{c}	1.4644^{c}	2.5319^{b}	2.1135^{c}
225	2.9037^{b}	2.1206^{c}	3.0178^{b}	1.4572^{ac}	2.5433^{b}	2.1186^{c}
P value	0.009	<0.001	<0.001	<0.001	<0.001	<0.001
± s.e.d	0.00743	0.01570	0.01002	0.00812	0.01416	0.00683
Cultivar * NPK fertilizer interaction						
P value	0.004	<0.001	<0.001	<0.001	0.002	0.006
± s.e.d	0.01287	0.02719	0.02439	0.01407	0.02452	0.01184
Cultivar * Ammonium nitrate fertilizer interaction						
P value	0.281	<0.001	<0.001	<0.001	<0.001	0.027
± s.e.d	0.01287	0.02719	0.02384	0.01407	0.02452	0.01184
NPK fertilizer * Ammonium nitrate fertilizer interaction						
P value	0.037	<0.001	<0.001	<0.001	<0.001	<0.001
± s.e.d	0.01486	0.03140	0.02033	0.01624	0.02831	0.01367
Cultivar * NPK fertilizer * Ammonium nitrate fertilizer interaction						
P value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
± s.e.d	0.02574	0.05438	0.03871	0.02813	0.04904	0.02367
CV%	1.9	1.9	2	3.4	3.3	1.9

Numbers with common superscripts within a single column are not significantly different (P > 0.05).

Appendix 7: Salinity damage in flood-recession maize at (a) Zhoubvunda and (b) Mukumbura in the Zambezi Valley in northern Zimbabwe

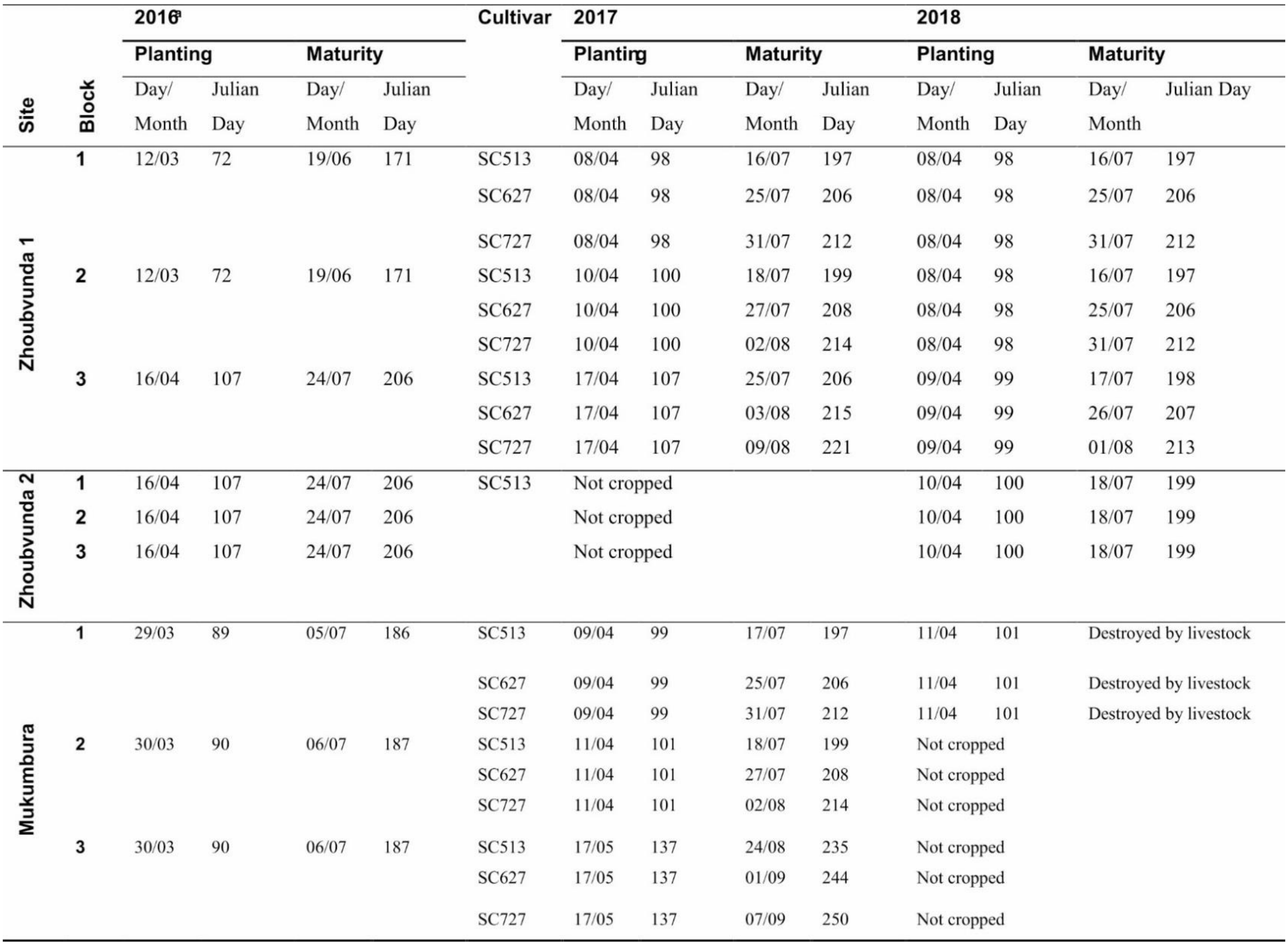
(a) **(b)**

Appendix 8: Time to 20, 50 and 80 % tasselling and silking for SC513, SC627 and SC727 maize cultivars during the 2018 flood-recession cropping season in the Zambezi Valley in northern Zimbabwe

Site	**Cultivar**	**20%**				**50%**				**80%**			
		Tasselling		**Silking**		**Tasselling**		**Silking**		**Tasselling**		**Silking**	
		DAP[1]	**Julian day**	**DAP**	**Julian day**	**DAP**	**Julian day**	**DAP**	**Julian day**	**DAP**	**Julian day**	**DAP**	**Julian day**
Zhoubvunda Block 1	SC513	55	153	60	158	59	157	63	161	63	161	67	165
	SC627	57	155	61	159	61	159	65	163	65	163	72	170
	SC727	64	162	66	164	67	165	69	167	70	168	74	172
Zhoubvunda Block 3	SC513	59	157	64	162	62	160	67	165	65	163	71	169
	SC627	59	157	62	160	62	160	65	163	64	162	69	167
	SC727	66	164	68	166	68	166	71	169	70	168	74	172
Zhoubvunda 2	SC513	59	159	65	165	62	162	68	168	65	165	70	170

[1] DAP represents days after planting

Appendix 9: Maize planting and maturity dates for the 2016-2018 flood-recession cropping seasons in the Zambezi Valley in northern Zimbabwe



Site	Block	2016[a]				Cultivar	2017				2018			
		Planting		Maturity			Planting		Maturity		Planting		Maturity	
		Day/ Month	Julian Day	Day/ Month	Julian Day		Day/ Month	Julian Day	Day/ Month	Julian Day	Day/ Month	Julian Day	Day/ Month	Julian Day
Zhoubvunda 1	1	12/03	72	19/06	171	SC513	08/04	98	16/07	197	08/04	98	16/07	197
						SC627	08/04	98	25/07	206	08/04	98	25/07	206
						SC727	08/04	98	31/07	212	08/04	98	31/07	212
	2	12/03	72	19/06	171	SC513	10/04	100	18/07	199	08/04	98	16/07	197
						SC627	10/04	100	27/07	208	08/04	98	25/07	206
						SC727	10/04	100	02/08	214	08/04	98	31/07	212
	3	16/04	107	24/07	206	SC513	17/04	107	25/07	206	09/04	99	17/07	198
						SC627	17/04	107	03/08	215	09/04	99	26/07	207
						SC727	17/04	107	09/08	221	09/04	99	01/08	213
Zhoubvunda 2	1	16/04	107	24/07	206	SC513	Not cropped				10/04	100	18/07	199
	2	16/04	107	24/07	206		Not cropped				10/04	100	18/07	199
	3	16/04	107	24/07	206		Not cropped				10/04	100	18/07	199
Mukumbura	1	29/03	89	05/07	186	SC513	09/04	99	17/07	197	11/04	101	Destroyed by livestock	
						SC627	09/04	99	25/07	206	11/04	101	Destroyed by livestock	
						SC727	09/04	99	31/07	212	11/04	101	Destroyed by livestock	
	2	30/03	90	06/07	187	SC513	11/04	101	18/07	199	Not cropped			
						SC627	11/04	101	27/07	208	Not cropped			
						SC727	11/04	101	02/08	214	Not cropped			
	3	30/03	90	06/07	187	SC513	17/05	137	24/08	235	Not cropped			
						SC627	17/05	137	01/09	244	Not cropped			
						SC727	17/05	137	07/09	250	Not cropped			

[1] In 2016, only SC513 was planted