STRAW AND WATER MANAGEMENT IN RICE PRODUCTION SYSTEMS IN LIRA DISTRICT, UGANDA

BY

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DECLARATION

I, Apiou David do hereby affirms that this work is entirely original and has never been submitted for any award by any university or higher institution of learning.

Signed...

Date...

APPROVAL

This is to certify that this work was conducted under our supervision as university supervisors and it is now ready for submission for examination.

Signed...

Date...

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DEDICATION

This work is dedicated to my parents Mr. Ongwech James and the late Mrs. Saida Ongwech, who funded my education from elementary level through graduate school.

ACKNOWLEDGMENTS

I want to start by gratefully thanking my Principal supervisor, Professor Bosco Bua for his insightful criticisms, remarks, and guidance over the course of this work. Words cannot express my indebtedness to my second supervisor Dr. Alex Barakagira for accepting to be part of the supervision team. I am also thankful to Dr. Juliet Akello who proof read my work and guided me in coming up with the final write up of the thesis. Your rigorous supervision constantly gave me the motivation to perform to my maximum ability. I want to express my gratitude to my family for providing me with moral, emotional, and financial support and everyone who helped me in one or the other while I was pursuing this research. Above all, I give thanks to God for making it possible for me to successfully finish this difficult but fascinating work.

ACRONYMS AND ABBREVIATIONS

ANOVA	Analysis of Variance
AWD	Alternate Wetting and Drying
CD	Continuous Drying
CF	Continuous Flooding
CPMI	Carbon Pool Management Index
FAO	Food and Agriculture Organisation
GHG	Greenhouse Gas
ICM	Integrated Crop Management
MAAIF	Ministry of Agriculture, Animal Industry and Fisheries
NaCRRI	National Crop Resources Research Institute
NERICA	New Rice for Africa
NUE	Nitrogen Use Efficiency
RRI	Rice Straw Incorporated
RRR	Rice Straw Removed
SDGs	Sustainable Development Goals
SOC	Soil Organic Carbon
SOM	Soil Organic Matter
SSA	Sub Saharan Africa
WUE	Water Use Efficiency

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ABSTRACT

About half of the world's population is fed by rice, and the crop produces about one billion tons of straw residue annually. In fact, rice production is anticipated to rise dramatically in the near future to feed the world's expanding population. On the other hand, water which is a major factor in rice production is becoming scarcer and more competitive on a global scale. Almost two third of water supply has been used for irrigated agriculture and roughly thirty percent of all irrigated land is used for rice production, making it the most common irrigated crop in agriculture. These therefore make rice straw management and water management regimes in rice production a global challenge. Improper management of rice straw and water management regimes limit rice production. The main objective of the study was to identify the most efficient and effective rice straw disposal and water management strategies for sustainable rice production. The specific objectives were: 1) to determine the effects of straw management on rice grain yield in Lira district, Northern Uganda, and 2) to assess the effects of water management regimes on rice grain yield in Lira district, Northern Uganda. Both experiments were conducted in Itek sub county, Lira district, Northern Uganda during the second and first season of 2021 and 2022 respectively. The experimental design for the two experiments were randomized complete block design arranged as split plots with three replications. For objective 1, a total of four treatments were evaluated, which included subjecting two rice varieties (i.e. PR107 and Namche 5) under two rice straw management regimes (i.e. rice straw incorporation (RRI) and rice straw removal (RRR)) for their effects on rice growth and grain yields. In the second objective, a total of six treatments were evaluated whereby the effects of alternate wetting and drying (AWD), continuous flooding (CF), and continuous drying (CD) on grain yield of K5 and PR107 rice varieties were assessed. The result of the assessment revealed that incorporation or removal of rice straw had minimal effect on rice growth, biomass and yield with mean straw and yield of 3.2 t/ha and 2.4 t/ha respectively, irrespective of season and treatment. However, rice growth biomass and yield depended on variety and season. Except for height, the average number of tillers (11.6) and number of panicles (121.6) produced by PR107 rice variety was significantly higher than that produced by Namche 5 (number of tillers = 8.5), number of panicles = 69.0). The height of Namche 5 variety (0.73m) was significantly higher than that of PR107 (0.69 m). The results of yield assessment further revealed that the rice variety PR107 produced a significantly higher tonnage of straw (4.2 t/ha) and grain yield (3.3 t/ha) than Namche 5 straw (2.2 t/ha) and grain yield (1.5 t/ha). For both variables, the weight of rice straw and rice grain yield that were obtained in the second season were significantly higher than that recorded in the first season. Similarly, the study showed that various water management regimes had no significant effect on growth and yield of two rice varieties. There was no significant difference in grain yield among treatments ($P>0.05$). Treatment with CD realized average highest grain yield across seasons. K5 performed better than PR107 under scarce water resource (first season). In conclusion, the greatest grain yield under CD treatments for both seasons present farmers a chance to enhance rice grain output despite limited irrigation water due to climate change.

CHAPTER ONE: INTRODUCTION

1.1 Background of the study

Rice is one of the most important cereal crops which is preferred by people worldwide (Khush, 2013). However, rice straw management both in upland and lowland ecosystems and water management regimes in paddy rice fields are among critical factors affecting rice grain yield production (Awio *et al.,* 2015). Water scarcity due to the consequences of climate change and improper rice straw disposal have resulted in to reduced rice grain yield (Elbasiouny and Elbehiry, 2020). Uganda like any other country in the world is experiencing reduction in rice grain yield because of challenges of rice straw disposal and water management regimes. This study was therefore conducted to unveil efficient, effective and sustainable rice straw management option and water management regime that could be employed in rice production. The study was conducted in Itek sub county, Lira district, Northern Uganda during the first and second rainy seasons of 2022 and 2021.

1.2 Importance of rice

Rice (*Oryza sativa* L.) makes up half of the basic foods consumed worldwide hence it is crucial for ensuring food security (Singha *et al.*, 2016). Accordingly, rice is the most important food crop in many developing and developed countries as evidenced by increased production and consumption over the years (Sack *et al.*, 2012). Areas in sub-Saharan Africa (SSA) where rice is grown have steadily increased from 2,694,000 hectares between 1961 and 1965 to 16,146,000 hectares between 2016 and 2020 (FAOSTAT, 2020, 2022). Indeed, the average annual rice production (milled equivalent) and consumption in SSA for the period between 2016 and 2020 was estimated at 15,402 and 27,246 million tons, respectively.

However, the per capita consumption of rice in SSA for the period 2013-2019 was estimated at 23kgs against 54kgs for the global (Soullier *et al.*, 2020). Accordingly, 40 percent of Africa's rice consumption comes from imports that bridge the gap of low level of production yet the demand is expected to increase by 130 % in 2035 (Saito *et al.*, 2015). Bua and Ojirot (2014), reported that in Uganda rice accounts for 34% and 36% as food and source of income, respectively. Rice sector in Uganda is developing at a pace of between 5% and 7% annually, where the domestic production and demand for the unprocessed is estimated at 237,000Mt and 331,857Mt, respectively (MAAIF, 2017).

1.3 Rice production regions in Uganda

In Uganda, rice is grown all over the country although the eastern region leads in lowland production followed by northern and western, respectively (Kijima *et al.*, 2012). According to Masao (2013), the lowland and upland varieties take 60% and 40% of the total production in the country, respectively. In accordance with Kayuki *et al.* (2017), Apac, Pallisa, Lira, Tororo, Kamwenge, Bugiri, Jinja, and Iganga are the principal rice-growing districts. In fact, the rate of adoption of upland rice cultivation is higher in the north compared to the other regions. However, Akongo *et al.* (2016), indicated that although northern Uganda is important for growing both low and upland rice varieties, upland rice cultivation is more prevalent in Acholi sub region particularly in the districts of Amuru, Nwoya and Gulu.

1.4 Constrains to rice production

Despite its importance, water scarcity and other rice straw management options negatively affect rice production (Hussain *et al.*, 2014). In fact, water for irrigation is becoming scarce day by day yet area under irrigated rice production is steadily increasing. According to Mohamed *et al.* (2019), the impact of water deficiency on both upland and lowland rice are more pronounced during the reproductive and ripening stages, respectively. As a result, the yield loss attributed to water stress during these reproductive and ripening stages were 52% and 55%, respectively. In reality, water stress during reproductive stage impacted more on the rate of grain filling and production of panicles by 19–32%, and 29–40%, respectively (Rahman and Yoshida, 1985). According to Tuong (2000), water management regimes that utilize minimum amount of water for the production of the unit quantity of rice should be prioritised. Later, Thakur *et al.* 2016) demonstrated that increasing rice yields while decreasing water use is possible. Accordingly, this therefore calls for the innovative technology that uses less water to produce more rice (Facon, 2000). Consequently, there is need to explore innovations of technologies that use minimum unit of water per unit yield of rice without compromising grain quality. However, it should also be noted that inadequate knowledge of water resource management is among the constraints farmers primarily deal with when producing rice (Nonvide *et al.*, 2018). Managing rice straw has also become a problem in regions where intensive rice farming is practiced to fulfill the increased demand. Accordingly, farmers usually choose to burn straws in open fields as a management approach, even though this practice contributes hazardous materials to the environment which may result in respiratory ailments and poor-quality air for humans (Gummert *et al.*, 2020). In fact, Xu *et al.* (2010) has reported burning of straw waste by farmers, yet it has been demonstrated that recycling the waste from rice straw can boost total soil fertility hence encouraging sustainable rice cultivation. Disposal of rice straw as well as water management regimes shall become important aspects of rice production in light of global warming (Samoy *et al.*, 2019). In an investigation by Ming *et al.* (2011) to determine the effects of long-term NPK fertiliser combined with organic amendment (rice straw) on rice grain production, the biomass of straw and harvest index rose gradually with the length of cultivation. In a similar study by Saothongnoi *et al.* (2014) to ascertain the impact of managing rice straw on the qualities of soil, the highest %OM and %OC were found in soils that had rice straw incorporated. This result suggested that the addition of rice straw improves soil fertility, which is beneficial for plant development.

1.5 Statement of the problem

In Uganda, especially Northern Uganda and particularly in Itek sub county - Lira district, improper rice straw management and poor water management regimes are limiting rice production in habitats that are both upland and lowland. Lengthy rainy season produces greater rice yields than shorter rainy season (Lansigan *et al.*, 2000). This therefore implies that adequate water should be provided for good rice grain yield to be realised. Adhikari (2015) examined the effects of climate change on rice production in Uganda by affecting the amount of water that could be used for irrigation and predicted that by the end of this century, rice production is expected to decrease by up to 45% in terms of grain yield. The contribution of rice growing to household earnings has dramatically decreased due to increased yield gap. In a study aimed at characterising rain-fed method of production and determining how climatic fluctuations affects rain-fed rice production in northern Uganda, Akongo (2022) reported that rice yield in lowland and upland areas show a notable yield differential, decreasing by 0.4 t ha-1 between 2013 and 2016. Senthilkumar (2022) reported that in Uganda, the average yield gaps between farmers and models were 1.9 t ha–1 for irrigated lowland, 4.6 t ha–1 for rainfed lowland, and 4 t ha–1 for rainfed upland with models realising higher yield in comparison with farmers. According to Hong *et al.* (2021), in a piece examining the present state of opportunities in Ugandan rice sector is estimated at 350,000 metric tons (MT) of rice a year, equivalent to 472,500 MT of rice straw with expected increase in years to come. Regretfully, the majority of rice straw generated is burned as waste, suggesting that many advantages are disregarded and missed out. Accordingly, appropriate water management practices and organic soil amendments, respectively, could mitigate the impacts of water stress and low soil fertility on rice grain yields. Nevertheless, a review of the literature revealed that Uganda has very few / limited studies on various water management regimes and rice straw management techniques to address the issue of lower rice grain yields. Therefore, more study is needed to figure out how to manage water and rice straw in rice farming without negatively affecting production of rice grains.

1.6 Justification of the study

Approximately 50% the total amount of calories that people on earth consume come from the top three food crops in the world, including rice. Therefore, anything which interferes with its production will be disastrous to achieving goals 1 and 2 of sustainable development goals (SDGs) as well as the national food security initiatives such as national development and vision 2040 among others (Awika., 2011). In many African nations, rice is a basic diet, and demand for it has skyrocketed in the last three decades yet its production remains low. However, a number of significant constraints in the rice industry are to blame for the failure of many SSA nations to produce enough rice on its own and this requires urgent intervention in order to avoid over reliance on imports to satisfy the ever-increasing demand (Balasubramanian *et al.*, 2007). Therefore, it would be disastrous for attempts to attain both national and global food security and to combat poverty if there were any significant negative effects on rice production brought on by climate change. Effective water management strategies and straw management options are believed to be among options to address challenges of rice productivity amidst the effects of global warming. However, details on how to handle water and straw in the rice growing process in Uganda is limited and scanty (Senthilkumar, 2022). This therefore makes the study imperative.

1.7 Objectives of the study

1.7.1 General objective

The main goal of this study was to identify the most efficient and effective straw and water management strategies for sustainable rice production in northern Uganda.

1.7.2 Specific objectives

The specific objectives were to;

1. Determine the effects of rice straw management on rice grain yields in Lira district, northern Uganda.
2. Assess the effects of different water management regimes on rice grain yields in Lira district, northern Uganda.

1.8 Hypothesis

1. Efficient and effective straw management strategies have significant effects on rice grain yields.
2. Water management regimes significantly influence rice grain yield.

1.9 Significance of the study

The findings of this study will help a number of stakeholders in the rice industry in the following ways:

1) Farmers will be guided on the recommended straw and water management practices that will help to improve rice grain yields.

2) Researchers will benefit from the information generated will act a source of reference to researchers. Areas for future research will also be recommended.

3) Agricultural extension: findings of the research will inform extension worker to guide farmers on improving rice grain yields amidst challenges of climate change.

4) Policy makers: policy makers will be guided to formulate policies and regulatory reforms informed by evidence to increase rice production.

5) Agricultural training institutions: training institutions will be encouraged to develop a training manual for rice production which is inclusive of addressing the challenges that rice production faces because of the effects of climate change.

10. Scope

10.1 Geographical scope: The study was conducted in Itek-Okile Lira district, northern Uganda.

10.2 Time scope: The research was done from October 2021 to September 2022.

10.3 Content scope: The study focused mainly on the effects of straw and water management on grain yields of rice in Lira district northern Uganda.

11 Limitations and Delimitations

11.1 Limitations

The limitation of this study included;

1. Unfavorable environmental / weather conditions during the study period.
2. Delayed experimental set up due to COVID 19 movement restrictions.

11.2 Delimitation

The above limitations were overcome as follows.

1. Used water from the reservoir to gravitationally supply water to plots using channels during second rainy season of 2021 where there was limited rainfall and manually irrigated treatments on the upland.
2. Rented nearer the experimental site in order to avoid movement restrictions which were imposed as a result of COVID 19.

CHAPTER TWO: LITERATURE REVIEW

2.0 Importance of rice and rice production constraints

Rice (*Oryza sativa* L.) makes up half of the basic foods consumed worldwide (Singha *et al.*, 2016). Accordingly, rice is the most important food crop in many developing and developed countries as evidenced by increased production and consumption over the years (Sack *et al.*, 2012). Areas in sub-Saharan Africa (SSA) where rice is grown have steadily increased from 2,694,000 hectares between 1961 and 1965 to 16,146,000 hectares between 2016 and 2020 (FAOSTAT, 2020, 2022). Indeed, the average annual rice production (milled equivalent) and consumption in SSA for the period between 2016 and 2020 was estimated at 15,402 and 27,246 million tons, respectively. However, the per capita consumption of rice in SSA for the period 2013-2019 was estimated at 23kgs against 54kgs for the global (Soullier *et al.*, 2020). Accordingly, 40 percent of Africa's rice consumption comes from imports that bridge the gap of low level of production yet the demand is expected to increase by 130 % in 2035 (Saito *et al.*, 2015). Bua and Ojirot (2014), reported that in Uganda rice accounts for 34% and 36% as food and source of income, respectively. Rice sector in Uganda is developing at a pace of between 5% and 7% annually, where the domestic production and demand for the unprocessed is estimated at 237,000Mt and 331,857Mt, respectively (MAAIF, 2017).

Despite the importance of rice, Fahad *et al.* (2019) claim that its production is limited by factors such as climate change, loss of wetlands, and increased salinity from saline water. Indeed, it is true that rice output has reportedly been significantly impacted by soil quality (Haefele *et al.*, 2014). As another production constraints in rice production inadequate research was also highlighted by John and Fielding (2014). Water scarcity and other rice straw management options negatively affect rice production (Hussain *et al.*, 2014). In fact, water for irrigation is becoming scarce day by day yet area under irrigated rice production is steadily increasing. Managing rice straw has also become a problem in regions where intensive rice farming is practiced to fulfill the increased demand. Disposal of rice straw as well as water management regimes shall become important aspects of rice production in light of global warming (Samoy *et al.*, 2019).

2.1 Effects of rice straw management on soil properties, rice growth and grain yields

Rice cultivation produces a large quantity of biomass especially straws and husks which are left in the fields during the harvesting process and milling, respectively (Singh and Patel, 2022). While rice bran, broken rice, and husked rice are processed with care, rice straw is left in the fields and burned in an open fire to provide the simplest disposal method. Yet, burning releases greenhouse gases and particulate matter into the atmosphere, which can adversely affect the environment, health of humans, and soil properties. However, Soam *et al.* (2017) had proposed that four most practical uses of straw which are field fertilisation, animal feed, producing electricity, and producing biogas. Using straw for the aforementioned life cycle assessment can help prevent the detrimental habit of burning straw. In order to manage rice straw sustainably by incorporating it in the soil, it will be necessary to review its impacts on soil properties, rice growth and grain yield.

According to Saothongnoi *et al.* (2014), soil treated with rice straw had higher potassium, organic matter, and organic carbon percentage than the control treatment. Correspondingly, the highest percentages of organic matter and organic carbon were found in soil that had rice straw incorporated. In fact, rice straw was found to increase soil fertility, which is beneficial for plant development. Also, the impact of incorporating rice straw on total SOC, active SOC fractions, and the carbon pool management index (CPMI) in paddy field was found to be significant (Wang *et al.*, 2015). Additionally, rice straw incorporation was found to have significant impacts on light fraction organic carbon and dissolved organic carbon. However, to ensure that rice benefits from a higher CPMI, straw wastes need to be incorporated into the aerobic environment at the beginning of paddy season. According to Chivenge *et al.* (2020), rice straw incorporation reduces fertiliser application in rice field since it contains about 80, 40 and 30% potassium, nitrogen and potassium taken up by rice plant, respectively. However, due to its slow decomposition, the timing of incorporation becomes crucial when combined with water management. The quality and amount of nutrients can be enhanced when farmyard manure is added to composted rice straw. SOC can also be increased by adding biochar which is produced by thermally burning rice straw for energy production (Chivenge *et al.*, 2020). Nonetheless, different uses that rice straw can be subjected to depend on the local circumstance. Additionally, numerous evaluations have been done on the impact of incorporating rice straw on the growth and yield of rice grain (Wei *et al.*, 2019). However, straw incorporation during the early phases of rice growth decreased plant height, number of tillers, biomass, and yield responses to irrigation management and straw incorporation due to the immobilisation.

Furthermore, the effects of straw incorporation on crop yield was found to increase rice yields by 4.1% in combination with fertilizers and green manure (Zhou *et al.,* 2020). Also, the green manure, rice straw and fertilizer combination were found to improve SOC, total nitrogen and accessible potassium (Zhou *et al.,* 2020). Zhao *et al.* (2019) examined the impact of complete straw incorporation on soil fertility and grain yield in a rice-wheat rotation and revealed that the incorporated straw greatly enhanced wheat production by an average of 58% compared to removal of straw however, rice yield showed no discernible change. For the treatments where rice straw was incorporated, the amount of accessible potassium, nitrogen and phosphate in the 0–20 cm soil layer rose by more than 15% as opposed to when straw was removed. Related to this study, it was also found out that application of bicochar enhanced phosphorus availability and cation exchange capacity which eventually led to significant increase in growth of agronomic parameters including plant height, dry biomass weight and tiller numbers (Kamara *et al.*, 2015). Ku *et al.* (2019) assessed the long-term effects of incorporating rice straw on the amount of SOC and rice yield and found out that the enhanced SOC levels of rice straw compost and rice straw treatments significantly increased grain yields by 11% and 9%, respectively in comparison with treatments where rice straw was not incorporated. Therefore, the best way to preserve SOC concentrations in soils is to amend them with rice straw.

However, Zhang *et al.* (2021) examined the effect of straw return on rice grain yield output and stability in the rice-wheat system at high fertilization levels over a period of nine years; but average rice output was not considerably impacted by the addition of straw. By adding straw, rice yield coefficient of variation was lowered while sustainable yield index was raised. Surprisingly, according to Ali *et al.* (2021), applying rice straw in conjunction with inorganic fertilizers did not significantly alter yield and yield-regulating parameters although it showed greater filled grain, 1000-grain weight, straw and grain yield in comparison to other treatments. With the exception of K, which was found to be high, the short-term incorporation of rice straw to the soil had no discernible effect on the post-harvest soil nutrient status.

2.2 Effects of water management regimes on rice growth and grain yields.

According to Datta *et al.* (2017), the world's water shortage seriously jeopardizes the ability to produce rice sustainably in order to feed the burgeoning population. Therefore, investigating alternative rice-growing methods that require less water is crucial for ensuring food security. As such, most current agricultural research focuses on water-efficient rice production technologies which target lowering the amount of water that is wasted. Those water-efficient technologies include alternating wet and dry conditions, the intensification system for rice, direct sowing, the ground cover rice production system and the aerobic rice system among others (Surendran *et al.*, 2021). These methods can all improve water use efficiencies (WUE) and drastically lower the quantity of water needed to grow rice. According to other studies aims are being pursued to enhance water economy and reduce yield losses. Analyzing the effects of different water management regimes on rice grain yields therefore necessitates review. Accordingly, Afifah *et al.* (2015) validated whether rice output is impacted by less water or not. In comparison with the different level of flooding, alternate wetting and drying (AWD) significantly reduced plant height and number of panicles. Grain yields also decreased as a result of increase in the number of unfilled grains. However, when the field was saturated at 1cm flooding 45% of the water used was saved than flooding at 5cm depth. Also, higher water use efficiency was demonstrated though rice yields was not significantly different at 5cm and flooding at 1-3 cm depth of flooding, respectively. Atwill *et al.* (2018) assessed the consequences of four different rice irrigation methods on, plant height, nitrogen use efficiency (NUE) and rice grain yield. Compared to the continuous flood (control), rice cultivated in an aerobic atmosphere had at least a 20% decrease in NUE and rice grain production.

However, AWD irrigation that is controlled well does not lower NUE, plant height and grain output in comparison to the continuously flooded systems. Similarly, Wang *et al.* (2016) conducted a study on grain yield and water utilization efficiency on irrigation regimes and nitrogen rates. Out of the three irrigation regimes, the alternate wetting and severe drying regime demonstrated the highest grain yield, water and nitrogen use efficiency with an increase in nitrogen rate. Consequently, the results show that by using a mild drying and alternate wetting regime in conjunction with an adequate nitrogen rate, higher grain yield, water efficiency, and nitrogen use efficiency can be achieved.

To investigate the effects of aerobic rice, AWD and continuous flooding (CF) on rice growth, grain yield and water productivity by Hussain *et al.* (2021), in comparison to AWD and CF, aerobic rice conserved the highest amount of water. In contrast to AWD and CF, aerobic rice recorded the least total dry weight and grain yields. Dou *et al.* (2016) examined the impacts of soil texture (clay and sandy loam), and water regime/condition (continuous flooding, saturated, and aerobic) on water productivity, yield components, and rice grain yield. Their findings reveled that continuous flooding produced a yield that was noticeably higher than any other treatment. Compared to sandy loam soil, clay soil produced greater rice grains. Additionally, saturated and continual flooding treatments produced more panicles than aerobic conditions. Furthermore, compared to sandy loam soil, the panicle numbers in clay soil was higher. Choosing soil types are therefore crucial considerations when choosing a water management strategy. Oliver *et al*, (2019) examined the impacts of AWD and CF on buildup of biomass (grain, above ground, and below ground). Result revealed that CF treatments produced more roots than AWD, no cultivar's overall yield was affected by treatment significantly. Towa *et al.* (2013) examined the effectiveness of rain-catching and controlled irrigation in weedy and mulching situations. Higher grain yield was obtained under mulching condition compared with weedy conditions.

Thakur *et al.* (2014) examined traditional transplanting system (CTS) and the system of rice intensification (SRI) on the production of rice grains and found out that SRI practice delivered better grain output with less water than CTS. Poddar *et al.* (2022) evaluated how three irrigation strategies - continuous ponding (CP), AWD and saturation affected grain yields and growth. CP, as opposed to AWD technique, produced significantly greater yields and all growth parameters as well as yield features. Feng *et al.* (2021) investigated the effects of two varieties of rice (ordinary and drought-resistant) and two distinct irrigation regimes (AWD and CF) on grain yields. The result showed that AWD significantly reduced grain yields and water inputs in comparison to CF.

In another study, water-saving measures, paddy yield, water productivity, and economics were compared and contrasted by Ishfaq *et al.* (2020). Irrigation regimes used were; aerobic rice grown under conventional transplanted rice (TPR) and dry direct seeded rice (DDSR), AWD, and CF. Compared to TPR, DDSR yielded better grains and required less water. AWD under DDSR enhanced the leaf area index (LAI), tillering, yield and water productivity while reducing the overall water input when compared to CF. Shao *et al.* (2014) examined the impact of controlled irrigation and drainage on the growth, yield, and water use of paddy rice at four different stages of tillering, booting, flowering and milky stage, AWD was throughout the entire stages. The tillering treatment had the lowest grain yield of all the treatments due to a decline in panicle counts and percentages of filled grains.

Mofijul *et al.* (2016) investigated how different fertilizer rates and application techniques affected rice grain yields and nitrogen utilization efficiency in the CF and AWD water regimes. Broadcast prilled urea NPK briquettes, deep placed urea briquettes, and a control group (in which N is absent) were among the fertilizer application. Although it did not considerably impact grain yields, fertilizer placed deeper during both the wet and dry seasons reduced N recovery. Liang *et al.* (2016) investigated three different water treatments - AWD with water level maintained at 15cm (AWD15), AWD with water level maintained at 30cm (AWD30), CF on the yield of a hybrid rice variety. The outcomes demonstrated that while water input dramatically decreased under the two AWD treatments for both dry and wet season, grain yields under AWD15 and AWD30 were equivalent with CF. These results showed that water conservation and grain yield may be achieved with the AWD15.

In a related study, Cesari *et al.* (2017) compared the effects of three rice water management strategies (dry seeding with delayed flooding, water seeding with CF, and dry seeding with intermittent irrigation) on rice grain yields. Water seeding with CF produced the highest grain yield followed by dry seeding with delayed flooding and finally dry seeding with intermittent irrigation. Indeed, Yan *et al.* (2022) found out that rainfall-adapted irrigation decreased both the overall amount of irrigation water used and numbers of irrigation as compared with the conventional flooding irrigation condition, indicating that irrigation using a rainfall-adapted system enhanced the capacity and consumption of rainwater storage. Along with these benefits, rainfall-adapted irrigation raised the harvest index, crop growth rate, percentage of tillers that are productive, net rate of photosynthetic activity, root length, and biomass of the roots and shoots. Zhang *et al.* (2018) looked into the potential gains in NUE, irrigation water productivity, and grain production. The findings demonstrated that progressive integrative crop management may enhance agronomic and physiological performances in addition to elevating the productivity of irrigation water, NUE, and grain output in contrast to local farmer's practice.

CHAPTER THREE: THE EFFECTS OF RICE STRAW MANAGEMENT ON RICE GRAIN YIELD

3.1 Introduction

Traditionally, both lowland and upland ecosystem continues to dominate rice production systems (Huaqi *et al.,* 2002). However, it is well acknowledged that one of the biggest difficulties in rice farming is disposal of the rice straw. While rice is processed meticulously to produce husk, bran, and broken rice, rice straw is left in the fields and at times burned in an open fire to provide the simplest means of disposal (Singh and Patel, 2022). For instance, in lowland paddy, anaerobic decomposition of the straw is responsible for methane emissions, one of the greenhouse gases connected to rice farming, whereas in upland rice farming, open field burning of the straw produces carbon dioxide and carbon monoxide (Kaur *et al.*, 2017). On the other hand, improper disposal of rice straw may promote the carryover of inoculum *Sclerotium oryzae* that causes stem rot disease to the subsequent rice plant (Cintas and Webster, 2001). However, in Uganda, information on straw management in rice fields is limited and scanty. Therefore, the objective of the study was to assess the effects of rice straw management on rice grain yield in Lira district, northern Uganda.

3.2 Materials and Methods

3.2.1 Site of the study

The study was conducted in Itek-Okile in Itek sub county Lira district, northern Uganda. Lira district has eight sub counties and two town councils but Itek sub county was chosen because it is one of the major rice growing sub counties in the district. The experiment was carried out on a farmer's field during the first and second rainy seasons of 2021 and 2022, respectively. First experiment started from the month of October, 2021 to February, 2022 and the second from the month of May,2022 to September, 2022. The coordinate of the site is $2^{0}11'55.4''N33^{0}05'21.3''E$ and the soil type of the site is clay. A tropical wet and dry/savanna climate is characteristic of Lira district, which is generally found at an altitude of 1084.11 meters (3556.79 feet) above sea level. The annual temperature is approximately 25.02 ˚C (77.04 °F) and is 1.55% higher than the national average for Uganda. The annual precipitation of the area is 168.7 millimeters (6.64 inches). The first season of the experiment was referred to as "dry season" because it was when average higher temperature, average lower rainfall and average lower relative humidity were recorded compared with the second season of the experiment when the repeat of the experiment was conducted which was termed "wet season".

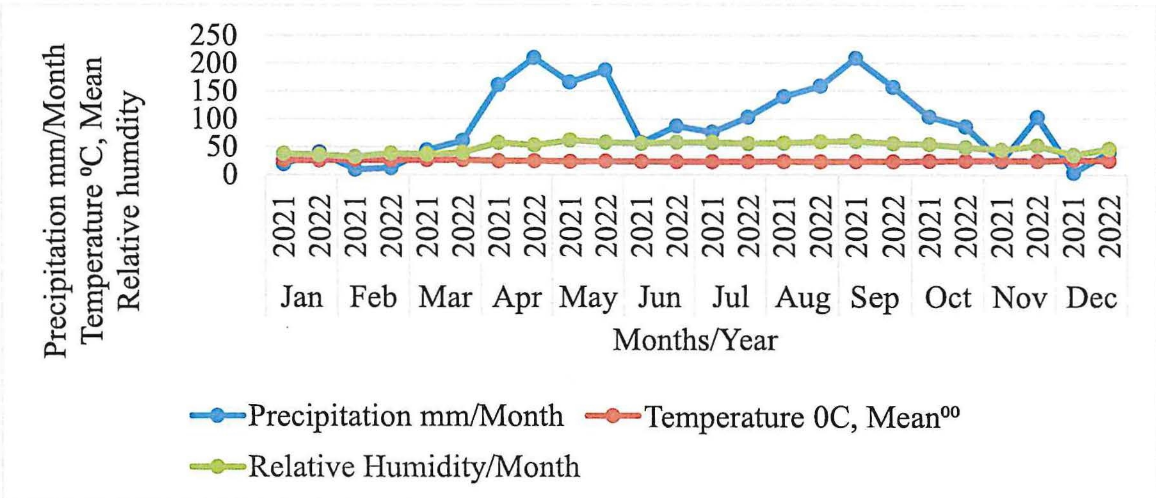

Figure 1: Data on precipitation (mm/month), temperature (°C) and mean relative humidity for the study site (Itek –Okile), Lira district covering two seasons that the experiments were conducted.

Source: Ngetta ZARDI meteorology station, Lira

Average temperature, rainfall and relative humidity for season one (first experiment) stood at 22.8°C, 2.16mm and 69.6 and for season two (second experiment) was at 21.76°C, 10.18mm and 82.72 respectively.

3.2.2 Experimental design

The experiment was set up as a split plot with three replications using a randomized complete block design. The sub plots were rice straw treatments, and the main plots were different types of rice. Rice varieties used during the two seasons of the experiment were PR107 and Namche 5. These represent both the lowland and upland varieties, respectively. The seeds for the two rice varieties were obtained from the cereals programme at the National Crop Resources Research Institute.

3.2.3 Field preparation and management

Before the experimental layout, the field was tilled and harrowed a week before planting for each of the season. For the first and second season, harrowing took place on the 7th October 2021 and 30th April 2022, respectively. Each plot measured 2m x 2m. The field was fully laid out and an alley of one (1) meter was left between the plots to ease movement within the plots. No fertilizer was used in any treatment during the two seasons. For the treatments where rice straws were incorporated, rice straw at a rate of five tons per hectare (5 t/ha) was chopped into small pieces of about two centimeters and then incorporated into the soil a week before planting as described by Goyal *et al.* (2009). For treatments where rice straws were removed, straws were cleared and removed prior to ploughing since the experiment was done where rice was planted previously. Planting was by direct seeding, two seeds per hill at the spacing of 30cm x15cm (Aleminew and Legas, 2015). For the first and second season, planting was done on 14^{th} October 2021 and 6th May 2022, respectively. First weeding was done at the second week after planting, second weeding was done at the first week of tillering, third weeding was done at the last week of tillering and the final weeding was done during panicle initiation (Singh *et al.*, 2006).

3.2.4 Data collection

Data collection started from 2^{nd} November 2021 and 20^{th} May 2022 for the first and second season and ended on 4^{th} February 2022 and 25^{th} August, 2022 for the first and second season, respectively. Data collection interval was after every two weeks for both seasons until harvesting time. Data were collected on plant height, tiller numbers, weight of straws, grain yield and number of panicles.

3.2.4.1 Plant height

This was measured from the soil level until the tip of the five randomly selected plants using a tape measure. Average plant height was computed by dividing total plant heights by the number of plants sampled in a given season.

3.2.4.2 Number of tillers

The number of tillers was counted from five plants randomly selected from each treatment during the two seasons. The average number of tillers for each season was determined by dividing the total number of tillers by number of plants sampled.

3.2.4.3 Number of panicles

The number of panicles was determined from five plants randomly selected from each treatment during both seasons. The average number of panicles per treatment for each season was calculated by dividing the total number of panicles per treatment by the number of plants sampled (five).

3.2.4.4 Grain weight

This was determined by harvesting one square meter of rice from the middle row of each treatment for both seasons. The grain from each treatment was threshed separately and sun dried until the moisture content of 12% was attained (Ziegler *et al.*, 2021). The dried grains were then cleaned, winnowed, and packaged in separate bags ready for weighing. Average weight for each season was determined by getting average grain yield for the treatments and then multiplying it by the total square area that the total treatment covered.

3.2.4.5 Weight of straw

This was determined by harvesting plants from a square meter from the middle row of each treatment during each season. The gathered straws were air dried under the shade until the constant moisture content was attained. Average straw weight for each treatment per season was determined by multiplying the total square area of the treatment by the weight of straw obtained from a square area harvested.

3.2.4.6 Soil sampling

Soil samples were collected in order to determine soil organic matter, soil organic carbon and Soil pH. For the determination of soil organic matter and soil organic carbon, soil samples were obtained before planting and after harvest. The method used in soil sampling was a zigzag method as described by Trajkova and Zlatkovski (2017). For each season, twelve (12) soil samples were obtained using soil auger which therefore translated in to one (1) sample per treatment. Soil surface litter and crop residues were scraped away from the site where the samples were obtained. Soil samples from the same treatment for each season were bulked together and properly labeled. From each sampling spot, at least two hundred grams (200g) of soil was obtained. The depth of sampling ranged from 0-20cm and 0-40cm for pH and fertility analysis, respectively (Trajkova and Zlatkovski, 2017). Soil samples from the same treatments were thoroughly mixed to get one composite sample. The composite sample was air dried on a newspaper, crushed and thoroughly mixed. Five hundred grams (500g) of a representative sample from the same treatment was then obtained for analysis.

3.2.5 Methods of chemical and physical soil analysis

For chemical and physical investigation, soil samples were taken both before and after harvesting, at a depth of 0-20cm and 0-40cm for pH and fertility analysis. Samples of soil were air-dried, crushed, and sieved through a 2 mm screen to remove any debris before being submitted to conventional procedures outlined by Okalebo *et al.* (2002) for chemical and physical analysis.

3.2.5.1 Determination of soil organic matter and soil organic carbon

Soil organic matter and soil organic carbon were determined from a soil sample of two grams (2g). Weight of the empty crucible was determined using electronic balance. Weight of both crucible and soil together was also determined and the soil sample in a crucible inserted in to a burning furnace to burn for two (2) hours. After burning, soil sample in a crucible was then removed and cooled. Weight of both crucible and soil after ignition and cooling was then determined and the percentage of soil organic matter and soil organic carbon calculated.

3.2.5.2 Determination of total nitrogen

Kjeldah method was used to determine total nitrogen in the soil sample. 0.2g of air-dried sample was digested by putting it in a digestion tube and 4ml of concentrated H_2SO4 added. One tablet of Kjeldah catalyst tablet (sodium sulphate) was added in to the content in the digestion tube. The content in the digestion tube was placed in to the graphite digester on a hotplate in a fume cupboard and each tube held in an upright position until the digestion tube became clear. After cooling, the solution was poured via a funnel in to a glass storage bottle and then topped up to fifty mills (50ml) mark with distilled water. Fifteen mills (15 ml) of NaOH solution were added in to ten mills (10ml) of the sample and then distilled using twenty-five (25) ml of 4% boric acid solution in to which two (2) drops of a mixed indicator solution was added. Drops of indicator emitted ammonia and ammonia was trapped by boric acid solution and the solution changed from colorless to green solution. The distilled solution was then titrated using 0.02N Hcl solution drop wise and the end point was reached when the green solution changed to a pink.

3.2.5.3 Determination of soil pH

As one of the physical properties of the soil, pH was determined by a pH meter. Twenty grams (20g) of the soil sample was weighed using electronic balance and into it was added forty mills (40 ml) of distilled water and then shaken vigorously. The content was left to settle for ten (10) minutes. The probe was then first dipped in to the distilled water and finally to the sample to determine its pH.

3.2.6 Data analysis

All data collected were subjected to general analysis of variance of the Genstat Computer Programme to test for the significance of the treatments. Means were separated using LSD at 5% probability level.

3.3 Results

3.3.1 Plant height

There was a significant effect of variety (P =0.039) and season (P<.001) but not treatment (P>0.05) on plant height. Across the two seasons and treatments, the average number of tillers was (0.71 ± 0.04 m). Irrespective of variety and treatment, taller plants were recorded during the second season (0.79 ± 0.04 m) when compared with the first season (0.64 ± 0.03 m). Plant height, however, depended on the interaction between variety and season (P=0.042) but was not dependent on the interaction between variety and treatment (P>0.05).

Although taller plants were obtained from the treatment where rice straw was removed during the two seasons, plant height did not differ (p>0.05) between the treatments where rice straw was incorporated or rice removed (Table 1). In season one, rice plant height was not affected by the variety, while in the second season the height of Namche 5 rice variety was significantly higher than that of variety PR107 (Table 1).

Table 1: The effect of variety on the height of rice plants after cultivation under different straw management systems for two seasons in Itek-Okile between 2021 and 2022.

Season	Variety	Mean of plant height (m)
One	Namche 5	0.640 ± 0.033 a
(October 2021-Febuary 2022)	PR107	0.640 ± 0.032 a
Two	Namche 5	0.825 ± 0.042 b
(May 2022 -September 2022)	PR107	0.745 ± 0.038 a

For each season, means in column followed by similar letters are not significantly different at a 5% probability level, LSD.

3.3.2 Number of tillers

Overall, the number of rice tillers was affected by variety ($p=0.002$) but not treatment or season ($P>0.05$). Across the two seasons and treatments, the average number of tillers was (10.2 ± 1.3). Irrespective of treatment and season, the rice variety PR107 (11.59 ± 1.5) had a significantly higher number of tillers than Namche 5 (8.84 ± 1.2). The was an interaction between variety and season ($p<.001$) but not between season and treatment ($P>0.05$). In the first season the rice variety PR107 registered a statistically higher number of tillers than Namche 5 variety (Table 2). In the second season, Namche 5 variety had a significantly higher number of tillers than the other variety (Table 2).

Table 2: The effect of variety on number of tillers of rice plant after cultivation under different straw management systems for two seasons in Itek-Okile between 2021 and 2022

Season	Variety	Mean of number of tillers
One	Namche 5	7.67 ± 1.00 b
(October 2021-Febuary 2022)	PR107	14.34 ± 1.85 a
Two	Namche 5	10.00 ± 1.30 a
(May 2022 -September 2022)	PR107	8.84 ± 1.15 a

For each season, means in column followed by similar letters are not significantly different at a 5% probability level, LSD.

3.3.3 Number of panicles

The number of panicles was affected by the treatment (P=0.017), variety (p<.001), and season (p=0.003). Overall, a statistically higher number of panicles were registered with the treatment where rice straw was removed from soil (i.e. RRR treatment =110.1 ± 3.0 panicles) when compared with the treatment where rice residue was incorporated in the soil (i.e. RRI treatment = 82.2 ± 2.2 panicles). On the other hand, the rice variety PR107 produced more number of panicles (121.6 ± 3.2) than Namche 5 (70.7 ± 1.9). Rice grown in the second season registered higher number of panicles (114.3 ± 3.1) than those cultivated in the first season (78.0 ± 2.1). However, the number of panicles depended on the interaction between variety and season (P=0.005) but not between variety and treatment (P>0.05). In both seasons the number of panicles produced by rice variety PR107 was significantly higher than that produced by Namche 5 variety (Table 3).

Table 3: The effect of variety on number of panicles of rice plant after cultivation under different straw management systems for two seasons in Itek-Okile between 2021 and 2022

Season	Variety	Mean of number of panicles
One	Namche 5	35.70 ± 0.96 b
(October 2021-Febuary 2022)	PR107	120.35 ± 3.23 a
Two	Namche 5	102.70 ± 2.84 b
(May 2022 -September 2022)	PR107	122.85 ± 3.30 a

For each season, means in column followed by similar letters are not significantly different at a 5% probability level, LSD.

3.3.4 Grain yield

Like straw weight, rice grain yield depended on the season (P=0.026) and variety (P<.001) but not on the treatment (P>0.05). Irrespective of treatment, season or variety, the average rice yield was 2.4 t/ha. The results of yield assessment further revealed that the rice variety PR107 produced a significantly higher grain yield than Namche 5, while the yield of rice recorded in the first season was significantly lower than that of the second season (Fig. 2). There was no interaction between variety and season as well as variety and treatment for rice grain yield (P>0.05).

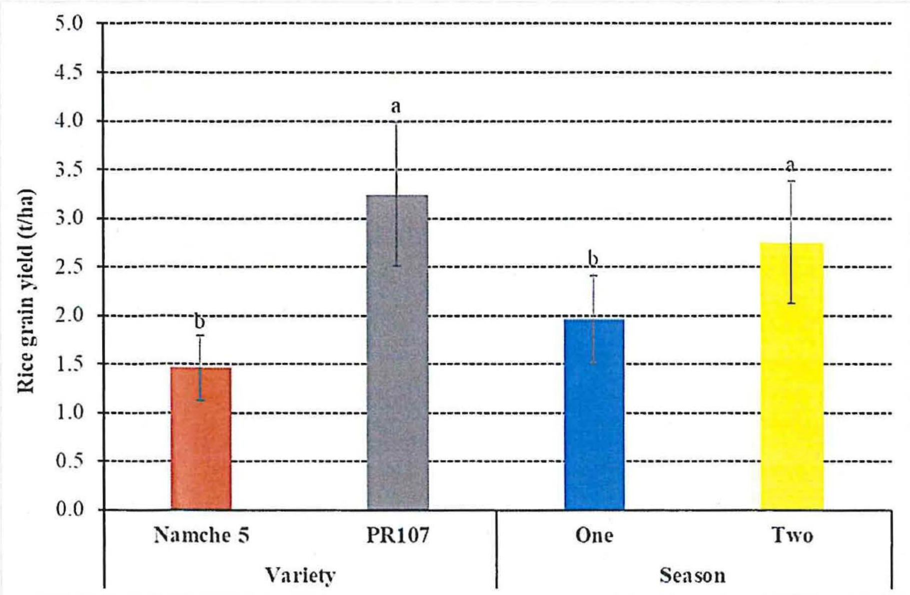

Figure 2: The effect of variety and season on the yield of rice after cultivation under different straw management systems in Itek-Okile between 2021 and 2022.

For each variety and season, bars followed by similar letters are not significantly different at a 5% probability level, LSD. Error bars represent the standard error of the mean.

3.3.5 Weight of straw

The results showed that the rice straws collected across the two seasons weighed on average 3.2 t/ha irrespective of season and treatment. The weight of the rice straw was dependent on the variety ($p<.001$)) and season ($P=0.024$). Though not significantly different, treatment with RRI registered higher weight of straw than RRR across seasons. On the other hand, the rice variety PR107 produced a significantly higher tonnage of straw than Namche 5, while the weight of straw recorded during the second season was significantly higher than that registered during the first season (Fig. 3). There was no interaction between variety and season as well as variety and treatment for the straw weight ($P>0.05$).

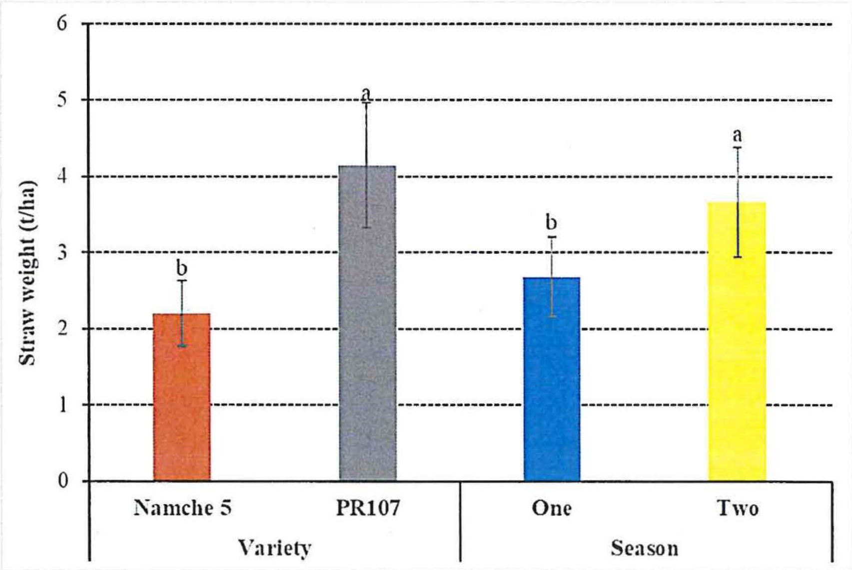

Figure 3: The effect of variety and season on the weight of straw after cultivation under different straw management systems in Itek-Okile between 2021 and 2022.

For each variety and season, bars followed by similar letters are not significantly different at a 5% probability level, LSD. Error bars represent the standard error of the mean.

3.3.6 Soil characteristics of upland and lowland ecosystems

The soil organic matter, which is key to soil fertility, has been estimated for productive agricultural soils to be in the range of 3 to 6%. In the present study, the soil was found to have more than double this organic matter level irrespective of the ecosystem. One week after crop harvest, soil organic matter increased in the first season and second by 3.8% and 0%, respectively, in the lowland ecosystem. In the upland ecosystem, there were minimal effects of ± 0.25% depending on the season. For soil organic carbon, a value of <1.2, 1.2-1.7+ or >1.7 % is often considered low, moderate or high, respectively (Musinguzi et al., 2016). In this study, very high levels (over 3 times higher than 1.7) were obtained in both ecosystems prior to planting (Table 4).

Table 4: Percentage of SOM, SOC and N in the soil samples during season one and season two under different straw management

Rice straw management practice	%SOM	%SOC	% N	Rice field ecosystem
Soil sample before planting	9.8 ± 0.3	5.67 ± 0.17	0.04 ± 0.00	Upland
Soil sample before planting	10.0 ± 0.3	5.81 ± 0.17	0.08 ± 0.01	Lowland
		Season one		
Soil samples 7 days after harvest	9.6 ± 0.3	5.6 ± 0.2	0.04 ± 0.00	Upland
	13.8 ± 0.4	8.3 ± 0.2	0.08 ± 0.01	Lowland
		Season Two		
Soil sample at 7 days after harvest	10.1 ± 0.3	5.8 ±0.2	0.12 ± 0.01	Upland
	10.1 ± 0.3	5.9 ± 0.2	0.1 ± 0.01	Lowland

SMO= Soil organic matter, SOC =Soil organic carbon, N= Nitrogen.

***Reference value for soil organic carbon: Low= <1.2%, Moderate/ Medium=1.2-1.7% and High= >1.7 % (Musinguzi *et al.*, 2016)

After planting, the carbon level in lowland ecosystem increased by 2.5 and 0.1%, in the first and second season, respectively. In the upland ecosystem, there was nearly no change in soil carbon level (±0.1%) over the two seasons. A good level of nitrogen in the soil is usually estimated at 0.3-0.4%. At the start of the experiment, the level of nitrogen in both ecosystems was 8-10 (upland) and 3-5 (lowland) times lower than this estimated value. At harvest, the nitrogen level remained very low in the soil with no change in season one but slightly increased in the second season by 0.1 and 0.02% in lowland and upland ecosystems, respectively (Table 4).

3.3.7 The level of potassium, phosphorus and the soil pH of upland and lowland ecosystems

The soil pH under the two rice ecosystems was slightly acidic in comparison to the recommended values that are often observed in lowlands and uplands. The results showed that the soil pH for the upland ecosystem (<5.6) could be categorized as "low" according to Cropnut classification; however, the pH observed in the lowland rice ecosystem was categorized as "moderate" and within the recommended range. For the values of potassium and phosphorus, it was observed that the values obtained in this study were 3.8-72.5 and 16.0-73.3 times, respectively, higher than what is often recommended for fertile soils depending on the ecosystem, i.e. whether lowland or upland (Table 5).

While the results revealed that the level of potassium in lowland was 0.85% higher in lowland than upland ecosystem, it was observed that the phosphorous level was higher in the upland ecosystem by 0.06% when compared with the lowland ecosystem (Table 5). However, irrespective of the ecosystem, the values for potassium were within the acceptable range while that of phosphorous exceeded the normal range.

Table 5: Soil pH, percentage of K and P for the different rice field ecosystem

Site	Depth of soil sampling (cm)	pH**	%K++	%P
Upland	10-15	5.5 ± 0.6	2.05 ± 0.25	0.22 ± 0.03
Lowland	10-15	6.0 ± 0.7	2.90 ± 0.35	0.16 ± 0.02

**Reference value Very Low (acidic)= 4.0-5.0, Low = 4.5-5.5, Medium = 5.6-6.5, High = 6.6-7.0, and very high (Alkaline) = >7.0. Source-https://cropnuts.helpscoutdocs.com/article/829-interpreting-your-soil-test-.

++Reference value for potassium of (0.04-3%) and Phosphorous (0.05-0.08%) Source:

https://www.ipipotash.org/udocs/Dynamics%20of%20K%20in%20Soils%20and%20Their%20Role%20in%20Management%20of%20K%20Nutrition.pdf

3.4 Discussion

3.4.1 Plant height

The result showed that there was significant difference in plant height for variety, season and interaction of variety x season, however, plant height did not differ significantly with treatment. In fact, taller plants were recorded during second season than first season. Reduced plant heights during first season could have been due to the stress caused by water shortage during the first season in comparison with second season (Fig. 1). Decrease in plant height might have therefore been attributed to water stress (Sarvestani *et al.*, 2008). Also, immobilization of inorganic N might have contributed to lower plant height when treated with RRI compared with RRR. Accordingly, immobilization of inorganic N by soil microbes to build their tissues is cited by Mandal *et al.* (2004) as the primary drawback of incorporation. Additionally, Rao and Mikkelsen (1976) carried out a study to investigate the issue under the circumstances of direct rice sowing, and the outcomes unmistakably showed that when soil and rice straw were not incubated prior to planting rice, applied N was immobilized, inhibiting plant growth and resulting in low N content in plants. However, long term effect could have resulted into treatments with RRI having higher plant heights than those with RRR. In fact, according to Dobermann & Fairhurst (2002), incorporation of the straw into the soil returns most of the nutrients and helps to conserve soil nutrients reserve in the long term but short-term effect is minimal. In a study by Bird *et al.* (2001), it was also discovered that there were no effects on the total soil C and N until six seasons had passed since the residues had been incorporated. However, throughout the fifth and sixth years of the study, RRI treatments had higher levels of microbial biomass C and N than RRR treatments. Namche 5 might have had a different genetic makeup because it consistently grew taller than PR107 across the seasons and according to Wei *et al.*, (2010), the three most important agronomic traits of rice namely yield, plant height, and flowering time are controlled by many quantitative trait loci (QTLs).

3.4.2 Number of tillers

According to the result, there was significant difference in the number of tillers for variety and interaction of variety x season. Much as the number of tillers were not significantly different for treatment, RRI treatment recorded a greater number of tillers than RRR. Reduced numbers of tillers in RRI treatment could have been as a result of inhibition during early stages of rice growth. According to Gao *et al*., (2004), straw incorporation significantly reduced number of tillers. Due to the genotype, PR107 has more tillers than Namche 5, and in general, PR107 is a higher tillering rice variety than Namche 5. As an upland rice variety that depended entirely on rainfall, Namche 5 had more tillers during the second season when average rainfall was higher.

3.4.3 Number of panicles

Result showed that there was significant difference in the number of panicles for variety and interaction of variety x season. PR107 produced more numbers of panicles than Namche 5 across seasons. In fact, higher numbers of panicles were recorded during second season. Number of panicles realised were attributed to genetical make up. PR107 which is high yielding than Namche 5 had a greater number of panicles across seasons. Higher number of panicles recorded during second season might have been attributed to increased amount of rainfall received.

3.4.4 Grain yield

There was significance difference in grain yield for season and variety. However, respond of grain yield to treatment was not significant. Grain yields were higher for PR107 than Namche 5 across seasons. Overall, grain yields were higher during second season when compared with first season. Insignificant difference in rice grain yields under different straw treatments could have been as a result of limited time given for treatment with RRI to mineralise N which might have resulted into the microbes immobilizing available N to build their own tissues. According to Arai *et al*., (2021), effects of RRI and RRR treatments on rice yields were also insignificant within short term. The main reason for reduced grain yield during first season was probably as a result of water stress during the critical stages of growth. Grain yield of Namche 5 which is an upland variety was severely affected than PR107 which is the lowland variety. Sarvestani *et al.* (2008) discovered that the decline in grain production caused by water stress occurred more during the flowering stage than during any other stage. The genetic composition of the cultivars was ascribed to PR107's higher grain yields than Namche 5 throughout the season. In terms of genetics, PR107 produces more rice grains than Namche 5. An increase in the quantity of rainfall received during the second season most likely contributed to a rise in grain yield of Namche 5 and PR107.

3.4.5 Weight of straw

The result showed that there was significant difference in the weight of straw for the variety and season. PR107 genotype produced more weight of straw than Namche 5 during both seasons. Overall, higher weight of straw was recorded during second season than first season for all the varieties. Lower weight of straw during fist season might have been attributed to water stress. According to a field experiment conducted by Sarvestani *et al.* (2008) to evaluate the consequences of water stress on biomass of the four rice cultivars, total biomass decreased under water stress in all cultivars under treatments of adding and removing straw. The reason for PR107 greater straw weight compared to Namche 5 throughout the seasons is thought to be related to its greater tillering capacity. The weight of straw recorded for each variety of rice was higher during second season than first season probably was as a result of increase in the amount of rainfall received during the second.

Percentage of soil organic matter, soil organic carbon and nitrogen

The result showed that soil sampled from treatments with RRI had higher percentages of soil organic matter, soil organic carbon and nitrogen compared with soil samples from treatments with RRR for both seasons.

Increase in the percentages of soil organic matter, soil organic carbon and nitrogen from the soil sampled from RRI treatments for both seasons could have been because of the contribution of rice straw incorporated. The result of the research conducted by Jing *et al.*, (2020) indicated that addition of rice straw increases soil organic carbon, soil organic matter and nitrogen, however, soil organic carbon decreases with rice growth period. This probably implies that soil organic carbon contributed is used by rice for its growth.

CHAPTER FOUR: THE EFFECTS OF DIFFERENT WATER MANAGEMENT REGIMES ON RICE GRAIN YIELD

4.1 Introduction

Rice production has historically been done in lowland ecosystems, which provide water and nutrients (Chivenge et al., 2020). However, in numerous locations of the country notably in the northern part of Uganda, rice cultivation is limited by scarcity of quality water (Akongo et al., 2017). Therefore, it is anticipated that rice production will further decline as a result of climate variability and change. Apart from these, the other rice production constraints include drought, degraded wetlands, competing uses of upland and lowland ecosystems, pest and disease outbreaks, weed competition, greenhouse gas emissions, and changes in social habits (Barrion, 2007). Alternate wetting and drying has been found to increase water use efficiency, hence decreasing the amount of water required for rice production (Chapagain et al., 2011). However, in Uganda, there is limited information and knowledge on the effects of various water management strategies on rice growth and grain yields. Therefore, the objective of this study was to assess the effects of different water management regimes on rice grain yield in Lira district, northern Uganda.

4.2 Materials and methods

4.2.1 Site of the study

The study was conducted in Itek-Okile in Itek sub county Lira district, northern Uganda. Lira district has eight sub counties and two town councils but Itek sub county was chosen because it is one of the major rice growing sub counties in the district. The experiment was carried out on a farmer's field during the first and second rainy seasons of 2021 and 2022, respectively. Details of coordinates, soil type, temperature and rainfall are provided in section 3.2.1.

4.2.2 Experimental design

The experiment was set up as a split plot with three replications using a randomized complete block design. The sub plots were distinct water regimes, whereas the main plots were diverse rice varieties. Alternate wetting and drying (AWD), continuous flooding (CF) and continuous drying (CD) were the three different water treatments. The two lowland rice varieties used during the two seasons were K5 and PR107. The seeds for the two lowland rice varieties were obtained from the cereals programme at National Crop Resources Research Institute (NaCRRI).

4.2.3 Field preparation and management

Before the experimental layout, the field was tilled and harrowed a week before planting for each of the season. For the first and second season, harrowing took place on the 7th October 2021 and 30th April 2022, respectively. Each plot measured 2m x 2m. The field was fully prepared and the bunds and canals constructed in between plots and an alley of one (1) meter was left between the plots to ease movement within the plots. No fertilizer was used in any treatment during the two seasons. Planting was by direct seeding, two seeds per hill at the spacing of 30cm x15cm (Aleminew and Legas, 2015). For the first and second season, planting was done on 14th October 2021 and 6th May 2022, respectively. First weeding was done at the second week after planting, second weeding was done at the first week of tillering, third weeding was done at the last week of tillering and the final weeding was done during panicle initiation (Singh *et al.*, 2006). For AWD, the field was alternately flooded and drained after every two weeks (14 days) throughout the rice growing period. Irrigation water was supplied gravitationally using water channels. For CD, the field depended solely on rainfall and for CF, irrigation water was continuously delivered to flood the field during the rice-growing season via the waterways. Water level was regulated during flooding at 5 cm above the soil's surface.

4.2.4 Data collection

Data collection started at two weeks after planting and data collection interval was after every two weeks for both seasons until harvesting time. Data were collected on plant height, tiller numbers, number of panicles, grain yield and weight of straw.

4.2.4.1 Plant height

This was measured from the soil level until the tip of the five randomly selected plants using a tape measure. Average plant height was computed by dividing total plant heights by the number of plants sampled in a given season.

4.2.4.2 Number of tillers

The number of tillers were counted from five plants selected randomly from each treatment during the two seasons. The average number of tillers for each season was determined by dividing the total number of tillers by number of plants sampled.

4.2.4.3 Number of panicles

The number of panicles were determined by randomly sampling five plants from each treatment and physically counting the number of panicles during both seasons. The average number of panicles per treatment for each season was calculated by dividing the total number of panicles per treatment by the number of plants sampled (five).

4.2.4.4 Grain weight

This was determined by harvesting one square meter of rice from the middle row of each treatment for both seasons. The grain from each treatment was threshed separately and sun dried until the moisture content of 12% was attained (Ziegler *et al.*, 2021) The dried grains were then cleaned, winnowed, and packaged in separate bags ready for weighing. Average weight for each season was determined by getting average grain yield for the treatments and then multiplying it by the total square area that the total treatment covered.

4.2.4.5 Weight of straw

This was determined by harvesting plants from a square meter from the middle row of each treatment during each season. The gathered straws were air dried under the shade until the constant moisture content was attained. Average straw weight for each treatment per season was determined by multiplying the total square area of the treatment by the weight of straw obtained from a square area harvested.

4.2.5 Data analysis

All data collected were subjected to general analysis of variance (ANOVA) of the Genstat Computer Programme to test for the significance of the treatments. Means were separated using LSD at 5% probability level.

4.3 Results

4.3.1 Plant height

The height of rice plants was affected by variety (P<.001), season (P<.001) but not treatment (P>0.05). Across seasons, the plant height of rice cultivated during the first season (0.76 ± 0.04m) was statistically lower than that attained by rice that were cultivated in the second season (0.83 ± 0.04m). On the other hand, the height of K5 rice variety (0.89 ± 0.04m) was significantly higher than that of PR107 variety (0.71 ± 0.04m). Although rice plants from the AWD treatment had the highest plant height across seasons, it was not significantly different from the CD and CF treatments. Plant height was affected by the interactions between variety and season (P=0.002) but not between variety and treatment (P>0.05). In both seasons, the rice variety K5 had a significantly higher height than the PR107 variety (Table 6).

Table 6: The effect of variety on the height of rice plant after cultivation under different water management regimes for two seasons in Itek-Okile between 2021 and 2022

Season	Variety	Mean of plant height (m)
One	K 5	0.87 ± 0.04 a
(October 2021-Febuary 2022)	PR107	0.65 ± 0.03 b
Two	K 5	0.90 ± 0.04 a
(May 2022 -September 2022)	PR107	0.76 ± 0.04 b

For each season, means in rows followed by similar letters are not significantly different at a 5% probability level, LSD.

4.3.2 Number of tillers

The results of this study revealed that the number of rice tillers depended on the treatment (P=0.018), season (P<.001) but not on variety (P>0.05). The number of tillers produced in the first season (13.7 ± 2.4) was significantly higher than that produced in the second season (9.6 ± 1.7). For the treatment effects, the number of tillers produced under AWD (15.4 ± 2.4) was significantly higher than that of CD (10.2 ± 1.7) and CF (9.3 ± 1.6). The number of tillers, however, depended on the interaction between treatment and season (P=0.001) but not between variety and season or between variety and treatment (P>0.05). In both seasons, rice from the plots that received alternate wetting and drying water management regimes produced a significantly higher number of tillers than the other treatments (i.e. Continuous drying or Continuous flooding) (Table 7).

Table 7: The effect of treatment on the number of tillers of rice plant after cultivation under different water management regimes for two seasons in Itek-Okile between 2021 and 2022

Season	Treatment	Mean of number of tillers
One	AWD	15.45 ± 2.98 a
(October 2021-Febuary 2022)	CF	12.34 ± 2.04 b
	CD	13.17 ± 2.24 b
Two	AWD	15.34 ± 2.93 a
(May 2022 -September 2022)	CF	6.34 ± 1.08 b
	CD	7.17 ± 1.18 b

Treatment AWD = Alternate wetting and drying, CD = Continuous drying and CF = Continuous flooding.

For each season, means in column followed by similar letters are not significantly different at a 5% probability level, LSD.

4.3.3 Number of panicles

The number of rice panicles was affected by the season (P<.001) but not variety or treatments (P>0.05). Irrespective of variety and treatment, the overall number of panicles were (188.1 ± 3.2). However, the number of panicles depended on the interaction between variety and season (P=0.005). While the average number of tillers attained by K5 rice variety was significantly higher than that of PR107 in the first season, no statistical difference was observed between the two varieties in the second season (Table 8).

Table 8: The effect of variety on number of panicles of rice plant after cultivation under different water management regimes for two seasons in Itek-Okile between 2021 and 2022

Season	Variety	Mean of number of panicles
One	K 5	250.23 ± 4.24 a
(October 2021-Febuary 2022)	PR107	204.67 ± 3.48 b
Two	K 5	129.87 ± 2.21 a
(May 2022 -September 2022)	PR107	167.43 ± 2.85 a

For each season, means in rows followed by similar letters are not significantly different at a 5% probability level, LSD.

4.3.4 Grain yield

Overall, a grain yield of 4.4 ± 0.4 t/ha was attained over the two cropping seasons. Grain yield was neither affected by season nor variety or treatment (P>0.1597). However, rice grain yield depended on the interaction between variety and season (P=0.0055) but not between variety and treatment (P=0.8556) or season and treatment (P=8248). In the first season, the grain yield for K5 rice variety was statistically higher than that of PR107 (P=0.0196). In the second season, no statistical difference existed between the two varieties (Table 9) (P=0.2049). Although grain yield of rice harvested from the CD treatment had the highest grain yield across seasons, it was not significantly different from AWD or CF treatments (Table 9).

Table 9: The effect of variety on grain yield of rice plant after cultivation under different water management regimes for two seasons in Itek-Okile between 2021 and 2022

Season		Average grain yield for variety (t/ha)		Average grain yield for treatment (t/ha)
One (Oct. 2021 - Feb. 2022)	K 5	5.39 ± 0.48 a	AWD	4.43 ± 0.62 a
	PR107	3.69 ± 0.30 b	CD	4.81 ± 0.61 a
	-		- CF	4.38 ± 0.66 a
Two (May - September 2022)	K 5	3.88 ± 0.33 a	AWD	3.74 ± 0.36 a
	PR107	4.48 ± 0.29 a	CD	4.66 ± 0.38 a
	-		- CF	4.14 ± 0.40 a

For each season and variable, means in column followed by similar letters are not significantly different at a 5% probability level, LSD.

4.3.5 Weight of straw

The weight of rice straw was affected by variety ($P<.001$), treatment ($P=0.005$) and season ($P=0.0038$). The average straw weight of rice cultivated during the first season (5.04 ± 0.73 t/ha) was statistically higher than that attained during the second season (4.26 ± 0.62 t/ha). For the varietal effect, K5 variety (5.31 ± 0.77 t/ha) produced a significantly higher straw weight than PR107 (3.99 ± 0.58 t/ha). On the other hand, the weight of rice straw for CD treatment (5.55 ± 0.80 t/ha) was significantly higher than that of CF (4.04 ± 0.58 t/ha) and AWD (4.37 ± 0.63 t/ha) treatments. However, rice straw weight depended on the interaction between variety and season ($P<.001$) (Table 10). Whereas the rice variety K5 had a significantly higher straw weight than PR107 in season one, the weight of rice straw observed for PR107 was significantly higher than for K5 variety in the second season (Table 10).

Table 10: The effect of variety on weight of straw of rice plant after cultivation under different water management regimes for two seasons in Itek-Okile between 2021 and 2022

Season	Variety	Mean of straw weight (t/ha)
One	K 5	6.47 ± 0.93 a
(October 2021-Febuary 2022)	PR107	3.61 ± 0.52 b
Two	K 5	4.14 ± 0.60 b
(May 2022 -September 2022)	PR107	4.38 ± 0.63 a

For each season, means in column followed by similar letters are not significantly different at a 5% probability level, LSD.

4.4 Discussion

4.4.1 Plant height

Result showed that there was significant difference in plant height for variety, season and interactions of variety x season. Plant heights were more for K5 variety compared with PR107 for both seasons. Overall, higher plant heights were recorded during second than first season. Lower plant height during first season might have been attributed to higher temperature compared with that of second season (Fig. 1). A study by Schaarschmidt *et al.* (2020) discovered that plant heights were somewhat lower during the dry season than during the rainy season. Differences in plant heights between varieties was most likely as a result genetical make up, genetically, K5 is taller than PR107.

4.4.2 Number of tillers

From the result, there was a significant difference in number of tillers for treatment, season and interactions of treatment x season. Number of tillers were more with AWD followed by CD and finally CF treatment for all the genotypes across seasons. First season resulted into a greater number of tillers than second season for all the varieties. Overall, K5 produced more tillers than PR107. More tillers that were observed under treatment with AWD could have been as a result of higher temperature that triggered more tiller development than in treatment under continuous flooding. Increase in tiller numbers which were also observed during first season might have been as a result of increase in temperature in comparison with second season (Fig. 1). Research conducted elsewhere reported that higher temperature increased number of tillers in rice plant (Yoshida 1973; Bade 1985; Baker *et al* 1992). More tillers which were produced by K5 across the seasons probably was as a result of the genetical trait. Yoshida

(1981) asserts that the ability for tillering can be used to assess a rice cultivar's prospective production, this was the case with K5, which produced more grains than PR107.

4.4.3 Number of panicles

According to research findings, there was significant difference in the number of panicles for season and interactions of variety x season. Treatments with AWD recorded highest average number of panicles followed by CD and finally CF. Overall, average numbers of panicles were higher during first season. Higher number of panicles during first season was most likely as a result of increased in tiller numbers. According to Yoshida (1981), tiller numbers per plant determine panicle numbers which is crucial for grain yield. In contrast, PR107 produced more panicles yet K5 had more tillers. The reason could have been that some of the tillers were not productive since some of them could have died before flowering because of shading by other tillers. According to Ulzen *et al.*, (2022), increased tiller numbers in rice do not always equate to increased panicle development and ultimate larger grain yield. Generally, increase in grain yields of PR107 under treatment of AWD during second season was most likely linked to a rise in plant heights, tiller numbers and panicles numbers hence increase in straw weight. Increase in grain yield of PR107 under CD during second season can be explained by increase in plant heights which also accounts for increase in straw weights realised. Treatment with CF resulted in to increased PR107 grain yields during second season and this probably can be explained by increase in plant height and number of tillers which ultimately resulted in to increase in straw weights. Reduction in grain yields for K5 variety for all the treatments (AWD, CD & CF) during second season most likely could be clarified by reduction in tiller numbers and panicle numbers which also contributed to the reduction in weight of straw when compared with first season.

4.4.4 Grain yield

Our research result showed that there was significant difference in grain yield for the interactions of variety x season. Treatment with CD realized the highest average grain yield followed by CF and finally AWD. Overall, higher grain yields were realised during first season. According to our findings, treatment with AWD resulted into the highest number of panicles and tillers, which are key factors in determining grain yields. According to an experiment conducted by Sriphirom *et al.*, (2019), increase in rice yield under AWD was brought about by an increase in the number of tillers and panicles. Another study carried out by Maneepitak *et al.*, (2019) also confirmed that numbers of panicles was reported higher with AWD when compared with CF treatment. However, according to our experiment, the highest grain yields was not registered under AWD but with CD which had the highest straw/biomass. This might have been as a result of the reduction in percentage of filled spikelet per panicle. Grain yield according to Yang *et al.* (2008), Miah *et al.* (1996), and Laza *et al.* (2003), depend on the buildup of biomass and straw from heading to maturity as well as the transfer reserves to kernels that have been pre-stored before heading. Our research also showed that first season with higher temperature than second season yielded more grains. Yang *et al.* (2008) claim that in tropical irrigation circumstances, rice output fluctuates according to the planting season. In fact, according to Wang *et al.* (2016), dry season has a larger rice output than the wet season.

4.4.5 Weight of straw

Result showed that there was significant difference in weight of straw for variety, treatment, season and interactions of variety x season. Overall, treatment with CD registered the highest weight of straw followed by CF and finally AWD during first season. CD treatments that produced the highest weight of straw probably was as a result of higher temperature since the treatment depended entirely on natural precipitation which resulted into more tillers being produced. Number of tillers directly affects the weight of straw though may not necessarily affect grain yield since not all tillers produced are productive. This also justifies higher straw weights during first season than second season for all the genotypes. According to Wang *et al.*, (2016), the overall dry weight increased by 30% in treatments with higher temperatures. Higher average temperature, lower rainfall and lower relative humidity during first season in comparison with second season most likely contributed to higher straw weight realised during first season (Fig. 1). K5 generally produced high straw weights across seasons compared with PR107 and this could probably be explained by genetical attributes of each variety. CD treatments that registered the highest straw weight might have been attributed to highest temperature within the treatments since it depended solely on rainfall with no irrigation.

CHAPTER FIVE: SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary of the study

Introduction

The specific objectives of this study were to i) determine the effects of rice straw management on rice grain yields in Lira district, northern Uganda and ii) assess the effects of different water management regimes on rice grain yields in Lira district, northern Uganda.

A split plot experiment with three replications using a randomized complete block design was used to address both of the specific objectives. For the first specific objective, rice varieties made up the main plot, while rice straw treatment made up the sub plot. The rice varieties used for both seasons were PR107 and Namche 5. Treatments under investigation were RRI and RRR. For the second specific objective, the main plot was the rice variety while the sub plot was the different water regime. AWD, CF and CD were the three different water treatments and K5 and PR107 were the lowland rice varieties used during the two seasons. For all the experiments, data were collected on plant height (m), tiller numbers, number of panicles, grain yield (t/ha) and straw weight (t/ha)). All data collected were subjected to general analysis of variance (ANOVA) of the Genstat Computer Programme to test for the significance of the treatments. Means were separated using LSD at 5% probability level. The studies were conducted in Itek sub county- Lira district, northern Uganda during the second rainy season of 2021 and the first rainy season of 2022.

Summary of findings

For rice straw management experiment, significant reduction in plant heights, straw weight and grain yield during first season were realised. In fact, height of plants and grain yield were significant for the variety of rice used. Plant heights and number of tillers were significantly inhibited by straw incorporation. Our finding also revealed that yield difference for straw management options (RRI and RRR) was insignificant within the short period (two seasons).

For the experiment on water management regimes, significantly lower plant heights during first season where average temperatures were higher in comparison with second season were recorded. In fact, plant heights were higher in plants subjected to AWD. CD treatments produced the highest weight of straw. Indeed, more tillers were observed under treatment with AWD than in treatment under continuous flooding. Our findings also revealed that greater grain yield was realised during first season of which higher temperatures were recorded than second season. CD treatment resulted in to increase in grain yield than the CF. There was increase in grain yield during first season and promotion of greater dry matter during second season under AWD treatments compared to CF. Higher number of panicles were observed during first season. Additionally, numbers of panicles were higher with AWD treatment when compared with CF. Finally, we concluded that higher grain yields can be achieved without flooding rice fields.

5.2 Conclusions

This study's findings have demonstrated that;

1) Rice straw incorporation within a period of two seasons does not contribute significantly to the grain yield of subsequently planted rice.

2) Incorporation of rice straw in the soil increases %SOM, %SOC and %N content of the soil.
3) K5 performs better than PR107 under scarce water resource /dry season.
4) To obtain the highest grain yield, rice field does not need to be fully flooded.

5.3 Recommendations

In line with the findings, the following are recommended;

1) There is need to conduct a study to determine the exact time when rice straw incorporation can lead to maximum rice grain yield.

2) A study on effects of straw management on greenhouse gases emitted by rice plants should be conducted.

3) Due to looming water scarcity for rice production, farmers are advised to opt for K5 for higher grain yields as opposed to PR107 rice variety.

4) A study on effects water management regimes on greenhouse gases emitted by rice plants should be conducted.

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