PERFORMANCE OF RICE UNDER DIFFERENT CULTIVATION AND GROUND COVER PRODUCTION SYSTEMS IN LIRA DISTRICT, UGANDA

BY

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DECLARATION

I, Echaku Samuel, do hereby declare that this is my original work and has never been submitted to any University or institution of higher learning for any award.

Signed ………………………………………………

Date…………………………………………………

APPROVAL

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

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DEDICATION

This work is dedicated to my dear parents Mr. Echaku Odongo Samuel and Mrs. Anabo Janet, sister, brothers and Mr. Arubu Samuel.

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ABBREVIATIONS AND ACRONYMS

AEY:	Agronomic Efficiency
ANOVA:	Analysis of Variance
APEY:	Agro Physiological Efficiency
AQUASTAT:	Water Statistics
AREY:	Apparent Recovery Efficiency
AWD:	Alternate wetting and drying
DAE:	Days After Emergence
FAO:	Food and Agriculture Organisation
Fe:	Iron element
GCRPS:	Ground Cover Rice Production System
IRRI:	International Rice Research Institute
Kg ha^{-1}:	Kilogrammes per hectare
Kg:	Kilogramme
$KgKg^{-1}$:	Kilogrammes per Kilogrammes Nutrient
KgM^{-3}	Kilogrammes per cubic meter
m:	Metre
MAAIF:	Ministry of Agriculture, Animal industry and Fisheries
mm:	Millimetres
MWE:	Ministry of Water and Environment

N:	Nitrogen
NERICA:	New Rice for Africa
NUE:	Nitrogen Use Efficiency
P:	Phosphorus
PEY:	Physiological Efficiency
pH:	Potential of Hydrogen
RCBD:	Randomized Complete Block Design
SRI:	System of Rice Intensification
t/Ha:	Tonnes per Hectare
UBOS:	Uganda Bureau Of Statistics
UEY:	Utilisation Efficiency
USDA:	United States Department of Agriculture
WUE:	Water Use Efficiency
Z:	Difference between an observed statistic and its hypothesized population parameter in units of standard deviation
ZARDI:	Zonal Agricultural Research and Development Institute

ABSTRACT

In Uganda, most of the soil in rice-growing areas is deficient in nitrogen, as it is one of the nutrient elements important for plant growth. At the same time, crops are exposed to soil moisture deficiencies at critical stages of their growth, as over 90% of the country is prone to drought episodes. Moreover, majority of soils in rice growing areas are deficient in nitrogen. Therefore, this study was carried out to assess the performance of rice under different cultivation and ground cover production systems (GCRPS) in Uganda during the period 2021/2022. The matched pair and randomized complete block designs were used. The varieties used in the study were NERICA 4 and PR-107. The treatments assessed comprised upland versus lowland cultivation systems, ground cover rice production system (GCRPS)bare un-mulched, GCRPS straw mulched, GCRPS polyethylene mulched, and flooded rice systems. Data was collected on plant height, grain yield, straw yield, thousand-seed weight, and % N in rice grain and straw. All the data were analyzed using the GENSTAT statistical package version 14. There were significant differences for upland versus lowland cultivation systems ($P<0.05$) on the number of productive tillers per plant and thousand seed weight. Plant height, grain yield, and straw yield, were not remarkably different ($P<0.05$) generally, between the cultivation systems. The statistical analysis showed significant differences ($P<0.05$) between the flooded rice, GCRPS bare un-mulched and the mulched GCRPS. The ground cover rice production system had a remarkable ($P<0.05$) effect on grain dry matter production and water use efficiency in both seasons. Similarly, there was an increase in grain dry matter yield from the mulched plots during both seasons. Additionally, the highest total N uptake and %N concentration during the two seasons were recorded from the mulched treatments compared to the un-mulched treatments. The GCRPS polyethylene mulched system had the highest nitrogen use efficiency among mulched plots. Overall, the use of GCRPS led to 76% and 84% water savings during the first and second seasons, respectively. Whereas the mulched GCRPS systems together with applied fertiliser improved water and N use efficiencies, respectively. Therefore, the mulched GCRPS systems can be an effective counter against low dry matter yields in N nutrient deficient soils and a declining water resource that cannot support efficient rice production.

CHAPTER ONE: INTRODUCTION

1.1 Background of the study

Rice (*Oryza sativa* L.) is a food staple primarily and a necessity for over fifty percent of the global populace (IRRI, 2010). According to FAO (2021), over 100 nations grow rice on 162.06 million hectares of land worldwide. However, all the ten largest rice-producing nations on the entire globe are located in Asia, apart from Brazil (Table 1). Rice production levels in East Africa are as follows Tanzania 1,848,000 MT, Kenya 122,465 MT and Uganda which produces up-to 350,000 metric tons (MT) of rice annually on approximately 178000 Hectares (Ha) (Hong *et al.*,2021; UBOS, 2020). In Uganda, rice is ranked as the fourth most important crop among the cereals (Akongo *et al.*, 2017; UBOS, 2017). Accordingly, rice has developed into a key rural source of income and urban staple food in Uganda (MAAIF, 2012; Bua & Ojirot, 2014). According to UBOS, (2017), much of Uganda's rice crop is grown in the eastern and northern regions, which account for 47.9 and 34.4% of the nation's total arable land, respectively. However, Apac, Lira, and Gulu districts, continue to be important rice-growing areas in the northern region (Akongo *et al*., 2017).

Globally, rice production is impacted by a myriad of challenges but climate variability, scarcity of good quality water, salt stress, insects attack, diseases, plant tissue nutrient imbalances and soil nutrient deficiencies are the broad constraints affecting rice cultivation (Fahad *et al.*, 2019). Although, improved rice varieties such as New Rice for Africa (NERICA) namely 1, 4 and 6 and SUPARICA namely 1 and 2, are widely used owing to the ability to withstand

and even thrive in the face of significant biotic and abiotic challenges, particularly pests, diseases, and drought (MAAIF, 2015). However, climate change and unpredictable weather characterized by variable weather patterns especially water scarcity, delayed onset of planting seasons, and rise in average temperature, along with nitrogen deficiency are still limiting production of rice (Rowhani *et al.*, 2011; Akongo *et al.*, 2017).

Table 1:Top ten global rice producers (2019-2020)

S/N	Country	Production (MT)
1	China	193,700,000
2	India	142,400,000
3	Indonesia	54,800,000
4	Bangladeshi	42,100,000
5	Vietnam	36,600,000
6	Thailand	29,600,000
7	Myanmar	24,700,000
8	Philippines	15,020,000
9	Japan	11,300,000
10	Brazil	11,200,000

Source: FAO, 2021

Despite, rice production increasing by over five hundred percent in Africa, it was constant at 3.5% in South America. Moreover, some major rice-producing nations have experienced plateauing in yield and production potential for years regardless of rising demand from people living in poverty (Bin Rahman & Zhang, 2022). According to Van Nguyen & Ferrero, (2006) in order to accommodate the worldwide growing population in rice-consuming countries, global rice production systems must raise rice production by 50% by 2030 to concurrently meet the rice demand of the growing populations.

Currently, finding appropriate solutions for significant problems like issues with increasing scarcity of water, increased nitrogen application rates causing nutrient pollution of water bodies, and improvement of rice yield are the key challenges facing the research and production in rice globally (Prasad *et al*., 2017). In Uganda, rice is grown primarily in swampy areas, either transplanted or direct seeded into the soil depending on the amount of precipitation intensity. However, upland rice cultivation system is commonly being practiced in areas which are not extremely inundated (MAAIF, 2012). Consequently, in the face of scarcity of resources such as water and soils with sufficient nitrogen, the flooded rice system is dwindling in popularity in favor of the aerobic rice systems which possess increased input use efficiencies marked by low amounts of water used by rice plants to produce a kilogramme of rice grain and less N fertiliser required to increase grain yield (Farooq *et al.*, 2023). Besides, the aerobic systems such as alternate drying and wetting system have shown reduced nitrogen-use efficiency apart from the Ground cover rice production systems (Farooq *et al.*, 2023*;* Shi *et al.*, 2019*).*

The ground cover rice production system (GCRPS), a relatively new idea, is becoming more popular in Asia, especially in China due to its capacity to decrease water demand, increase nitrogen use efficiency, improve crop growth and yield, and lower the release of greenhouse gases from fields of rice (Qu *et al.,* 2012; Guo *et al*., 2020). Furthermore, Zhang *et al.* (2017) demonstrated that alternative biodegradable film could also improve N uptake and growth rate from panicle initiation to maturity. In fact, Ren *et al.* (2023) noted the tendency of the GCRPS to improve crop growth and yield under stress conditions of drought, early low-temperature stress and low rainfall, respectively. Currently, there is little information available about the GCRPS's potential to increase rice grain yield while also increasing the efficiency of water and nitrogen use in Uganda. Therefore, this study was conducted to assess how well rice performed under different rice cultivation systems including the ground cover rice production system in Lira district, northern Uganda.

1.2 Statement of the problem

Rice is a significant staple food both globally and in many sub Saharan African countries including Uganda. Despite, rice farming having been done traditionally for a long time with a yield potential of 5 t/ha, rice productivity under farmer's field conditions in many parts of the country including Lira district, northern Uganda has remained averaging low at 1.7t/ha (Okello *et al.,* 2019). The inherent low yield may be attributable to a number of factors including reliance on rain-fed agriculture to cultivate crops and growing rice on Nitrogen (N) deficient soils. The variability in precipitation experienced in rain-fed agriculture in Uganda has led to water scarcity occurring at critical stages of crop development (MWE, 2013), while at the same time soil fertility has been shown to be declining with nitrogen the most limiting nutrient for rice production in many areas of Uganda (MAAIF, 2009; Wanyama *et al.*,2015). Kitilu *et al. (*2019) simulated drought events during vegetative and reproductive phases which led to 26 - 36% grain yield reduction in upland rice varieties and 38 - 46% reduction for lowland varieties during the same stress period resulting in decreased plant height, shoot dry weight, number of tillers, grain yield and 1000 grain weight. In addition, low use of fertilisers along with lack of credit, pest and disease attacks and inefficient water use & high evapotranspiration rates due to high temperatures among others (Defeng *et al.*, 2010:Dossou-Yovo *et al.*, 2022), have further decreased rice grain yields in Uganda as evidenced by a low national average yield of 2800kg/ha compared to the world average of 4700kg/ha (FAO, 2021). Therefore, the predicted worsening of drought and decline in soil fertility in Africa, constitutes a great threat to rice production and productivity, for millions of lives, especially in poor areas, were rice constitutes a staple (Shiferaw *et al.*, 2014:Dossou-Yovo, et al., 2022). Consequent to reduction in grain yield will increase if no measures are taken to mitigate the effects of drought and declining soil fertility. There is need to test appropriate measures such as mulching, fertilizer application and use of different rice cultivation systems (Guo *et al.*, 2020) to ameliorate the effects of low precipitation causing water scarcity and the accompanying nitrogen deficiencies in soils of Lira district, northern Uganda.

Therefore, the ground cover rice production system (GCRPS) has been shown to be an effective and efficient choice for reducing crop water demand. The system entails mulching of rice plants, application of water through furrows running at one metre intervals along the periphery of whole fields, enclosing raised rice beds and application of fertilisers, in reality, it encourages resource efficiency by minimizing seasonal input costs like weeding. It also indirectly reduces greenhouse gas emissions (Liang, *et al.*, 2019). However, there is scarce information about GCRPS and it’s potential to improve rice water & N use efficiency and grain yield in Uganda.

1.3 Objectives of the study

1.3.1 General objective

To understand how the different rice cultivation systems and the Ground cover rice production system significantly influence the performance of rice in Lira district.

1.3.2 Specific objectives

1. To assess the performance of rice under different cultivation systems in northern Uganda.
2. To determine the effects of GCRPS on water saving and nitrogen use efficiency in Lira district.

1.4 Hypotheses

1. Rice cultivation systems significantly influences the performance of rice cultivars.
2. Ground cover rice production systems have the synergistic effects of water saving and nitrogen use efficiencies in rice.

1.5 Significance of the Study

In Uganda, most of the soil in rice growing areas is deficient in nitrogen, and crops are exposed to soil moisture deficits at their critical growth stages (MAAIF, 2009; MWE, 2013; Wanyama *et al.,* 2015).

Therefore, the assessment of the performance of different rice cultivation and ground cover rice production systems will inform stakeholders in the rice industry on the best cultivation system to use for enhancing rice grain yield, water & nitrogen use efficiency, and enable policy makers make the most appropriate decisions concerning cultivation system to use in the region and other similar areas. The results of this study will benefit extension workers by providing relevant options to northern Uganda farmers regarding rice production. The study will also provide a justification for resource allocation for improving the rice industry.

1.6 Scope of the study

The research was done at Itek-Okile irrigation scheme at Itek sub-county, Ayel parish, Lira District, northern Uganda**.** Itek is one of the sub counties in Lira district known for rice growing. The sub county is bordered by Alebere in the east, Abolet B in the north, Aduku to the west and Amach to the south (Lira District| Local Government, 2015). The study was conducted during the period October 2021 and July 2022.The study focused mainly on assessing the performance of rice cultivars from different cultivation systems and ground cover rice production systems in Lira district, northern Uganda.

1.7 Limitations

During, the study the following were encountered:

1. Delayed start of the experiment due to COVID-19 restrictions.

2. Long distance to the experimental field site from the location of equipment for data collection at Itek-Okile irrigation scheme was expensive and inconveniencing in terms of time and transport.
3. Destruction of the experiments by stray cattle looking for pasture and water.

1.8 Delimitations

The above limitations were counteracted as follows:

1. Setting up the experiments immediately after the COVID 19 restrictions were eased.
2. Staying near the experimental site.
3. Planting a guard rows/ protective strip of vegetables and erecting a temporary thorn bush boundary around the experiments.

CHAPTER TWO: LITERATURE REVIEW

2.1 Rice cultivation systems

The types and purposes of rice cultivation systems vary depending on the availability of water resources, soil, fertiliser and planting techniques, respectively. According to Haider *et al*. (2022), there are four main types of rice cultivation systems namely; irrigated lowlands, rain-fed lowlands, irrigated (aerobic) upland, and upland, respectively. However, there are variations in rice cultivation systems occasioned by the differences in access to water resources (Shin *et al*., 2003; Ramesh & Rathika, 2020). Moreover, organic and conventional rice cultivation techniques have also evolved from the already existing traditional systems. Interestingly, these use various methods for managing the soil, with the sources for rice crop nutrients also influencing these approaches (Adigbo *et al.*, 2007; Abduh *et al.*, 2020).

2.2 Types of rice cultivation systems

2.2.1 Irrigated and rain-fed lowland rice cultivation systems

Globally, in some countries lowland rice is rotated with wheat (Jin *et al.*, 2021). According to (GRiSP, 2013), about 52 million hectares of rain-fed lowlands rice provide almost 25% of the world’s rice production. Additionally, 93 million hectares of irrigated lowland rice produce three quarters for the worldwide rice (GRiSP, 2013). However, the primary factor controlling the lowland rice cultivation system is the method of water applications, which can either be natural precipitation or irrigation. For instance, the bunds are used in the lowland rice cultivation system to regulate the inflows and outflows of water in the fields. Flooding is mostly used to manage weeds and make sure the rice plants receive enough water. When flooding rice, the water level is initially held at 3 cm rising to 7–10 cm before the harvest time approaches (IRRI, 2023).

However, rice planting methods in the lowland cultivation systems vary with transplanted rice being the most common though the direct seeding is also becoming an important practice of planting rice. In fact, Haider *et al*. (2022), has demonstrated the popularity of the method because the rice crop establishes quickly and reach maturity earlier compared to the transplanted rice plants. When using, the transplanting method, seeds are usually planted in seed trays or on wet-beds near the rice fields and later transplanted when it is between one to 3 weeks after sowing. During transplanting, rice seedlings are normally uprooted and transplanted to the main rice fields (Pasuquin, Lafarge, & Tubana, 2008). However, for direct seeding, seeds are planted in furrows between 10 – 15mm deep in the field and lightly covered with soil (IRRI, 2023). Accordingly, when rice seeds are planted in fields with dry conditions, it is called dry direct seeded rice, meanwhile if seeds are sown in wet prepared rice fields then this is called wet direct seeding of rice. However, the yields obtained from lowland rice cultivation systems are usually higher (GRiSP, 2013).

2.2.2 Upland rice cultivation system

It has been reported that about 15 million hectares of upland soils account for 4% of the global rice production (GRiSP, 2013). Accordingly, the upland rice cultivation systems mainly comprise of rice farmed in fields without superficial water collection on rain-fed, naturally well-drained soils. In this system, rice seeds are broadcast, drilled and/or dibbled into unsaturated soils before the emergence of rice plants (JICA, 2012). However, the upland habitat is considered prone to drought, typically comprised of sloping ground with erosion issues, and home to soils with deficient physical and chemical qualities (IRRI, 2023). According to Saito *et al*. (2018), the area under upland rice systems has expanded by one million hectares in Africa compared to the other continents. In fact, on average one ton/ha of rice is harvested from this system globally (GRiSP, 2013).

2.2.3 Irrigated aerobic or upland rice cultivation system

The aerobic rice cultivation system relies on direct seeding of rice into unsaturated and un puddled soil with the aim of maximising water savings and cutting down on labour and greenhouse gases' emissions (Kato & Katsura, 2014). Accordingly, it has been demonstrated that the aerobic cultivation system produces rice yields that are comparable to the lowland cultivation system. However, the lowland rice cultivars are capable of producing higher yields of 4-6 t/ha as opposed to the aerobic rice varieties grown under the aerobic cultivation system (Atlin *et al.,* 2006). Although, aerobic rice cultivation faces difficulties such as weed infestations and micronutrient deficiencies such as zinc in marginal soils, it has shown consistency in being able to produce high yields (Gao *et al.*, 2006).

The aerobic rice culture would be a technically viable option to alleviate the already worsening global water scarcity which is predicted to become severe by 2025, making it more difficult and challenging to manage the available water. (Sing *et al.,* n.d). Therefore, in aerobic rice culture, the rice crop is subjected to normal unsaturated conditions similar to those applied to other cereals like maize or sorghum (Mahapatra *et al.,* 2021). Surface irrigations are provided as necessary with accompanying intensive agronomic practices. In fact, savings on water requirements has been reported to vary from 30 - 50% less compared to that for flooded rice. In addition, supplementary irrigation can be applied as and when need arises just like in other upland cereals (Wang *et al., 2002;* Bouman *et al.*, 2005;). The aerobic rice cultivation system has been manipulated to suit the water and fertiliser resources availability based on the basic principles such as direct seeding, applying and maintaining water at merely field saturation and utilisation of best management practices along with use of compost, farm yard manure or vermicomposting respectively (Jana *et al.,* 2018). Consequently, the three major variants have arisen from the continued practice of the aerobic cultivation system namely, ground cover rice production (GCRPS), system of rice intensification (SRI) and alternate wetting and drying system (AWD) (Lal *et al*., 2013; Kato & Katsura, 2014).

2.2.3.1 The major approaches to aerobic rice cultivation

2.2.3.1.1 Ground cover rice production systems

The ground cover rice production system (GCRPS) has essential components which include the use of raised beds to aerate soils in which rice seeds or plants are dibbled or transplanted with the goal of maximising root development. Moreover, either plastic or organic mulch is also applied with aim of conserving water available and increasing water available for rice growth which subsequently increases rice yield (Shi *et al.*, 2019). Thus, the GCRPS has been reported to result in water savings of between 61 - 81% compared to the flooded rice production system (Jin *et al.*, 2016). According to Qu *et al.* (2012), the GCRPS is highly stable and adaptable in high clay soils, as yield differences were remarkably decreased during a seven-year period. Overall, the GCRPS is based on principles such as 1) directly seeding or transplanting of 14-day old seedlings, 2) using of mulch to cover the soil, 3) addition of chemical or organic fertilisers and 4) planting rice on raised beds.

2.2.3.1.2 System of rice intensification

The system of rice intensification (SRI) is based on agroecologically sound methods that improve rice-growing (Dobermann, 2004), especially on soils which are chemically low in pH, CEC, available P and have high concentrations of soluble Fe and Al (Oldeman, 1990). According to Uphoff (2002), this framework is expected to increase rice field production based on 1) nurturing seedlings in highly controlled nurseries, 2) cautious transplanting of solitary, young seedlings (8–15 days old) at wide planting density (commencing at 25x25 centimetres, and yet steadily rising to 50x50 centimeters), 3) infrequent irrigation to prevent lasting flooding during the vegetative growth phase, and 4) supplying nutrients to the soil especially in natural form like compost, farm yard manure and or vermicompost instead of synthetic fertilizers. However, when the best practices are followed, this technique has been proven to produce 10 to 15 tonnes / ha grain yield (Rafaralahy, 2002).

2.2.3.1.3 Alternate wetting and drying

Alternate wetting and drying (AWD) is primarily based on the infrequent application of water to rice fields with the aim of eliciting dry soil conditions in wetland soils which cause improved root growth due to aeration and improves general rice plant growth (FAO, 2013). According to Ishfaqa *et al*. (2020), this system was developed as an ecologically friendly water saving technology used to improve rice grain yields in areas with scarce or limited water resources. The AWD consist of light flooding during the first two weeks after seeding or transplanting to help seedlings recuperate from transplanting stress and to reduce weed emergence. During inflorescence initiation to flowering end should have a light coating (2–3 centimetres) of stagnant water since this time phase is particularly prone to water shortages. All the other growth phases should have an infrequent wetting and drying cycle (Bouman *et al*., 2006;Liang *et al.*, 2013;Yang *et al.*, 2017). However, irrespective of its advantages, this system suffers from challenges of micronutrient deficiencies and weed infestations due to relatively long periods of un-submerged soil surfaces and dry drained soil conditions (Rong-li *et al.*, 2012;Pandey, et al., 2020).

2.3 Effects of aerobic rice cultivation systems on nitrogen use efficiency (NUE)

Due to the uncertainty of weather, it is necessary to use agronomically important methods, specifically output systems and management strategies to increase rice productivity. According to Ishfaq *et al*. (2020), aerobic cultivation systems improved the total N uptake in comparison to transplanted rice (42%), agronomic NUE (15.8 Kg grain/Kg) and apparent recovery efficiency (22.5%). Similarly, alternate wetting and drying has been shown to improve N use efficiency (26kg grain/kg N), physiological efficiency (53 kg/kg) and apparent recovery efficiency (49%) (Thind *et al.*, 2017). However, for a paddy variety grown in mulched and aerated soil, a slightly lower NUE (39.4 Kg/Kg) was found for soil kept at 80% moisture level compared to soil at saturated moisture level with 150 Kg N/ha applied (Liang *et al*., 2019). Kato & Katsura (2014) indicated that there have been attempts to breed specialised aerobic rice types that are suited to high production rates in unsaturated soils, and that these crosses have included (*Oryza sativa x indica*) variants as well as others. Interestingly, lowland rice cultivars have exhibited better seed yield, water use efficiency and nitrogen utilization efficiency for grain production (NUE) in systems of aerobic rice production than upland varieties by 26.9%, 14.6%, and 26.6%, respectively (Liu *et al.,* 2019). Therefore, aerobic rice cultivation system generally demonstrates the possibility of improving responses to N fertilisation with high water use efficiency (Maragatham *et al*., 2010)**.**

2.4 Effects of factors affecting the system of ground cover rice production on rice cultivation practices.

The deploying of different rice varieties, cultivation systems, water & irrigation methods and fertiliser application practices on rice fields are highlighted below.

2.4.1 Varietal effects

In aerobic rice cultivation systems, the potential yield has been shown to be about 11t/ha in temperate climates with the majority of rice cultivars being lowland types (Kato & Katsura, 2014). For example, in Brazil, a cross between *Oryza indica x japonica* measured 90-100 centimetres tall and yielded 6 t/ha

(Pinheiro, 2006). However, in China, a cross of upland and lowland *cultivars* was found to be shorter than the upland parent but comparable in yield to those reported in Brazil (Wang *et al*., 2002).

2.4.2 Cultivation effects

The use of the aerobic cultivation systems has been shown to increase the incidence of the rice blast disease which is associated with growing non adapted lowland rice varieties in upland drought prone aerated soils (Puntener, 1981). For example, subsequent research, in the USA showed increased rice infection by blast disease caused by *Magnaporthe oryzae* especially on irrigated lowland rice cultivar in upland soil (McCauley, 1990). Furthermore, rice grown in the aerobic systems suffer intense effect of weed infestation, increased attack by rodents which dig up and eat seeds easily. In fact, the damage by insect pests especially borers have been reported to be more severe in aerobic systems than the lowland systems (Saito *et al.*, 2006). However, the GCRPS a variant of the aerobic rice cultivation system, relies on covering the soil with either plastic or organic mulch which stops weed growth thereby greatly reducing the cost of labour for weeding and also ensures more fertiliser uptake by rice plants rather than weeds (He *et al.,* 2013; Ishfaqa *et al.,* 2020).

2.4.3 Water management effects

The GCRPS, which uses either plastic film or straw mulch along with rice beds kept at a moisture level of 70 to 80 percent, reduces water consumption of lowland rice, while increasing the grain amount produced per 1000 litres of water applied to fields of rice (Dittert *et al*., 2002). According to Xu *et al*. (2015), direct sowing, use of drought resistant and early maturing rice cultivars shortens the duration of flooding hence increases water savings from lowland rice systems. Therefore, the overall effect of the GCRPS is an increased water use efficiency (Jin *et al.*, 2016). Overall, the GCRPS can mitigate water challenges in comparison to conventional flooded rice production by decreasing the water demand for rice plants (Tao *et al.*, 2014).

2.3.4 Fertilizer management effects

Shi *et al*. (2019) reported that the GCRPS boosts rice grain yields by 50% with 36% less N and 30% higher N use efficiency when rice is planted on raised beds and mulched with polyethylene or straw. According to Tao *et al.* (2014), GCRPS improved yields by 3% over the flooded rice system with an average grain yield of 6.87 t/ha, when coupled with application of either urea or chicken manure fertiliser.

CHAPTER THREE:

PERFORMANCE OF UPLAND RICE VARIETY IN LOWLAND AND UPLAND CULTIVATION SYSTEMS

3.1 Introduction

Traditionally, lowland ecosystems have been the home of rice production offering a stable water and nutrient supply, respectively. However, lack of water, greenhouse gases emissions, pests and diseases infestations are known to negatively impact rice production globally (Rao *et al.*, 2017; Ramesh & Rathika, 2020). Hence, with the variability and change in climate, rice production is expected to further decline due to a host of production constraints including lack of water, deterioration of wetlands, competing uses of upland and lowland ecosystems, ravages of pests and diseases, competition from weeds, greenhouse gas emissions, availability of water to support proper plant development in the ecosystem and changing social habits among others (Defeng *et al.*, 2010;Reynolds *et al.,* 2015; Prasad, Shivay & Kumar, 2017; Dossou-Yovo *et al.*, 2022). Additionally, rice production *per se* has also been blamed for accelerating environmental degradation through cultivation of unsuitable land parcels. Accordingly, new technologies and a greater understanding of the rice ecosystems would contribute to more effective and sustainable production and water management in rice fields (Nawaz *et al.*, 2022). Accordingly, this calls for shifts in production practices and new environmental conditions that farmers may adopt to cope with the changing climate. For instance, the selection of high yielding rice varieties that are resilient to moisture stress, acceptable to the consumers and improved rice production systems for sustainable use that can cope with changing climate conditions is mandatory (Shiferaw *et al.,* 2014). Indeed, high yielding rice varieties developed in Asia have been demonstrated to contribute to the achievement of Millennium Development Goals (MDGs) because of the increase in production of up to 86% (Zeigler., 2007; FAO, 2021). However, in Uganda, although, the New Rice for Africa varieties has gained popularity in northern Uganda, the varieties have never been evaluated under different cultivation systems with emphasis on drought resistance or tolerance. Therefore, the objective of this study was to assess the performance of NERICA 4 rice variety in upland and lowland cultivation systems in Lira district.

3.2 Materials and Methods

3.2.1 Study area

The study was conducted between October 2021 and April 2022 in Itek-okile, Lira district. The area was chosen due to its importance as one of the major rice-growing areas in Lira district, northern Uganda (Akongo *et al*., 2017). Itek-okile is one the 5 sub counties in Lira district. Itek-okile consists of Ober, Olilo, onywako, Abunga, Alebere, Ayira parishes but the study was conducted in Ayel parish in a farmers' field (Lira District Local Government, 2015). The coordinates for the study site are; $02^{0}.11^{\prime}\,55.4^{0}$N $033^{0}05^{\prime}\,21.3^{0}$E. The annual rainfall distribution over the two seasons (March-June) and (August-December) are 644 mm and 605mm, respectively (Figure 1) (AQUASTAT). The area is characterised by the moist and sub-humid climatic conditions

(Kumakech *et al.*, 2014). The annual temperature ranges between 30 and 18.29 degrees Celsius, respectively. The soils are sandy loam in texture (USDA soil classification system) (Otim *et al.*, 2015).

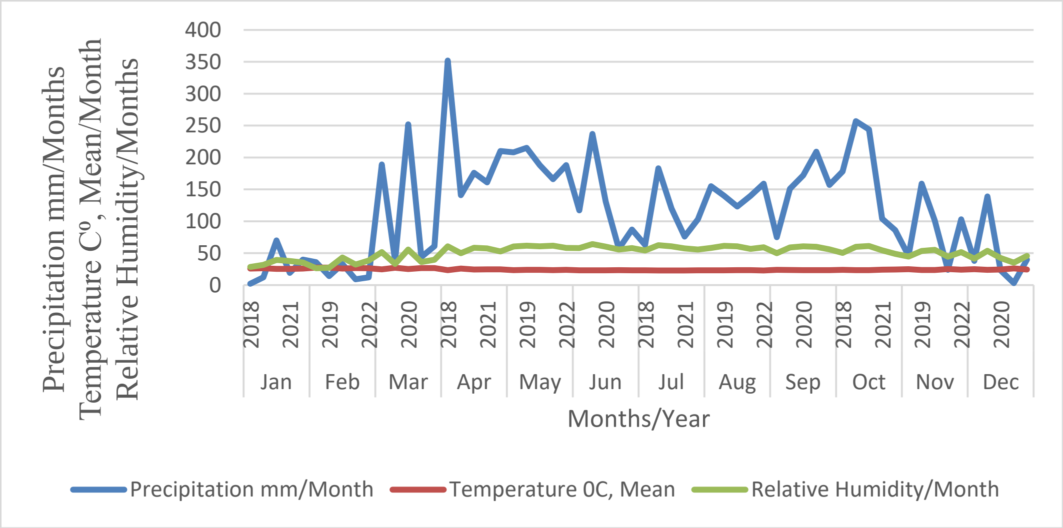

Figure 1:Precipitation mm, Temperature ℃, Mean and Relative Humidity per month five years 2018 - 2022 retrieved from AQUASTAT information tool for Ngetta ZARDI, meteorology station Lira.

3.2.2 Soil characterisation

Soil sampling was accomplished using the zig-zag method in which soil samples were randomly retrieved from cores in the top 0–20 cm of the field, bulked into a plastic bucket, and thoroughly mixed to form a composite sample from which one kilogramme was picked and taken to Kyambogo University for laboratory analysis (Faithfull, 2002;Imakumbili *et al.*, 2022). Soil physical and chemical properties were determined as shown below.

The physical feel approach was used to determine the soil texture by physical investigation as described by Moorberg & Crouse, (2021) whereas pH was determined on a 1:2 water suspension and organic matter was determined by dry combustion at 400 ^{0} C (Faithfull, 2002). Potassium and phosphorus in soil was measured using a flame photometer and the Bray 1 method, respectively. Meanwhile, total soil nitrogen was determined by Kjedhal method (Seki,1990).

Table 2: Soil physical and chemical characteristics of farmers field in Itek sub-county, 2021/2022

Soil sample	pH	OM (%)	Total N (%)	P (%)	K (%)	Soil Texture
First season (October 2021-February 2022)						
	5.48	5.5	0.08	0.15	2.89	Clay
Second season (May-September 2022)						
	6.03	7.5	0.03	0.22	2.04	Clay
Critical levels	5.6	3	0.20	0.0015	0.0133	-

3.2.3 Experimental design

The experimental design used was a matched pairs design comprised of two groups upland and lowland cultivation systems with a total of six plots per group for both seasons, respectively (Siebert & Siebert, 2018). The Wilcoxon matched pair sign rank test was chosen as it is able to test for a difference in the mean (median) of paired observations which do not meet the assumption of being normal (Siebert & Siebert, 2018). The rice variety NERICA 4 was selected based on its relative popularity among the smallholder farmers in northern Uganda including moderate tolerant to drought stress, adaptation to low phosphorus tolerance and early maturity (MAAIF, 2015). The experiment contained plots with dimensions 1.8 m x 2.5 m (4.5 m^2) and alley between plots measured 0.5m and one metre between the blocks while the area covered by the experiment was 39.1m^2 (Gomez, 1972;Fageria, 2007) (Figures 2 and 3).

Figure 2:NERICA 4 rice variety under lowland cultivation system at Itek-okile, 2021/2022

Figure 3:NERICA 4 rice variety under upland cultivation system at Itek-okile, 2021/2022

3.2.4 Field management

A number of field management practices were undertaken during the experimental period namely,

Ploughing was carried out on 7/10/2021 for season one and 28/4/2022 for second season, using ox-plough before the land was levelled and the experimental plots were marked out ready for planting. A main levee was constructed enclosing the whole experimental plots but with an inlet and outlet to allow water in and out of the experimental area (Tokedo *et al.*, 2019). This exercise was done on 10/10/2021 and 2/5/2022 for season one and season two, respectively. The individual experimental plots were also separated by levees except for the upland plots. Prior to planting the experimental area was drained on 12/10/2021 for season one and 2/5/2022 for season two, respectively. Thereby, the rice seeds were dibbled direct into the soil for all the plots.

Planting was done on experimental plots which were marked out to show their dimensions, after which the inter row spacing of 0.3m was marked at the opposite ends of the experimental plots across their length. Four rice seeds were then planted along the intra row for each hole at a spacing of 0.15m. Planting was done on 14/10/2021 and 06/05/2022 for first season and second season, respectively. Two weeks after germination, thinning was done leaving two seedlings per hill (Archibold, 1990).

Weeding was done four times, starting from 14 days after germination and continued at a monthly interval until physiological maturity (MAAIF, 2015). For season one, the weeding was done on 10/11/2021, 15/12/2022, 5/1/2021 and 20/1/2021, respectively. Whereas for season two it was done on 18/6/2022, 2/7/2022, 15/7/2022 and 26/8/2022, respectively. Weeding was generally done using hand hoes coupled with uprooting of weed plants for both lowland and upland rice.

3.2.3 Data collection

Data collection commenced on 89 days after emergence (DAE) for season one and 92 DAEfor season two, respectively. The different data collected during the two seasons are highlighted below:

3.2.3.1 Germination counts

The counts for germination were done in the laboratory as Seeds were sampled from the middle of the container holding them and the sides of the container to get a representative sample of 100 seeds which were placed on top of two layers of toilet tissue paper and the seeds were wetted with a sprinkle of clean water and the seeds were covered with tissue paper, the seeds were checked every two days to check for moisture, after which at 10 days 89 seeds had germinated. The germination percentage was computed by dividing the number of germinated seeds by the total number of seeds tested after which it was multiplied by 100 to get a germination percentage of 89 percent for season one while for season two the germination percentage was 92 percent for NERICA 4 rice variety (IRRI, 2023).

3.2.3.2 Plant height

This was measured by taking the distance between the ground level and the highest leaf's tip of the selected rice plant. A total of 5 plants were randomly selected at time of height measurement and this was accomplished at 89 days after planting for season one and 92 days after planting for season two (Fageria, 2007).

3.2.3.3 Number of productive tillers per plant

The number of productive tillers per plant for lowland versus upland cultivation systems were recorded at 89 days after planting for season one and 92 days after planting for season two. and only the tillers with panicle heads were considered. Five rice plants were selected randomly for each plot at two weeks before harvest (Gomez, 1972;Fageria, 2007).

3.2.3.4 Rice grain yield

The mature rice was harvested by cutting the rice stalks from the two middle rows of each plot which is equivalent to one square meter of the treatment plot (Gomez & Gomez, 1984). The rice stalks with the grain attached were immediately placed on a tarpaulin and threshed by beating the rice panicles upon a piece of wood after which the grain was gathered together and winnowed to clean all foreign materials ready for storage into a polythene bag, which had a tag marked with the treatment name and code. Harvesting for the first and second season was done on 25/1/2022 and 20/8/2022, respectively. Each of the rice stored in polyethylene bags from the different plots were sun dried daily on the tarpaulin separately to avoid mixing until the constant moisture level of 14% was attained. The grain was then transported to Kyambogo University soil science laboratory for weighing. Grain from each treatment was weighed separately using a laboratory beam balance and weights recorded before the grain yield per square metre was computed and converted to kilogrammes per hectare as described by Sapkota *et al.* (2016*).*

3.2.3.5 A thousand seed weight

The 1000 seed weight was taken by shaking thoroughly a storage bag containing dry rice grain to mix rice seeds and seeds were scooped from the bag of which 100 seeds were counted manually for each treatment, this was repeated until 1000 seed count was reached after which the seed weight was measured using a laboratory beam balance and recorded. This process was repeated for each treatment, until all treatment a thousand seed weights were measured (Gomez, 1972; Fageria, 2007).

3.2.3.6 Rice straw yield

The rice straw was harvested by cutting the rice stalks from the two middle rows of each plot which is equivalent to one square meter of the treatment plot. Harvesting for the first and second season was done on 25/1/2022 and 20/8/2022, respectively. After removal of rice grain by threshing, the straw was tied in bundles and placed on drying racks in a room. Air drying was done until the straw attained 14% moisture content (Faithfull, 2002). The straw was then transported to Kyambogo University soil science laboratory were each treatment was weighed using a laboratory beam balance and weights were recorded before the straw yield per square metre was converted to kilogrammes per hectare.

3.2.7 Data analysis

Prior to analysis, all the data was examined for normality. Data found to be non-normal was subjected to wilcoxon matched pair sign rank non-parametric test to determine the level of significance of the difference between the treatment groups following the procedures of Siebert & Siebert (2018).

3.3 Results

3.3.2 Comparison of upland and lowland cultivation systems

3.3.2.1 Influence of upland and lowland cultivation systems on growth parameters.

The results of the Wilcoxon Sign-rank test indicated that there was a non-significant small difference between Lowland (Median = 84.1, sample size = 6) and Upland rice cultivation systems (Median, Mdn = 80.8, Sample size, n = 6), Wilcoxon sign rank difference, W+ = 4, p = .219, Effect size, r = -0.5 for plant height. Also, results of the wilcoxon sign-rank test indicated that there was a significant large difference between Lowland (Mdn = 15.6, n = 6) and Upland cultivation systems (Mdn = 11.8, n = 6), W+ = 0, p = .031, r = -0.9, for number of productive tillers per plant (NPP). However, results showed the plant height and number of productive tillers per plant increased consistently for first and second season in the lowland cultivation system over the upland cultivation system. (Table 3).

Table 3:Mean values for plant height and number of productive tillers per plant comparison between upland & lowland rice cultivation systems

	Plant height (PH) (m)	**Number of productive tillers per plant (NPP)**
First season (Oct 2021-Feb 2022)		
Upland cultivation system	0.74±0.44	10.9±0.48
Lowland cultivation system	0.84±0.66	15.3±0.43
Second season (May-September 2022)		
Upland cultivation system	0.74±0.24	13.7±0.98
Lowland cultivation system	0.86±2.34	16.1±1.03

± standard error of means

3.3.2.2 Influence of upland and lowland cultivation systems on yield and yield component

The results of the wilcoxon signed-rank test indicated that there was a non-significant small difference between Lowland (Median, Mdn = 4.3 , Sample size, n=6) and Upland cultivation systems (Median, Mdn = 2.9 , Sample size, n = 6), Wilcoxon's difference in sign ranks, W+ = 6, p = .438, Effect size, r= -0.3 for grain yield (GY) t/h and for straw yield (SY) t/ha Lowland (Mdn = 3.5 ,n = 6) and Upland cultivation systems (Mdn = 2.9 ,n = 6), W+ = 7, p = .563, r = -

0.2, except for thousand seed weight (TSW) as the Wilcoxon sign rank test indicated that there was a large significant difference between lowland (Mdn=28, n=6) and upland cultivation systems (Mdn=24, n=6), Z=-2.1, p=.036, r=-0.9. The thousand seed weight improved in the first and second season except for the grain and straw yield in the lowland cultivation system, respectively. (Table 4).

Table 4:Mean values for Grain yield , straw yield and a thousand seed weight comparison between Upland and Lowland cultivation system in Itek-Okile 2021 and 2022 at harvest.

	Grain yield (GY) (tha^{-1})	**Straw yield (SY) (tha^{-1})**	**1000 seed weight (TSW) (g)**
First season (Oct 2021-Feb 2022)			
Upland cultivation system	1.25±0.09	2.98±0.40	24.00±0.58
Lowland cultivation system	5.66±0.71	5.66±0.55	27.50±0.76
second season (May- Sept 2022)			
Upland cultivation system	4.68±0.27	3.43±0.96	24.00±0.28
Lowland cultivation system	3.43±0.31	2.72±0.08	27.33±0.76

± standard error of means

3.4 Discussion

The results of this study have shown that the lowland cultivation system improved both the growth and yield parameters of NERICA 4 rice variety during the two seasons with exception for plant height and thousand seed weight which were improved significantly for the lowland cultivation system. Nerica 4 rice variety produced taller rice plants under the lowland cultivation system than the upland cultivation system at maturity. The difference could be attributed to the phenomena of interaction between the genotype and the environment, which greatly influences plant height (Liliane & Charles, 2020). However, the differences were more pronounced in the first season which was drier and received low rainfall averages than the second season. In first season reduced rainfall was received causing soil moisture deficits which could have greatly reduced the rice plants ability to absorb nutrients from the soil and hence their inability to complete proper plant transpiration and photosynthesis that support growth. This therefore caused the upland cultivation system to consistently produce shorter plants in comparison to the lowland cultivation system which experienced no moisture deficits. Kitilu *et al.* (2019), confirmed the negative influence of moisture deficit occurring at different stages of rice growth which curtails plant height. Similarly, Kadiyala *et al.* (2012) & Matsumoto *et al.* (2014), confirm that different cultivation systems have varied effects on rice plant growth. The number of productive tillers for the upland compared to lowland rice production systems was lower by 1.40 & 1.18 times for season one and two respectively. The difference in number of productive tillers between upland and lowland cultivation system could be explained by variations in water stress intensities along the soil gradient which could have caused an increase in the number of unproductive tillers as a result of unfilled spikelets causing a reduced number of productive tillers in the upland cultivation system, Similar findings were reported earlier by Kikuta e*t al.* (2017) on two upland NERICA's grown in upland and lowland cultivation systems. Overall, the lowland cultivation system showed consistency in improving number of productive tillers than the upland cultivation system. Similar results were obtained by Garcia & Dionesio (2020), who reported an increase in the number of tillers in upland rice cultivars grown in lowland conditions. The episodes of flash floods due to heavy rains occurring early in the season, could have also caused rice seeds to germinate under low oxygen levels and or submergence of rice seedlings, which could have also reduced rice plant growth vigor and hence ability to tiller properly in the wet season In the lowland cultivation system. Generally, the rice grain yield for the upland cultivation system was less than that for the lowland cultivation system. This could be attributed to the fact that grain yield is influenced by yield components such as number of productive tillers and thousand seed weight which recorded low values. In the current study NERICA 4 rice variety was used which is reported to tolerate harsh growth conditions (Hong *et al*., 2021), This could imply that the low rainfall averages received through the drier first season, could have been worsened along the growing season by high evapo-transpiration rates of the rice plants due to high daily mean solar radiations mostly during the dry season. In a study conducted by (Matsumoto *et al.*, 2014), similar results were recorded with grain yields of 6.12 t/ha for lowland and upland cultivation system 2.83 t/ha for NERICA 4, but in this study fertilizers were applied. Furthermore, the rice grain yield within the lowland cultivation system reduced in the second season by 2.3 t/ha compared to upland rice cultivation. This implied that yields in the upland cultivation system were more stable, irrespective of the slight changes. Accordingly, the variation in grain yield among the rice cultivation systems could have also been occasioned by the low rainfall amid high temperatures experienced during the first season or the flash floods experienced during the second season which submerged rice seedlings under lowland cultivation for a duration of six days. This may have contributed to the reduction in growth at the stage of four leaves therefore causing a reduction in dry matter production which translated in grain yield differences between seasons. These findings were confirmed by Shaibu *et al*. (2015) who reported that high temperatures experienced during the dry season and flash floods experienced during the early vegetative stages of rice growth in a lowland production system could have been responsible for the variation in rice grain yield. Additionally, Das *et al.* (2009) also showed that flash-floods which covered seedlings for one to two weeks had a negative impact on rice grain yield. In fact, it has also been reported that limited rainfall and high temperatures experienced early in the season significantly shortened the vegetative growth stage and reduced the rice grain yield, respectively (Matsumoto *et al.,* 2014; Promchote *et al.,* 2022*)*. In the dry season increased lowland rice yields suggest high solar radiation during the grain filling to maturation stage which improved the overall grain yield in the first season (Yang *et al*., 2008*)*. Consequently, the mean grain yields per hectare obtained for both seasons for lowland cultivation system (2.96t/ha) and upland cultivation system (4.55t/ha) in the current study were above the Ugandan

National rice average yield of 2.8 t/ha but not world average yield of 4.7t/ha (FAO, 2021), the result implies there is an opportunity to improve actual rice grain yield in northern Uganda. Also, the straw yield in the upland cultivation system was always less than that for the lowland cultivation system probably due to differences in soil moisture, as water is the main driver and contributor to photosynthesis which is the main process responsible for accumulation of food inform of starch in plants and building of plant organs. the straw yield within the lowland cultivation system also showed a large difference of 3t/ha between both seasons compared to upland cultivation system, this suggests that due to high mean solar radiation during early in the first season, this may have enhanced accumulation of vegetative material, which lead to a high straw yield at maturity compared to the wet season. Hussain *et al.* (2021) concluded that water stressed rice was negatively impacted, resulting in an almost 50% reduction in biomass output. In the current study a wide percentage difference between seasons (First season 62.04% and second season 23.09%) in straw yield was observed in the lowland cultivation versus upland cultivation system. Similarly, flash floods experienced in the second season, in which rice seedlings were submerged for six days could have also contributed to this outcome. These results conform to (Singh *et al.*, 2014)'s study in which submergence due to flash floods was shown to inhibit dry matter accumulation in rice plants experiencing water submergence. A thousand seed weight was improved by the lowland cultivation system consistently compared to the upland cultivation system. Studies show that a thousand seed weight is determined by moisture and fertiliser application mostly nitrogen and phosphorous (Shrestha *et al.*, 2020). However, in the current study no fertiliser was applied implying that the difference in a thousand seed weight was due to soil moisture differences between upland and lowland cultivation systems, which was further worsened by differences in rainfall amount between the first and second seasons (Appendix 1 and 2).The results above were confirmed by Hossain *et al*., (2014) who demonstrated a decrease in thousand grain weight for rice at 80% and 30% field capacity compared to a 5 cm standing layer of water on the rice field.This indicates that a thousand grain weight of rice is mainly dependent on availability of sufficient soil moisture.

CHAPTER FOUR:

EFFECT OF GROUND COVER RICE PRODUCTION SYSTEM ON WATER SAVING AND NITROGEN USE EFFICIENCY

4.1 Introduction

Increasingly, water scarcity is becoming a serious threat to agricultural production affecting crops such as rice with higher water use efficiency. According to IRRI (2009), water scarcity affects more than 23 million hectares of rain-fed rice production areas in south and south-east Asia whereas recurring drought affects nearly 80% of the potential 20 million hectares of rain-fed lowland rice in Africa. Moreover, the contamination of the environment, water bodies and degraded upland areas as well as varieties less adapted to climate change further exacerbates the problem. Yet, rice growing in both the lowland and upland ecosystems continues to dominate cropping systems (Lin *et al.,* 2002*)*. Therefore, one of the options being explored for water saving and improved nitrogen use efficiency in rice production is ground cover rice production systems (GCRPS) (Qu *et al.,* 2012). According to Lin *et al.* (2002) application of GCRPS saved between 68-75% water usages in rice production in countries such as China. However, in Uganda, information on GCRPS is scanty and limited. Therefore, the objective of this study was to assess the effect of GCRPS for water saving and nitrogen use efficiency in rice, respectively.

4.2 Materials and Methods

4.2.1 Study Area

The same study area described in Chapter 3, was used for the study.

4.2.2 Soil characterisation

The soil characterisation is the same as described in chapter 3.

4.2.3 Experimental design

The experimental design was a Randomized Complete Block Design (RCBD) replicated three times for the two seasons. The treatments assessed on the rice variety PR-107 included i) T1-Traditional flooded rice, ii) T2-Straw mulched rice soil with rice plants + Urea, iii) T3- Polyethylene mulched soil with rice plants+ Urea, vi) T4-Bare soil planted with rice and. Each experimental plot measured 3 m x 2.5 m (7.5 m^2). For the Traditional flooded rice system, a sunken basin was used as the plot area meanwhile for the GCRPS treatments raised beds where used as the plots, a total of three strips with dimensions 1m x 2.5 m and alley of 0.50 m between strips and one meter between the blocks were used. Each strip was enclosed with a shallow furrow 0.15m deep and 0.20m wide while the paddy rice treatment was surrounded by polyethylene sheets buried 0.60m deep to prevent horizontal movement of water between treatments (Figure 4 & 5). PR-107 rice variety was chosen due to its early maturity, moderately aromatic, and long grain attribute (Alibu *et al.,* 2022). The total area covered by the experiment was 183.5 m^2 (Tao *et al.,* 2014).

Figure 4: Lowland cultivation system, polyethylene mulched and straw mulched ground cover rice production system treatments.

Figure 5: Un-mulched and straw mulched ground cover rice production system

4.2.4 Field management

This was carried out as described in chapter 3 except for fertiliser application, irrigation and mulching as described below;

Fertilizer was applied as basal application by digging shallow furrows 0.1m away from the rice plants and placing fertilizer in them before covering with soil. This was done two weeks after germination for the GCRPS at a rate of 120 kg/ha (Tao *et al.,* 2006). For each of the treatments water was applied up to the 0.10m mark which was measured by considering the floor of treatment and height of water layer along the levee or bunds of the treatment for the flooded rice treatment meanwhile for the GCRPS the furrows enclosing the plot was considered and 0.10m layer was applied which was measured from the floor of the furrow to 0.10m along the furrow wall. The amount of water was computed from the dimensions of the treatment plot or furrows after-which the total amount was then derived. In the first season which consisted of short rains the flooded rice received seven irrigation applications while the GCRPS received 4 irrigation applications. For second season which comprised of long rains the flooded rice received 5 irrigation applications and 2 irrigation applications where applied for GCRPS. The computation of amount of irrigation water applied to the field was based on computation considering the dimensions of the treatment plot holding water and the furrows.

Mulching was applied to the mulched treatments using polyethylene or straw as the mulching material (Qu *et al.,* 2012). The mulching was done at the time of planting on 14/10/2021 for season one and 6/5/2022 for second season, respectively. The straw mulch was applied to a depth of 0.15 m. Over the season, straw was added to maintain the depth of mulching. The polythene mulch had round holes (measuring 5 centimeters in diameter) punched using a cork borer. The holes were to allow the dibbling of rice seeds and tillers to grow easily from the mother plant (Shi *et al.,* 2019). Rice seeds were planted direct into the raised beds and lowland treatments. Fourteen (14) days after germination, light flooding was applied for the traditional lowland rice treatment (Marasini *et al*., 2016).

4.2.5 Data collection

4.2.5.1 Germination counts

Germination counts were recorded in the laboratory so as to calculate the germination percentage by sampling Seeds from the middle of the container while holding the seeds and the sides to get a representative sample of 100 seeds which were placed on top of two layers of toilet tissue paper and the seeds were wetted with a sprinkle of clean water and the seeds were covered with tissue paper, the seeds were checked every two days to check for moisture, after which at 10 days 90 seeds had germinated. The germination percentage was computed by dividing the number of germinated seeds by the total number of seeds tested after which it was multiplied by 100 to get a germination percentage of 90 percent for season one while for season two the germination percentage was 94 percent for PR-107 rice variety (IRRI, 2023).

4.2.5.2 Grain yield

The mature rice was harvested by cutting the rice stalks from the two middle rows of each plot which is equivalent to one square meter of the treatment plot (Gomez & Gomez, 1984). The rice stalks with the grain attached were immediately placed on a tarpaulin and threshed by beating the rice panicles upon a piece of wood after which the grain was gathered together and winnowed to clean all foreign materials ready for storage into a polythene bag, which had a tag marked with the treatment name and code. Harvesting for the first and second season was done on 25/1/2022 and 20/8/2022, respectively. Each of the polythene bags containing stored rice grain from the different plots were sun dried daily on the tarpaulin separately to avoid mixing until the constant moisture level of 14% was attained. Grain from each treatment was weighed separately using a laboratory beam balance and weights recorded before the grain yield per square metre was converted to kilogrammes per hectare as described by Sapkota *et al.* (2016)**.**

4.2.5.3 Straw yield

After removal of rice grain by threshing from rice panicles, the straw was tied in bundles and placed on drying racks in a room. The straw was then transported to Kyambogo University soil science laboratory were each treatment was weighed using a laboratory beam balance and weights were recorded before the straw yield per square metre was converted to kilogrammes per hectare.

4.2.6 Measurement of shoot N concentration using Kjedhal method

Separate harvests of the grain and straw samples were made earlier than other samples and where washed with water by placement of the samples on a screen and allowing running water to pour over them for five minutes so as to remove any dust and soil particles. The samples from the different plots were then placed on wooden racks to be air dried inside a room (Faithfull, 2002). The samples where then transported to Kyambogo University, Soil Science laboratory where they were ground using a hand driven plate mill. To avoid contamination of the samples, the grinding head was disassembled and plates were removed and thoroughly cleaned between the grinding of each sample (Faithfull, 2002). Each ground sample was then sieved through a 2-millimeter screen mesh and then 0.1 g was weighed using an electronic balance (Afcoset Fx-400) and placed into boiling tubes, meanwhile the digestion tubes containing the samples were placed onto a laboratory holding rack. A single tablet of a selenium-based catalyst and 2 millimeters of concentrated sulfuric acid were added into the sample contained in the tubes. After which the digestion tubes were placed onto a graphite heating plate which had the temperature programmed to rise at increments of 50 º C up to a final temperature of 400 º C. The samples were boiled for three point five hours at which point the sample turned into colourless solid (Faithfull, 2002). The colourless solid sample was dissolved by washing it out of the tubes using distilled water. The sample liquid was then poured into a 50 mls flask for dilution and distilled water was added until the 50 ml mark was reached. A 15 millimeters sodium hydroxide solution plus 10 ml of sample were added into the distillation flask and boiled to release nitrogen inform of ammonia which was trapped by a 25 ml mixture of Boric acid and 2 drops of methyl red plus methylene blue indicator, at which point the solution turned green. The percentage of nitrogen in the sample was determined by titrating the green solution with 0.02N concentrated Hydrochloric acid until the solution turned pink. The % N in the grain and straw of each sample was determined using the following equation (Seki, 1990):

Nitrogen % concentration=(V1-V2) xNxFx0.014x100/S

Where; V1 *is Titre volume for sample (Mls)*

V2 *is Titre volume for blank (Mls)*

N *is normality of standard Hcl solution*

S *is weight of the sample in grams*

F *is factor of standard Hcl solution*

4.2.7 Calculation of N use efficiencies

The following formulae were used to compute the various nitrogen use efficiencies:

I) **Agronomic Efficiency (AEY)** is the amount of grain produced for each applied unit of nitrogen. The equation below was used for computing results:

$$\text{AEY} \ (Kg\ Kg^{-1}) = \frac{\text{fertilized treatment yield in kg} - \text{unfertilized treatment yield in kg}}{\text{Amount of nitrogen applied in kg}}$$

(Equation 1)

II) **Utilisation Efficiency (UE)** is the product of apparent recovery efficiency and physiological efficiency

$$\text{UEY} \ (Kg\ Kg^{-1}) = \text{PEY.AREY} \qquad \text{(Equation 2)}$$

III) **Physiological Efficiency (PEY**) is the grain plus straw yield achieved per unit of nitrogen absorbed. It was calculated using. the following equation;

$$\text{PEY}(Kg\ Kg^{-1}) = \frac{\text{A(kg)} - \text{B(kg)}}{\text{AN(kg)} - \text{BN(kg)}} \qquad \text{(Equation 3)}$$

where AN= Grain and straw N uptake of fertilized plot

A= Grain plus straw of fertilized plot

B= Biological yield of unfertilized plot and

BN= Biological yield (grain plus straw) of unfertilized plot.

IV) **Agro physiological Efficiency (APE**) is the economic output achieved per unit of nitrogen absorbed. The equation below was used for computing results:

APEY ($Kg\ Kg^{-1}$) = $\frac{\mathrm{A(kg)} - \mathrm{B(kg)}}{\mathrm{NA(kg)} - \mathrm{NB(kg)}}$ (Equation 4)

Where NA= Grain plus straw N uptake of fertilized treatment

NB=Grain plus straw N uptake of unfertilized treatment

A= grain yield of fertilized treatment and

B= grain yield of unfertilized treatment

V) **Apparent Recovery Efficiency (AREY)** refers to the amount of nitrogen absorbed for each applied unit of nitrogen. The equation below was used for computing results:

AREY (%) = ($\frac{\mathrm{A} - \mathrm{B}}{\text{amount of nitrogen applied}}$)*100 (Equation 5)

Where A=Grain and straw nitrogen uptake of the treatment and

B= Grain and straw nitrogen uptake of the unfertilized treatment (Baligar & Fageria, 2015).

4.2.7.1 Nitrogen harvest index (NHI)

This the ratio between N accumulated in grain to N accumulated in grain plus straw (Fagerua, 2014).

4.2.8 Calculation of Water Use Efficiency (WUE)

The grain output in kilograms per hectare was divided by the total applied irrigation water to the field to determine the irrigation water use efficiency, or IWUE (Qin *et al.*, 2006).

4.2.9 Data analysis

The significance of the treatments was determined using Analysis of Variance (ANOVA) of the Genstat statistical programme version 14. Where means were significantly different, they were seperated using the Fishers LSD at 5% probability levels (Gomez & Gomez, 1984).

4.3 Results

4.3.2 Water Use Efficiency

In both seasons water use efficiency was remarkably different ($p<0.05$) among the rice cultivation systems. During the first season, GCRPS straw mulched recorded the highest WUE (KgM^{-3}) while in second season GCRPS polyethylene mulched recorded the highest WUE (KgM^{-3}) (Table 5). The mulched GCRPS systems registered constantly high percentage increments in WUE relative to flooded rice. There was a 76% and 84% decrease in water applied to the GCRPS systems in the first and second seasons, respectively. (Table 5).

4.3.3 Dry matter and percent Nitrogen content from different rice cultivation systems

In the first season GCRPS polyethylene mulched registered significantly ($p<0.05$) high grain Dry matter (DM) compared to the flooded and GCRPS bare un-mulched rice system, but in second season both mulched GCRPS systems recorded high grain yield which was not statistically different. During both seasons, GCRPS bare un-mulch registered low DM yield compared to flooded rice. The straw DM followed a similar trend, meanwhile the mulched GCRPS systems registered high straw DM yield, with the flooded rice and GCRPS bare un-mulched also registering low straw DM in both seasons, however in second season the flooded rice system recorded straw DM yield which was 9.3% less than that for GCRPS bare (Table 6).

The concentrations of N in the straw plant material in first season ranged between 0.42 - 0.59% and in second season by 0.82 - 0.39%. (Table 6).

Table 5: Mean values for grain yield, water use efficiency (WUE) and absolute values for water applied, water saved and percentage increments in water use efficiency relative to flooded rice.

	Grain Yield ($Kgha^{-1}$)	**Water applied (Kg/ha)**	**WUE (KgM^{-3})**	**Water saving (Kg/ha)**	**% Increment WUE relative to flooded rice**
First season (October 2021-February 2022)					
Flooded rice	3640	6933.3	0.59A	-	-
GCRPS straw	4370	1653.3	6.21B	5280	952.5
GCRPS bare	3560	1653.3	3.41C	5280	477.9
GCRPS Poly	5050	1653.3	6.18D	5280	947.4
Grand mean	4155	2973.3	5.27	5280	792.6
Second season (May-September 2022)					
Flooded rice	2950	5000	0.52A	-	-
GCRPS straw	4960	800	2.60B	4200	400
GCRPS bare	2730	800	2.10C	4200	303.8
GCRPS Poly	4940	800	3.00D	4200	476.9
Grand mean	3,895	1,850	2.06	4200	393.5

Means followed by the different letters, uppercase in the column, are significantly different according to the least significant difference test at 5% probability.

Table 6:Mean values for Grain dry matter, Straw dry matter and percentage nitrogen concentration in plant tissues with different cultivation systems at Itek-Okile 2021/2022 at harvest.

	Grain Dry Matter ($Kgha^{-1}$)	**Straw Dry matter ($Kgha^{-1}$)**	**At harvest**	**%N**
			Grain	Straw
First season (October 2021-February 2022)				
GCRPS Poly	5050A	5820A	0.60	0.48
GCRPS straw	4370BA	5310A	0.60	0.59
Flooded rice	3640C	4560A	0.74	0.42
GCRPS bare	3560D	4170A	0.59	0.50
Grand mean	4155	4965	0.63	0.50
Second season (May-september 2022)				
GCRPS Poly	4940A	6980A	0.63	0.39
GCRPS straw	4960BA	6710A	0.32	0.82
Flooded rice	2950C	4080A	0.59	0.69
GCRPS bare	2730D	4460A	0.42	0.60
Grand mean	3895	5558	0.49	0.63

Means followed by the different letters, uppercase in the column, are significantly different according to the least significant difference test at 5% probability.

4.3.4 N uptake and N Harvest indices

In the first and second season the mulched GCRPS systems had a high total N Uptake, followed by flooded rice system as compared to GCRPS bare system. The GCRPS poly had the highest constant total N uptake of any system in both years. however, in comparison to GCRPS poly, GCRPS straw showed a total N uptake that was 17.7% higher. In relation to other systems, the GCRPS bare registered the lowest nitrogen uptake in straw and grain dry matter in both years. Mean while the Nitrogen Harvest index (NHI) for GCRPS poly was constantly 0.52 and above in both years however, generally the NHI varied between 0.29 and 0.58 for all cultivation systems in both years. It is certain that N uptake had a strong contribution to grain and straw dry matter production in rice plants (Table 7).

Table 7: Values for Grain N Uptake, straw N uptake, Total N uptake and nitrogen harvest indices with different rice cultivation systems at Itek-okile 2021-2022 at harvest.

	Grain N $(Kgha^{-1})$	Straw N $(Kgha^{-1})$	Total N $(Kgha^{-1})$	NHI
First season (October 2021-February 2022)				
Flooded rice	26.94	19.15	46.09	0.58
GCRPS straw	26.22	31.33	57.55	0.46
GCRPS bare	21	20.85	41.85	0.50
GCRPS Poly	30.3	27.94	58.24	0.52
Second season(May-September 2022)				
Flooded rice	17.40	40.8	58.20	0.29
GCRPS straw	15.87	55.02	70.89	0.22
GCRPS bare	11.47	26.76	38.23	0.30
GCRPS Poly	31.12	27.22	58.34	0.53

4.3.5 Nitrogen Use efficiencies of the mulched treatments

Agronomic efficiency (AEY), physiological efficiency (PEY), agro physiological efficiency (APEY), apparent recovery efficiency (AREY), and nitrogen utilization efficiency all generally increased in second season at a nitrogen application rate of 120 kg per hectare for both GCRPS mulched systems. However, in second season Physiological efficiency PE decreased by 73.7% and Apparent Recovery Efficiency ARE increased by 108% in the GCRPS straw system. Nitrogen Utilization efficiency NUE for the GCRPS poly in both years was high while NUE decreased by 45.3% in GCRPS straw in second season compared to first season. In general, across both years the average of means for GCRPS poly system, for nitrogen use efficiencies were calculated as shown below; Agronomic efficiency was 15.42 kilograms of grain produced for every kilogram of nitrogen applied, physiological efficiency was 213.3 kilograms of biological yield (grain and straw) for every kilogram of nitrogen accumulated, agro-physiological efficiency was 100.7 kilograms of grain produced for every kilogram of nitrogen stored in the grain and straw, apparent recovery efficiency was 15.2%, and nitrogen use efficiency produced 32.77 kilograms of grain produced for every kilogram of nitrogen used (Table 8).

Table 8: Values for Agronomic efficiency (AEY), Physiological efficiency (PEY), Agro-physiological efficiency (APEY), Apparent Recovery Efficiency (AREY) and Utilisation efficiency as a function of the mulched ground cover rice production systems at Itek-Okile 2021-2022 at harvest.

	Different Nitrogen Use Efficiencies				
	AEY ($KgKg^{-1}$)	**PEY ($KgKg^{-1}$)**	**APEY ($KgKg^{-1}$)**	**AREY (%)**	**UEY ($KgKg^{-1}$)**
First season (October 2021-February 2022)					
GCRPS Poly	12.42	191.5	90.90	13.65	26.15
GCRPS straw	6.75	124.2	51.59	13.08	16.24
Second season (May-September 2022)					
GCRPS Poly	18.42	235.21	110.5	16.75	39.39
GCRPS straw	18.58	32.66	68.27	27.21	8.88

APEY is for agro-physiological efficiency, PEY stands for agronomic efficiency, AREY stands for apparent recovery efficiency and UEY stands for utilisation efficiency.

4.4 Discussion

The GCRPS poly had the highest yield among the rice cultivation systems. This was probably due to the influence of the polyethylene sheet, which traps the water evaporating from the soil and cools it into condensate water which drops back into the soil material. This therefore increases the soil moisture; hence more grain can be formed from the increased soil water. Similar results were confirmed by Tao *et al.* (2006) and Guo *et al.* (2020) and, in which the rice grain yield for the GCRPS poly system was greater than or equal to that for flooded rice. However, most earlier research on water use efficiency had placed greater emphasis on describing how GCRPS alters grain production compared to the nitrogen fertilised flooded rice system (Tao *et al.*, 2014). The popularity of the GCRPS system is also hinged on it's effective and efficient water saving ability (Tao *et al.*, 2014). Therefore, this results showed that there was a decrease in water applied to the GCRPS system by 76% and 84% for the first and second seasons, respectively. Meanwhile the percentage increments in WUE relative to flooded rice system ranged between 303.8 to 947%, respectively. This implies that water applied in mulched GCRPS was consumed by rice plants to produce more grain which was achieved by reducing rice water consumption constituted by transpiration, evaporation, and field percolation (Shizhang *et al.*, 1994). Subsequent studies also demonstrated the ability of the mulched GCRPS systems to conserve more water and increase the root growth in the soil to provide for more water needs meant for rice plant grain formation (Zhanga *et al.*, 2017). Therefore, GCRPS would be a more effective approach to grow lowland rice varieties in upland environments due to less irrigation water being used.

The results also showed that mulched GCRPS registered the highest grain and straw dry matter over the GCRPS bare and flooded rice. This could have been due to the response of the lowland rice under mulching to increased water availability and nitrogen in the soil since rice is a nitrogen responsive crop (Rahman *et al*., 2007). The findings further demonstrated that the addition of mulch and nitrogen had a favorable impact on the yield of grain and straw in both years. In fact, Bhuiyana *et al*. (2017) reported similar results as nitrogen fertiliser application increased rice dry matter production. Similarly, He *et al.* (2013) had also reported the same findings by showing that plastic mulching and irrigation improved dry matter production in upland grown lowland rice. The results indicate that rice mulching enhances rice grain and straw yield.

The results further showed that the %N concentration varied between the years suggesting that water availability in the soil and nitrogen fertilisation could have caused these effects. According to Ye *et al*. (2014), the concentration of Nitrogen in rice plants exposed to different water regimes and nitrogen fertilisation, remarkably influence plant tissue N concentration at harvest. This indicates that rice cultivation systems influence rice plant tissue concentrations. Mulching improved the nitrogen uptake and nitrogen harvest index in the mulched systems. This suggests mulching increased the amount of water that was available to the rice plants, which boosted the plant's ability to absorb nitrogen from the soil due to the rice plant roots’ ability to absorb N in soil solution. Similarly, studies have shown that mulching improves the soil temperatures hence enhances root growth (Shi *et al.*, 2019). Furthermore, the findings of Li *et al.* (2018) had earlier demonstrated that the mulched GCRPS systems benefited at the start of the growth season, from a combination of greater soil temperature caused by thermal insulation from cold ambient temperatures which can effectively alleviate cold stress in early growth stages of rice plants and less nitrogen loss due to reduction in non-physiological water consumption leading to an increase in the quantity of nitrogen that was available to plants. Certainly, this led to more nitrogen being absorbed by the plants which resulted in high N in the plant tissues. Therefore, the results indicate mulched GCRPS systems improved nitrogen uptake in the rice plant, particularly in the grain. The nitrogen use efficiencies for the GCRPS polyethylene mulched system was high during both seasons. However, the agronomic efficiency of lowland rice has been shown to vary from 6 to 25 Kilogrammes grain per Kilogramme N in the tropics (Yoshida, 1981; Cassman *et al.*, 1996; Haefele *et al.,* 2008). Accordingly, the current results are within those limits. Tao *et al*. (2015) also reported findings which were within those limits for the mulched GCRPS as the AEY ranged from 10 to 11.6 Kilograms of grains for every Kilogram of nitrogen. Comparatively, the lower figures of AEY could be attributed to the differences in the soil textures between the study sites (Tao *et al.,* 2015). The physiological efficiency had high values in both seasons compared to the Agro-physiological efficiency whereas the Apparent recovery efficiency AREY fluctuated between 13.08 - 27.21%. Accordingly, Dass *et al.* (2015) reported an ARE of 44%, other studies have also shown ARE of 9 - 23% for rice (Haefele *et al.,* 2008), but in the tropics it usually ranges between 30% and 50% (Prasad & De Datta, 1979), Therefore, the current results are approximately within the boundaries. However, the low N recovery from the upland soil conditions of applied N could be attributed to natural processes such as volatilization or leaching. For example, earlier Ju *et* *al.* (2009) demonstrated that in lowland conditions ammonium ion is predominantly absorbed by the rice plants directly. Also, under aerobic conditions, the nitrification of ammonium ions to nitrate ions occurs hence exposing the accumulated dominant Nitrite ion in soil to increased instances of loss through leaching and volatilization. Khatun *et al*. (2015) also reported a utilization efficiency for lowland rice that ranged between 9 - 37 Kilograms grain for every Kilogram nitrogen. However, the UEY for production of grain in the tropics is about 50 kilogrammes of grain produced for every kilogram of nitrogen (Yoshida, 1981). Therefore, the results of the current study are approximately within the limits.

CHAPTER FIVE: GENERAL DISCUSSIONS, CONCLUSIONS AND RECOMMENDATIONS

5.1 General Discussion

5.1.1 Performance of upland rice variety in lowland and upland cultivation systems.

It was hypothesized that rice cultivation systems significantly influence the performance of rice cultivars. This study confirmed this hypothesis. Indeed, this study showed that the number of productive tillers per plant and thousand seed weight showed a large significant different ($p<0.05$) between the cultivation systems. Besides, plant height and number of productive tillers were improved consistently between seasons in the lowland cultivation system. This study identified moisture stress due to moisture deficits in soils as one of the constraint, which could have caused slow growth leading to short plants in the upland cultivation system, which recorded shorter plants in the first and second seasons. These results were confirmed by Kitilu *et al.* (2019), Kadiyala *et al.* (2012) and Matsumoto *et al.* (2014), who reported the negative influence of moisture stress in upland rice cultivation systems on plant height.

In this study number of productive tillers per plant reduced by 1.40 & 1.18 times for season one and two respectively, in the upland cultivation system compared to lowland cultivation system. This could probably be explained by variations in water stress intensities along the soil gradient, causing a reduced number of productive tillers in the upland cultivation system (Yang *et al.*, 2008). These results were confirmed by Kikuta e*t al.* (2017) on two upland

NERICA’s grown in upland and lowland cultivation systems which recorded reduced number of productive tillers in upland cultivation system.

Additionally, although NERICA 4 rice variety has been tested differently among the cultivation systems in Uganda, the differences in yield parameters and their components between cultivation systems for grain yield and thousand seed weight were improved consistently in the lowland cultivation system except for straw yield. The differences in yield parameters and components between cultivation systems which could be explained by occurrence of drought due to low rainfall amount received along the season and soil moisture differences between cultivation systems due to reductions in soil moisture along the soil gradient and submergence of rice plants early in the season. In this study the results are in agreement with Das *et al.* (2009), Matsumoto *et al.* (2014), Hossain *et al.* (2014), Shaibu *et al*. (2015) and Promchote *et al.* (2022), who reported limited rainfall and high temperatures and moisture stress due to drought and slowed growth due to seedling submergence to be the causes of low grain yield, straw yield and thousand seed weight between cultivation systems.

5.1.2 Effect of Ground cover rice production system (GCRPS) on water saving and Nitrogen use efficiency.

It was hypothesized in this study that the Ground cover rice production systems have the synergistic effects of water saving and nitrogen use efficiencies in rice. This study confirmed this hypothesis. This study aimed to assess the GCRPS for water saving and nitrogen use efficiency in Uganda, and there is no known information pertaining to the subject currently in Uganda. The mulched ground cover rice production systems were shown to improve water use efficiency consistently and significantly in the first and second season. This was achieved according to Shizhang *et al.* (1994), by reducing rice water consumption constituted by transpiration, evaporation, and field percolation.

Furthermore, in this study water savings of 76% to 84% were shown to be attainable, this was probably achieved due to mulching which reduced non-consumptive water losses such as deep drainage and evaporation, these results are in agreement with the findings of (Jin *et al.*, 2016) and (Tao *et al.*, 2006) who showed water savings that ranged between 70% - 80% in their experiments.

The mulched GCRPS recorded the highest grain and straw yield compared to the flooded rice and GCRPS bare un-mulched systems. This could have been due to the response of the lowland rice variety to increased water availability and nitrogen in soil. These results were confirmed by Bhuiyana *et al*. (2017) and He *et al.* (2013), who reported similar results as nitrogen application, mulching and irrigation improved dry matter of upland grown lowland rice.

The % Nitrogen concentration in the rice grain and straw varied in both seasons suggesting that nitrogen application and water availability in the soil could have caused these effects. The results are in agreement with Ye *et al*. (2014)'s, report that shows the concentration of Nitrogen in rice plants tissues exposed to different water regimes and nitrogen fertilisation, remarkably influence plant tissue N concentration at harvest.

In this study N use for the GCRPS showed a high total N uptake and NHI by the mulched GCRPS along with flooded rice system in both seasons, this suggests according to findings of Li *et al.* (2018), that increased N uptake was a function of reduced N losses early in the season and improved soil temperature leading to increased root growth due to mulching, hence an increase in quantity of water and increased N absorbed available for plant use.

Finally, the nitrogen use efficiencies analysed in the current study were shown to be within the known limits except for some differences which were shown to be due to differences between soil texture causing different soil nutrient dynamics between the current study site and those in literature, as confirmed by Prasad & De Datta (1979), Yoshida, (1981), Cassman *et al.* (1996), Haefele *et al.* (2008), Khatun *et al*. (2015), Tao *et al*. (2015), Dass *et al.* (2015).

5.2 Conclusions

It was concluded from the outcomes of the study, that lowland cultivation of rice consistently improved the number of productive tillers per plant, plant height and a thousand seed weight. Overall, upland versus lowland cultivation systems significantly influenced ($p<0.05$) the number of productive tillers per plant and thousand seed weight.The grain yield and straw yield were not significantly different ($p>0.05$) between the cultivation systems.The study also revealed that although the lowland cultivation system was consistent in enhancing growth and yield parameters, however, challenging climatic conditions such as flash floods which caused uncontrolled flooding leading to seedling submergence and drought spells experienced within the seasons do-not present optimum ecosystem conditions for rice growth and yield improvement in northern Uganda.

In this study it was concluded that the mulched GCRPS substantially ($p<0.05$) increased grain dry matter and water use efficiency. The straw dry-matter, N uptake and %N concentration were also improved in the GCRPS polyethylene mulch over other cultivation systems. The GCRPS polyethylene mulch system consistently improved physiological, agrophysiological, apparent recovery, and utilisation efficiency. The nitrogen use efficiencies were generally comparable to the high yielding lowland rice cultivation systems in reviewed literature, which implied the GCRPS can effectively replace lowland rice ecosystems in terms of improving nitrogen use efficiency. The mulched GCRPS systems also caused water saving of between 76% to 84% of applied water on flooded rice.The mulched GCRPS systems together with applied fertiliser improved water and N use efficiencies.

5.3 Recommendations

Having documented the performance of upland rice variety in lowland versus upland rice cultivation systems and effect of the ground cover rice production systems on water and nitrogen use efficiency in northern Uganda, future efforts to further our understanding of performance of different rice cultivation and the ground cover rice production systems in Uganda, should focus on the following recommendations.

1. The study confirmed the presence of non-optimum conditions such as drought due to low rainfall received in a season. Therefore, the controlled moisture management of upland soils to supplement on rainfall received within the season through irrigation, would be the best option to improve performance of the upland cultivation system.
2. The study has confirmed that soils deficient in nitrogen in northern Uganda, can be productive if the mulched GCRPS systems are used which can be an effective counter against low dry matter yields in N nutrient deficient soils with a declining water resource that cannot support efficient rice production.
3. The study confirmed that among the rice production systems the GCRPS polyethylene mulched system was the best compared to the GCRPS straw mulched system for farmers to grow lowland rice in environments which are constrained by a lack of water, while also saving the irrigation water that is already available.However, due to

cost implications of purchasing polyethylene mulch, the straw mulch would be a better option for poor farmers.

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APPENDIX

Appendix 1:Precipitation, Temperature and Relative Humidity for an average of five months period over two season for the experimental site

Year	Precipitation,mm/M	Temperature,C mean	Relative Humidity
2021			
Total	183	127.7	207.7
Average	36.6	25.5	41.5
2022			
Total	694	116.1	287
Average	139	23.2	57.4

Appendix 2:Precipitation mm, Temperature ºC, Mean, Relative Humidity and sunshine radiation per month 2021 - 2022 retrieved from AQUASTAT information.

Year	**Month**	**Precipitation.**	**Minimum temperature °C**	**Maximum temperature °C**	**Mean Temperat °C**	**Rel. Humidity %**	**Sun shine J m^{-2} day^{-1}**
				Season one			
2021	**Oct**	104	18.8	29.4	24.1	54.9	22,140,476
2021	**Nov**	24	19.2	30.7	25	44.7	21,401,131
2021	**Dec**	3	19.8	32.4	26.1	35.3	21,124,622
2022	**Jan**	40	19.5	32.1	25.8	35.8	21,768,170
				Season two			
2022	**May**	188	19	28.2	23.6	59.3	20,399,811
2022	**Jun**	87	18.3	27.1	22.7	58.9	19,587,263
2022	**Jul**	103	18.6	27	22.8	56.4	18,574,224
2022	**Aug**	159	18.2	26.9	22.6	59.8	19,061,305