بسم الله الرحمن الرحيم

Sudan University of Science and Technology

College of Graduate Studies

Integration of Cultural and Chemical Methods for Purple nutsedge (*Cyperus rotundus* L.) Management.

تكامل الطرق الفلاحية والكيميائية لإدارة السعدة الأرجوانية

A Thesis submitted in fulfillment of the requirements for the Degree of Master of Science (M.Sc.) in Plant Protection

By

Mohammed Ahmed Mirgani Abdalla

B.Sc. Pesticide and Toxicology (Toxicology), College of Agricultural Science, University of Gezira (2004).

Supervisor:

Prof. Abd Elgabar Altayeb Babiker

Environment and Natural Resources and Desertification

National Centre for Research

Co. Supervisor:

Prof. Dr. Hassan Ibrahim Mohamed

Sudan University of Science and Technology

College of Agricultural Studies, Department of Agricultural Engineering

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DEDICATION

I would like to dedicate this work to my dear father, lovely mother, sweet sisters, my brothers Mirgani and Elnazeir and to my dear beloved uncle Mohammed Mirgani Abdalla Dodeyha.

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First my thanks are due to almightily Allah, the beneficent and the merciful, for giving me health and strength to accomplish this work. Further, I would like to express my special thanks and gratitude to Prof. Abd Elgabar Eltayeib Babiker and Prof. Hassan Ibrahim who supervised the work throughout the study. Thanks are extended to former minister of Agriculture North Kordofan State, Dr. Elzobeir Eid ElZain, University of Kordofan, eng. Kamal Bala Shaga and Mrs. Mohammed Madani / Manager of Civil Affairs- North Kordofan State. Iam also grateful to Dr. Omran Mousa Department of Agricltural Engenering, College of Agricultural Studies (CAS), Sudan University of Science and Technology (SUST) and the excellent technical support provided by the staff of the Computer Modeling Laboratory of the National Centre for Research- Environment and Natural Resources and Desertification Institute. Thanks are also extended to Eng. Ahmed Adam Omer, Eng. Abutaleb Madani ,technical assistant Elfatih Ahmed Fadl-alla, Eng. Omsalama Mousa, Eng. Nada omer, Eng. Fatima Salim, Eng. Maha Dolleb, Mr. Emad Ahmed and to all my colleagues in Abu-habil Project. Special thanks are due to Farmers Union especially union leader Elssadeg Elafefe.

Abstract

Cyperus rotundus is a pernicious, perennial and a difficult to control weed. The weed presents a serious constraint to crop production under spate irrigation particularly at Elsemeyh Agricultural Scheme (EAS) in Western Sudan where disc harrowing supplemented by hand weeding is the standard method of weed control. The EAS (21 thousand feddan) constitutes 33% of Khor Abu Habil Project. The present study was made to develop an integrated management strategy for *C. rotundus* in cotton. The investigation, comprising field and supplementary laboratory and screen house experiments was undertaken at the College of Agricultural Studies Sudan University of Science and Technology and EAS results revealed that *C. rotundus* tuber population density was highest (49.33%), intermediate (29.72%) and lowest (20.95%) at 0-10 cm, 10-20 cm and 20-30 cm soil depth, respectively. *C. rotundus* tubers progressively lose moisture, sprouting capacity and viability when exposed to heat. Tubers exhumed from 0-10 cm depth showed 0.89, 0.94 and 5.56% loss in moisture content, 88.78, 88.78 and 100% loss in sprouting capacity and 7.75, 56.25 and 100% loss in viability following exposure at 70 °C for 1, 2 and 4 h, respectively. Tubers exhumed from deeper soil depths lost moisture contents less rapidly. However, sprouting capacity and viability were completely lost within 1-4 h of exposure. Tubers placed on the soil surface for 16 days displayed 19.97% loss in moisture content and complete loss in sprouting capacity. Deep blading, and disc ploughing, in April, resulted in excellent (>80%) suppression of *C. rotundus* at cotton planting time in July. However, regeneration occurred 2 and 3 weeks later. Among all treatments disc ploughing in April supplemented by a tank mix of glyphosate and pendimethalin at cotton planting effected the

best weed control and achieved over 50% more seed cotton yield than the 10 years average of the scheme.

Data availed by this study clearly showed that no single method sustained, spatially and temporally, consistent weed control and profitable cotton yield in the EAS and that the conventional tillage practices need to be supplemented by herbicides. Furthermore, the results suggest that improvement of cultural practices, particularly those which lead to rapid crop canopy closure, together with improvement of herbicides application technology are imperative. Moreover, introduction of glyphosate resistant cotton, suitable for growing under Sudan conditions, could be a significant part of the solution.

الخلاصة:-

السعدة هي حشيشة معمرة واسعة الإنتشار، تشكل عائقآ خطيرا في إنتاج القطن في مناطق الري الفيضي في مشروع السميح الزراعي بغرب السودان. الدسك هرو مدعوما بالعزيق اليدوي هو الطريقة المستخدمة في السيطرة علي السعدة. الهدف من هذه الدراسة هو وضع إستراتيجية متكاملة لإدارة السعدة في محصول القطن. أجريت التجارب الحقلية بمشروع السميح الزراعي اما الدراسات المعملية في البيت المحمي فقد أجريت بكلية الدراسات الزراعية ـ جامعة السودان للعلوم والتكنولوجيا ومشروع السميح الزراعي . أوضحت التجارب أن أعلي كثافة للسعدة كانت بنسبة 49.33% وتوسطتها بنسبة 29.72% وادناها 20.95% عند عمق تربة 0 ـ 10سم، 10 ـ 20سم و 20- 30سم علي التوالي. كورمات السعدة فقدت محتواها الرطوبي، القدرة علي الإنبات والحيوية بصورة تدرجية عندما تعرضت الي الحرارة. الكورمات التي جمعت من عمق 0 -10سم فقدت 0.89%، 0.94% و5.56% من رطوبتها كما فقدت القدرة علي الإنبات بنسبة 88.78%، 88.78% و100% وفقدت حيويتها بنسبة 7.75%، 56.25% و100% عند التعرض لدرجة حرارة بلغت 70م° لفترة زمنية 1 -2 و4 ساعة علي التوالي. الكورمات التي جمعت من تربة أكثر عمقآ فقدت محتواها الرطوبي بسرعة أقل، ولكنها فقدت قدرتها علي الإنبات والحيوية تماما في غضون 1 ـ 4 ساعة. الكورمات التي وضعت علي سطح التربة لمدة 16 يوم فقدت القدرة علي الإنبات تمامآ عندما انخفض المحتوي الرطوبي بنسبة 19.97%. عملية القطع العميق والدسك بلاو في شهر أبريل أسفرت عن نتائج ممتازة (أكثر من 80%) للحد من السعدة عند زراعة القطن في شهر يوليو. إلا إنها استعادت قدرتها علي الإنتشار بعد 2 الي 3 أسابيع. من بين كل المعاملات فالدسك بلاو في أبريل مدعوما بخليط من مبيد الجلايفوزيت والبنديميثالين عند زراعة القطن تعتبر هي الافضل للتحكم في السعدة وحققت زيادة في إنتاج القطن الزهرة بنسبة فاقت 50% عن متوسط إنتاج للعشرة سنوات السابقة بالمشروع. هذه الدراسة أوضحت أنه ليس هنالك طريقة واحدة لا مكانيا ولا زمانيا بإمكانها السيطرة علي الحشائش وتحسين الإنتاج في القطن بمشروع السميح الزراعي، كذلك عمليات الحراثة المتبعة تحتاج الي ان تدعم بمبيدات الحشائش، علاوة الي ذلك النتائج تشير الي تحسين العمليات الفلاحية عمليا تلك التي تتعلق بالمسافات لإغلاق الفراغات العلوية للمحصول جنبا الي جنب مع تحسين تطبيق مبيدات الأعشاب. بالإضافة الي ذلك ضرورة إستقدام قطن مقاوم للجلايفوزيت مناسب لينمو تحت ظروف السودان أمر حتمي يمكن ان يكون جزءا كبيرا من الحل.

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List of abbreviations

AHP	Abu habel project
a.e	acid equivalent
cɑ	About
a.i	Active ingredient
CAS	College of Agricultural Studies
˚C	Degree centigrade
cm	Centimetre
DAS	Days after sowing
EAS	Elsemeyh Agricultural Scheme
g	Gram
h	Hour
i.d.	Internal diameter
IWM	Integrated weed management
kg	Kilogram
Khor	Seasonal water course with a distinct path
LSD	Least significant difference
L	Litre
mg	Milligram
m	Meter
mL	Milliliter
m^{-2}	Per meter squire
NS	Non significant.
NKS	Northern Kordofan State
RCB	Randomized complete block
SE±	Standard Error
SUST	Sudan University of Science and Technology
SCW	Seed cotton weight

TTC	2,3,5-triphenyl tetrazolium chloride
USDA-ARS	United States Department Agriculture- Agricultural Research Service
v/ v	Volume to volume
WAHT	Weeks after herbicide treatment
WASI	Week after spate irrigation
%	Percent
/	Per

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CHAPTER ONE

INTRODUCTION

Weeds are plants which grow where not desired (Itamar and Luis, 2004). Their economic significance stems from their interference with human activities and interest in crop production. Weeds, which could be terrestrial, aquatic, annuals or perennials, free living or parasitic, constitute major constraints to crop production (Moody, 1977). Weeds interfere with crops through competition, parasitism and allelopathy and thus result in serious losses in crop yield and yields quality (Zohaib *et al*., 2016).

Purple nutsedge (*Cyperus rotundus* L.), a Cyperaceae, is a pernicious difficult to control perennial weed. The weed, albeit cosmopolitan, is more prevalent in tropical and subtropical regions (Holm *et al*., 1977a). *C. rotundus*, which has been described as the worst weed and most pestiferous plant in the world, was reported in 52 crops in 91 countries (Holm *et al*., 1977b, Webster 2005; Omezine and Harzallah, 2009; Igbal, *et al*., 2012). Fast growth, rhizomatous habit, prolific reproduction, regenerative capacity, an efficient C4 photosynthetic pathway and plasticity, conferred by genetic variability, increased the geographical amplitude of *C. rotundus* and make it an aggressive competitor and a serious invader that threatens biodiversity and ecosystems functioning (Lati *et al*., 2011, Igbal *et al*.,2012, Cheema, 2015). The weed often reproduces and spreads by tubers as production of viable seeds is very rare in the species (Holem *et al*., 1977b; Cheema, 2015). For short distance transport tubers and rhizomes are spread by farm implements. However, for long distance transport nursery stocks and water are the vectors of paramount importance (Holm *et al*., 1977b; Wills, 1987, Cheema, 2015).

C. rotundus initiates its growth cycle from tubers the dormancy of which is broken by light and diurnal temperature fluctuations (Miles *et al*, 2002). The sprouting buds form roots and rhizomes (Stoller and Sweet, 1987). The latter may extend vertically and develop into overground shoots with swelling (basal bulbs) at their bases. Subsequently rhizomes are produced by buds located on tubers and basal bulbs and grow either into overground shoots with basal bulbs or expand plagiotropically to form a tuber chain (Hauser, 1962b; Wills, 1987). Initiation of plagiotropic rhizomes coincides with flowering which occurs 7-8 weeks after shoot emergence (Omezine and Harzallah, 2009). The phenomenon occurs repeatedly leading to an extensive underground system of roots tubers, basal bulbs and connecting rhizomes. Webster (2005) reported that a single tuber formed a patch of 22.1m^2 containing 3,440 shoots at 60 weeks after planting.

The weed is a very serious competitor for water and nutrients (Omezine and Harzallah, 2009). Reports indicated serious yield losses in several economically important crops. Keeley (1987) reported 89% loss in yield of onion (*Allium fistulosum* L), Santos *et al*. (1998), reported 70% loss in yield of radish (*Raphanus sativus*), Holm *et al*., (1977a) reported over 60% losses in sugarcane (*Saccharum officinarum* L) and sugar yield, Keeley and Thullen (1975) reported 34% losses in cotton(*Gossypium hirsutum* L) yield. Moreover, root exudates and subterranean tissues, on decomposition, release toxins that impair crop growth and decrease yield (Holm, 1977b; Javaid *et al*., 2007; Cirujeda *etal*, 2012).

The complex biology of the weed, high photosynthetic efficiency, rapid growth, regenerative capacity, drought and flood tolerance, prolific propagation by tubers, tuber longevity, and spatial distribution make *C. rotundus* a difficult weed to control (Holm, 1977b; Stoller and Sweet, 1987; Cirujeda *etal*, 2012). Though most tubers (.80%) are often found within the top 2-20 cm soil depth, but deeply buried tubers (>40 cm) are not uncommon particularly in light textured soils (Loustalot, *et al*., 1954; Bhowmik, 1997). A tuber has several dormant buds the repeated sprouting of which renders manual methods of control ineffective. Apical dominance and dormancy of buds and tubers in chains together with the huge underground systems curtail translocation of herbicides and through growth dilution effects impairs herbicidal efficacy (Pereria and Crabtree, 1967). Experience has shown that the most vulnerable period in the life history of nutsedge, to control measures, is within 3 weeks after the first sprouts appear. During this period the weed is rapidly growing and no new tubers are yet initiated (Loustalot, *etal*. 1954; Nishimoto, 2001).Tubers and buds are very sensitive to desiccation and are killed by drying on exposure to sunlight and heat. However, the time taken by the tubers to lose viability is weather dependent (Senarathne, *teal* 2012).

In Sudan, *C. rotundus* was problematic in the Gezira scheme (Mahmoud, 1987). However, repeated cutting of the weed roots below the lowest tuber and leaving the severed tubers in the soil for at least a month provided adequate control (Andrews, 1940). Currently the weed constitutes a serious constraint to cotton production under spate irrigation in Elsemeyh Agricultural Scheme (EAS), in western Sudan (plate.1), where disc harrowing supplemented by hand weeding is the standard method of control.

Plate 1.1: *C. rotundus* stand in a farmer field under spate irrigation in Elsemeyh Agricultural Scheme.

The present study, comprising field and supplementary laboratory and screen house experiments, was therefore set with the primary objective of developing an integrated management strategy focusing on integration of cultural and chemical methods of control. Field and supplementary laboratory and green house experiments were set to determine the effects of temperature on tuber moisture loss, sprouting and viability, spatial distribution in soil and the efficacy of cultural and chemicals methods and their combination on management of the weed in EAS.

CHAPTER TWO

LITERATURE REVIEW

2.1. Purple Nutsedge

2.1.1. General:

Cyperus spp, commonly known nutsedges and/or nutsedge, are serious terrestrial and aquatic weeds. *C. rotundus* is ubiquitous in the world's humid tropics and subtropics and is considered the world's worst weed (Holm *et al*., 1977a). It is highly competitive, fast growing, and prolific. One of the main reasons for the difficulty in controlling it is the presence of tubers (Miles *et al*., 2002). The plants produce rhizomes, tubers, basal bulbs and fibrous roots below ground, and rosettes of leaves, scapes, and umbels above ground (Plate 2.1).

Plate 2.1: *C. rotundus* whole plant showing: tubers, basal bulbs, rhizomes and shoots.

The main type of underground stem found in Cyperaceae is the rhizome (Metcalfe, 1971). In some species, such as *C. rotundus*, the stem system consists of branches which combine to form a true underground network (Wills and Briscoe, 1970; Gifford and Bayer, 1995). Infestations predominantly originate in irrigated or low-lying, poorly drained areas, but can easily spread through the disturbance and growth of the aggressive rhizomes. *C. rotundus* is a prolific plant. It produces basal bulbs and tubers. McCarty *et al* (2008) observed the production of 174 to

554 *C. rotundus* tubers from a single plant after 18 wk of undisturbed growth. According to Bangarwa *et al.* (2008) Tubers may remain viable for more than 3 years if soil remains moist (Stoller and Sweet 1987), but survival in dry soil only lasts for a short period of time. The most important adaptation that enables *C. rotundus* to persist in turf is tuber dormancy. Dormancy prevents tubers from sprouting all at once, helping to maintain a reservoir of potential new plants in the soil profile (Stoller and Sweet, 1987).

2.1.2 Description

C. rotundus is highly variable perennial sedge. Flowering stems are erect up to 60 cm tall, 3-sided, smooth with swollen basses (basal bulbs).

The weed has an extensive subterranean tuber system connected with rhizomes (Hauser, 1962a; Quayyum *et al*. 2000; Singh *teal* 2009) (Plate 2.2).

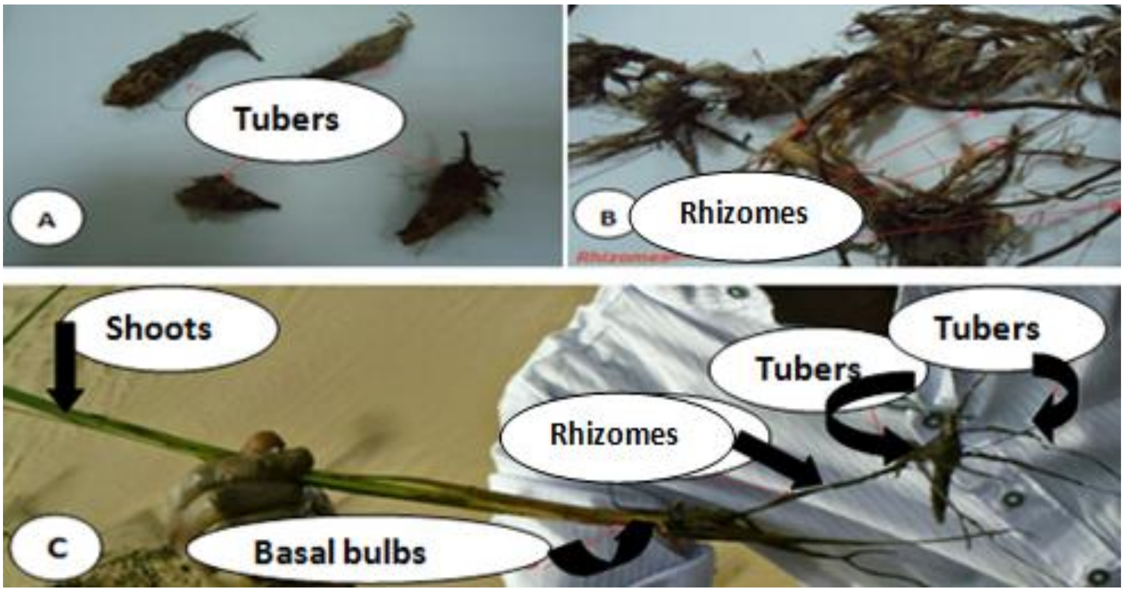


Plate 2.2: (A) *C. rotundus*: morphology of tubers, (B) rhizomes, (C) adult plant with basal bulbs.

The leaves have a distinct midrib, and they are linear, usually shorter than the flowering stem up to 7 mm wide and emerge from a sheath around the shoot base. The inflorescence is a terminal, open umbel subtended by several leafy bracts. Several unequal rays, 2-6 cm long, support 3-8 reddish-brown to purplish-brown flattened spikelet's, 1-2 cm long and 2 mm wide each with up to 30 glumes, 3.5-4 mm long. Roots are fibrous. Rhizomes are wiry, dark and persistent, connecting a network of daughter shoots and tubers. The tubers are dark brown to black, irregularly shaped and 1-2 cm long when fully grown. Each tuber has an apical bud and several lateral buds.

2.1.3.Taxonomic tree

Kingdom; plante – plants

Subkingdom; Tracheobionta – Vascular plants

Superdivision; Spermatophyta – seed plants

Division; Magnoliophyta – flowering plants

Class; Liliopsida – Monocotyledons

Subclass; Commelinidae

Order; Cyperales

Family; Cyperaceae – sedge family

Genus; *Cyperus* L. – flatsedge

Species; *Cyperus rotundus* L. – nutgrass

2.1.4 Origin and distribution

C. rotundus is thought by some authorities to have originated in India but others believe that the origins are more widespread, including northern and eastern Australia (Parsons and Cuthbertson, 1992). At present, the most widely accepted distribution range considers this species as native to the tropical and subtropical old world, principally Africa and Eurasia (Govaerts, 2014; USDA-ARS, 2014). Holm *et al*. (1977a) have recorded its occurrence in 92 countries but its presence can be assumed in all countries of the tropics and subtropics.

2.1.5. Economic importance

C. rotundus is among the world's worst weeds (Holm *et al*, 1977a). It is a serious problem in a wide range of crops throughout tropical and temperate areas, causing large losses in crop yield Holm *et al*. (1977b), Bewick. *et al*. (1995); Holm *et al*. (1991), Stall and Gilreath. (2001) reported that *C. rotundus* is particularly difficult to control. *C. rotundus* and *C. esculentus have* a remarkable ability to survive adverse conditions and then grows explosively under favorable conditions (Tumbleson and Kommedahl, 1961). *C. rotundus* impact varies with location, probably due to biotype, differences in climate, crop rotation, crop cultivar and species (Costa and Appleby, 1976; Keeley, *et al.*1983; Horak, *et al.* 1987). Losses can result when *C. rotundus* competes with crops to decrease yield or directly damage below-ground plant parts, such as onion bulbs (*Allium fistulosum* L*)* and potato (*Solanum tuberosum* L*)* tubers (Keeley, 1987).

2.1.6. Tuber biology

Approximately 50% of total dry matter produced by *C. rotundus*, partitioned into underground tubers and corms, are utilized for new sprouts and tuber multiplication (Jordan-Molero and Stoller, 1978). Tubers are recognized as the primary dispersal unit for the species. Tubers are produced on rhizomes and consist of rhizomatous tissue with numerous buds. The buds sprout and initiate rhizomatous growth which develop into seedlings typical of most monocotyledonous plants and eventually grow into mature plants.

In *C. rotundus*, basal bulbs are similar to tubers in appearance and sprouting. Basal bulbs, sometimes called corms are, also reported to fuse with tubers to form propgules with large amounts of starch. Hauser. (1962a) reported that basal bulbs sprout and differentiate into plants quickly, whereas tubers often remain dormant. Morphological differences between tubers and basal bulbs have not been described adequately, making the interpretation of some tuber biology literature tentative (Hauser. 1962a). However, the biology of these structures may be similar enough to make exact identification superfluous (Hauser, 1962a). *C. rotundus* produces a complex underground system of basal bulbs, rhizomes, and tubers. Shoots arise from the basal bulbs as a fascicle. Basal bulbs are primary site for prolific vegetative growth because they contain the meristems for leaves, rhizomes, roots, and flower stalks (Stoller and Sweet, 1987).

2.1.6.1. Tuberization and tuber longevity

Tuber formation begins from 4 to 6 weeks after seedling emergence. Many authors reported that more than 95% of *C. rotundus* tubers usually are formed in the upper 45 cm of most soils and more than 80% of tubers occur in the upper 15 cm (Stoller and Sweet, 1987). When *C. rotundus* are cultured in fields without interference from other plants, they produce an estimated 10 to 30 million tubers per ha in a season (Hauser, 1962a; Horowitz, 1972; Stoller and sweet, 1987). Rhizomes do not penetrate deeply in heavy textured soils, so tubers are distributed deepest in light-textured soils (Stoller and Sweet, 1987). Due to apical dominance and bud dormancy, tubers remain in the soil for extended periods before sprouting. Control would be facilitated if tuber longevity were short enough so that all buds could sprout at the same time so the resultant plants could be killed (Stoller and Sweet, 1987). Tuber longevity is influenced by soil moisture and temperature. Davis (1942) reported that for tuber survival a minimum of 6% soil moisture is required.

2.1.6.2. Tuber dormancy

Each tuber of *C. rotundus* has multiple buds, most of which remain dormant and act as a reserve in the event that the active shoot is destroyed (Stoller and Sweet, 1987). Tuber chains (Plate 2.3) show apical dominance, so that the terminal tuber initiates active growth while many or all of the others on the chain remain dormant unless the terminal tuber is destroyed or the chain is broken (Joel *et al* 2002).

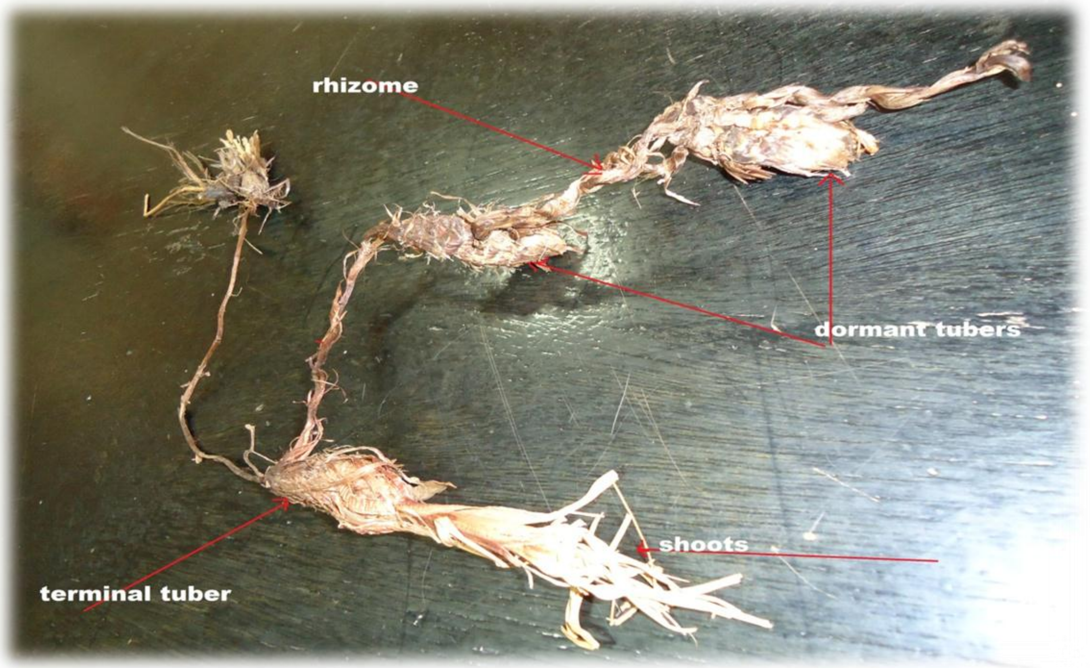


Plate 2.3: A chain of *C. rotundus* tubers showing a shoot arising from a terminal tuber and dormant tubers

Dormant tubers commonly persist in the soil for 3 -4 years and can remain viable for as long as 10 years in some conditions (Horowitz, 1972). *C. rotundus* initiates its seasonal growth cycle almost entirely from tubers, as viable seeds rarely occur in this species. Tuber dormancy is broken by high temperature (90-100 °F) and diurnal temperature fluctuations (Horowitz, 1972). In Hawaii populations, 30 minute daily pulses of 95 °F over a baseline of 68 °F stimulated shoot emergence from tubers as effectively as continuous 95 °F and an alternating regime of 65 °F and 75 °F resulted in more emergence than constant 75°F (Miles *et al*., 1996). This response to temperature fluctuation promotes nutsedge emergence in the absence of a shading canopy. Chilling has been reported to promote tuber sprouting (Shamsi *et al*., 1978) but tubers are killed by freezing temperatures (Holm *et al*., 1991).

2.1.7 Effect of temperature on tuber sprouting

Tubers are sensitive to temperature fluctuations. Negligible sprouting occurs at low temperature (10 °C). However, optimum temperature for germination is at variance. Horowitz (1972) reported a temperature of 25-35 °C as optimum for sprouting. Nishimoto. (2001) reported that high summer temperature has no negative effect on tuber production, and maximum tuber sprouting occurs at 43 °C. Both increased overall temperatures and daily temperature differences could have significant effects on tuber sprouting. An increase in temperature over 43 °C is enough to kill tubers (Horowitz *et al*., 1983) or newly emerging plantlets (Chase *et al*. 1999; Patterson 1998). However, temperatures lethal to tubers were attained only in the top few centimeters (Horowitz *et al*., 1983; Chellemi *et al*., 1997; Rubin and Benjamin, 1983, 1984). In Hawaii, 10% of the tubers were found below 15 cm (Siriwardana and Nishimoto, 1987), where lethal temperature would be unlikely to occur.

2.2. Control Methods

Several methods have been tried for the control of *C. rotundus*, including cultural, biological and chemical measures (Barberi, 2002). These methods, however, have only limited impact when each was used alone and a need for integrating various methods is a necessity for adequate control (Barberi, 2002). *C. rotundus* is renowned for its invasive nature and accordingly combinations of control methods should be adopted as deemed necessary taking into account the stage of the invasion process, size of infected area and its importance with respect to expansion of the weed into neighboring free areas. For invasive weeds all methods of control including prevention, cultural, chemical and biological could be rallied with the primary objective of curtailing spread of the weed.

2.2.1. Prevention

Prevention of spread of the weed should be an integral part of the management strategy. Tubers spread over long distances through farm equipment, water and soil movement particularly with transplants (Menashe,1972) Cleaning farm equipment from adhering soil, prohibition of moving transplants from infected sites together with continuous monitoring of *C. rotundus* free areas and eradication of new infestation will be quite effective in deterring the weed spread to new areas.

2.2.2. Cultural methods.

These comprise many of the traditional methods, including, hand pulling, mowing, solarization, tillage comprising, harrowing, ploughing and deep – blading, crop rotation and nitrogen fertilizers.

2.2.2.1. Manual control

Hand pulling is a common procedure adopted by small farmers. However, it is tedious, not effective and not practical under heavy infestation.

Plate 2.4: Cultural methods of control: hand pulling

2.2.2.2. Mowing

C. rotundus can successfully grow under continuous mowing without losing tuber-sprouting ability (Santos *et al*. 1997). Summerlin *et al*. (2000) reported reductions in *C. rotundus* rhizome length, tuber size, and tuber production when plants were mowed at 1.3 and 3.8 cm compared with a non-mowed check. Although mowing has been shown to suppress growth, additional control methods must be used to effectively reduce *C. rotundus* populations over time.

Plate 2.5: cultural methods of control: mowing

2.2.2.3. Solarization

Soil solarization using polyethylene films were reported to effect adequate control of several weed species including C. *rotundus* through increasing soil temperature (Katan *et al*., 1976). Horowitz *et al.* (1983) suggested that the polyethylene films could also provide a physical barrier. However, reports on the effectiveness of polyethylene mulch on suppression of *C. rotundus* are contradictory (Locascio *et al*.,1997; Motis *et al*., 2002, 2003). Omezine and Harzallah. (2009) reported reduction in top growth, but no effect on regeneration. Patterson, (1998) reported that the efficiency of the polyethylene mulch is dependent on colour. In the dark polyethylene mulch, irrespective of colour or opaqueness provided good suppression of the weed. Under light the weed is capable of penetrating black and opaque polyethylene mulch but not colour translucent ones. Shoots emerging under clear or translucent films become trapped as their leaves open in response to light. The trapped foliage is often heat killed, where as tubers are weakened but rarely killed.

2.2.2.4. Crop rotation

C. rotundus, a C4 plant is endowed with high photosynthetic capacity and high water use efficiency under high temperature and high light intensity (Lati *et al*., 2011; Igbal *et al*., 2012). However, the plant is sensitive to shading. Shade is reported to reduce growth, competitive potential and tuberization (Pereria and Crabtree, 1967). Crop varieties characterized by rapid canopy closure may be effective in suppressing the weed. Fodder crops, by virtue of high seeding rate and the need for animal feed in summer, are more suitable to be included in the rotation. Sudan grass (*Sorghum sudanense* L.*)* which is a common warm season forage crop that grows well under hot climate conditions effectively reduced *C. rotundus* growth and tuber production. Further, it provides the additional benefit of producing an economically valuable crop.

2.2.2.5. Fertilizers.

Fertilizers may be an important component of integrated *C. rotundus* management. Richards and Whytock (1993) found that the weed cover and the weed biomass were higher at high nitrogen rates. However, reports on the effects of fertilizers specially nitrogen on growth and tuberization are at variance. Garg *et al*., (1967); Kim and Nakayama, (1984) and Bohowmik, (1997) reported that nitrogen affects rhizome differentiation into basal bulbs and tuber forming rhizomes and an increase in nitrogen promoted basal bulb formation and shoot growth, but reduced tuberization. However, Igbal *et al*., (2012) reported an increase in number of tubers and aboveground parts of the plant.

2.2.2.6. Tillage

Tillage is one of the major cultural control methods for *C. rotundus*. Hauser (1962a) reported that a single cultivation does not impact the number of *C. rotundus* tubers. However, repeated shallow tillage at frequent intervals was recommended to reduce *C. rotundus* tuber multiplication (McGiffen *et al*., 1997). Approximately 95% of *C. rotundus* tubers are confined to the top 12 cm of soil (Bangarwa *et al*., 2008). Tillage causes a breakup of tubers from aerial shoots, roots, and other tubers in chains, bringing them close to the soil surface where they are subjected to temperature fluctuation, which could be promotive to sprouting and establishment or destruction depending on soil temperature and moisture, carbohydrate starvation, desiccation, and injury (Smith and Mayton, 1938; Hauser, 1962b; Glaze, 1987). (plate 2.7). The depth of tillage is an important factor in the disturbance and mixing of soil and in the cutting of weed roots.

Deep-blading in the Gezira, using the Felico blade was found to be the most effective method for controlling *C. rotundus*, *Cynodon dactylon* and *Ischarmum afrum* (Andrews, 1940). Selection of type machine to be used depends on the crop to be grown, the nature of weed, and the level of infestation. Consequently, land in the Gezira was classified into four categories (Mahmoud, 1987).

Category 1: Included cotton land which is moderately infested mainly with *Cynodon dactylon* L. and *Ischarmum afrum* L.

The primary tillage system adopted for this category was deep ploughing (30-40 cm). The implements used were the Felico blade, disc plough, and chisel plough (Plates2.6-2.8).

Plate 2.6: cultural methods of control: disc harrow

Plate 2.7: cultural methods of control, disc plough

Plate 2.8: Cultural methods of control: deep blading

Category 2: Included cotton land which is heavily infested with noxious weeds. The dominant weed is *Cyperus rotundus* (nut grass). These areas were treated with the Felico blade at 30-40 cm depth.

Category 3: Comprised the fallow land which is intended to he planted with cotton in the following season. This land is deeply ploughed with the Felico blade. The aim was to cut the weed roots-mainly *Cyperus rotundus*, *Cynodon dactylon* and *Ischarmum afrum* and expose them to dry during the hot summer period.

Category4: Included the other crop areas (groundnut, wheat, and sorghum). These areas received minimum soil manipulation depending on the degree of weed infestation. Some areas were treated with shallow harrowing, others were ridged with a lister ridging machine (dry ridging). Immediately prior to planting, the ridges were split with the same machine oriented to build the new ridge on the old furrow. It is evident from the above review of the past practices in land preparation that Felico blade was the main tool used extensively in the Gezira scheme to control perennials weeds. The Felico blade is a wide tine which requires high draught when working at 30-40 cm depth. The blade cuts the soil at depth and raises the cut soil upwards with little disturbance. As the blade moves away, the cut soil returns to its original position. For this study a proto-type Felico blade machine was adapted as depicted in plate 2.8 (Appendix1).

2.2.3. Biological methods

Most of the biological control work undertaken so far has involved insect natural enemies with little success (Julien and Griffiths 1998). Kadir and Charudattan (2000) reported a host specific fungal isolate that induces leaf spots which cause foliar lesions and kills *C. rotundus*. However, performance of the fungus is influenced by environmental conditions.

2.2.4. Chemichal methods

Various chemicals including herbicides and fumigants have been used to combat *C. rotudus*.

2.2.4.1 Herbicides

According to Webster (2005) glyphosate and paraquat are commonly used nonselective herbicide for controlling weeds. Several herbicides have been recommended for control of *C. rotundus*. Among these herbicides, glyphosate, a foliar acting non-selective herbicide, is the most commonly used. The herbicide, translocates through the chains of *C. rotundus* tubers and reduces tuber viability and production. Zandstra and Nishimoto (1977) and Doll and Piedrahita, (1982) showed that glyphosate is absorbed by *C. rotundus* within one hour after spraying, resulting in adequate control. Glyphosate inhibits the shikemic acid pathway resulting in inhibition of biosynthesis of aromatic amino acids which are essential for protein synthesis. Fischer *et al*. (1995a) found that the total free amino acids in *C. rotundus* tubers progressively decreased during the first 2 weeks after sprouting and disappeared by the end of the fourth week. The slow disappearance of the amino acid reserves is consistent with the slow action of the herbicide as manifested in the slow development of phytotoxicity symptoms (Burke *et al*. 2008).

To determine the optimal application timing of glyphosate, it is important to determine the most sensitive stage of *C. rotundus* growth. In perennial weeds timing of application of foliar herbicides is to be synchronized with the stage, where carbohydrates reserves are lowest (Babiker, 1976). At the lowest carbohydrate reserves bud formation is maximal and also is basipetal translocation of assimilates which follow a source sink relationship (Fischer *et al*., 1995a).

The tubers serve as perenniating organs by storing carbohydrates in a continuous reproductive cycle. When a tuber sprouts carbohydrates are consumed and initially the growing shoot depends entirely on carbohydrates supply from the storage reserves in the tubers. However, when assimilation exceeds the growth requirements of the plant, downwards translocation of carbohydrates, driven by a strong sink comprising initiation and sprouting of buds, commences. Foliar applied systemic herbicides including glyphosate are renowned for their movements with assimilates following a sink-source relationship. Jordan, (1996) and Anderson, (1999) reported that chlorimuron and imazethapyr applied to 2- to 6cm. tall *C. rotundus* gave better control than when applied to 8- to 10-cm-tall *C. rotundus*. Fischer *et al*. (1995b) pointed out that the young shoot growth of *C. rotundus*, within 8 days after tuber sprouting, was sensitive to benfuresate in soil, whereas the older plants recovered from herbicide injury. Nonselective herbicides can be used before crop sowing to reduce *C. rotundus* infestation. On the whole, the effectiveness of herbicides on *C. rotundus* showed dependence on the cropping system. Options to control this weed in direct-seeded rice are limited (Chauhan. 2012). The aerobic soil conditions in direct-seeded rice were reported to increase infestation (Mahajan and Chauhan, 2011). Recently, there has been an interest in integrating cultural practices with herbicides in management programs in direct-seeded rice (Johnson, 2010 and Chauhan, 2012).

To date, there have been few studies focusing on the determination of the growth stage of *C. rotundus*, which is most sensitive to glyphosate. *C. rotundus* bud growth is found to be more sensitive than tuber sprouting to glyphosate when glyphosate is directly absorbed by the tubers and roots. Therefore, if cultivation practices in fallow or before cropping could promote sprouting of tubers a better kill of the weed will be realized.

2.2.4.2. Fumigants

Currently, the most effective *C. rotundus* control strategy in tomato is the combination of between row application of nonselective herbicides such as paraquat, along with in-bed fumigations with a broad-spectrum soil fumigant, such as methyl bromide (MBr) (James and Bielinski, 2005).

2.2.5. Integrated management

Most of the above methods have been used to combat *C. rotundus* in several production schemes, and integrated strategies were used to manage purple nutsedge (Bangarwa *et al.*, 2008). However none of these methods, effected adequate control when used alone and the need for an integrated approach is imperative. Integrated weed management (IWM) is a cropping systems approach that relies on essential knowledge for its implementation and focuses on crop health (Neeser. *et al.*, 1997) and on ecological mechanisms, whereby the farming practices can contribute to weed suppression, with particular attention to impacts on weed regeneration, resource use, allelopathic interactions and soil-borne pathogens (Davis and Liemman 1999). *C. rotundus* is a prolific tuber producer (Joel *et al.*, 2002). The amount of tubers produced thus affects efficacy and sustainability of management. Any practice that reduces tuber production should be considered a key element in a sustainable *C. rotundus* management programme (Chauhan, 2012). Tuberization is influenced by a multitude of factors including shading which could be achieved through selection of crop species, crop cultivar, seed rate, and spatial arrangement of crop plants. Further seed bed preparation and crop residues suppress and delay emergence of the weed. Post-emergence herbicides as glyphosate and the fumigant methyl bromide could effect adequate control if properly used. Methyl bromide was a critical component of *C. rotundus* management (Schneider *et al.*, 2003). However, the use of methyl bromide as a pre-plant pest management tool was abolished (Webster, 2005). Thus, it is apparent that the complexity of *C. rotundus* necessitates employment of several tactics for its management (Patterson, 1998; Webster, 2005). Brecke *et al*. (2005) noted that *C. rotundus* control, averaged across all herbicides, improved from 60 to 66% when supplemented by hand weeding at weekly interval.

CHAPTER THREE

MATERIALS AND METHODS

3.1. General

A series of field and supplementary laboratory and screen house experiments was undertaken during the course of this study. The laboratory experiments were conducted at the College of Agricultural Studies (CAS), Sudan University of Science and Technology (SUST) at Shambat. The field experiments were undertaken in the Northern Kordofan State (NKS) at the premises of EAS during seasons 2013/14 and 2014/15 in field known to be heavily infested by *C. rotundus*. The primary objective of the experiments was to develop an integrated management strategy for *C. rotundus* which resides on cultural and chemicals methods of control to improve cotton production.

3.2. Laboratory Experiments

The laboratory experiments were undertaken employing tubers collected from a field at EAS in April 2013 to study spatial distribution of *C. rotundus* within the top 30 cm of soil, fluctuations in tuber moisture contents with soil depth, rate of moisture loss and sprouting capacity of *C. rotundus* tubers as influenced by the soil depth in which they were in before exhumation and effects of temperature on tuber sprouting and viability. Experimental design was complete randomized with 4-5 replicates.

3.2.1. Tubers collection and preparation

Tuber samples were taken from 2 sites (125×125m each) 7 kilometers apart. In each site soil pits, 1 m^2 in area and 0.3 m in depth and 20 m between pits were dug along a set of intersecting horizontal and vertical lines traversing each site as shown in plate 3.1, A and B.

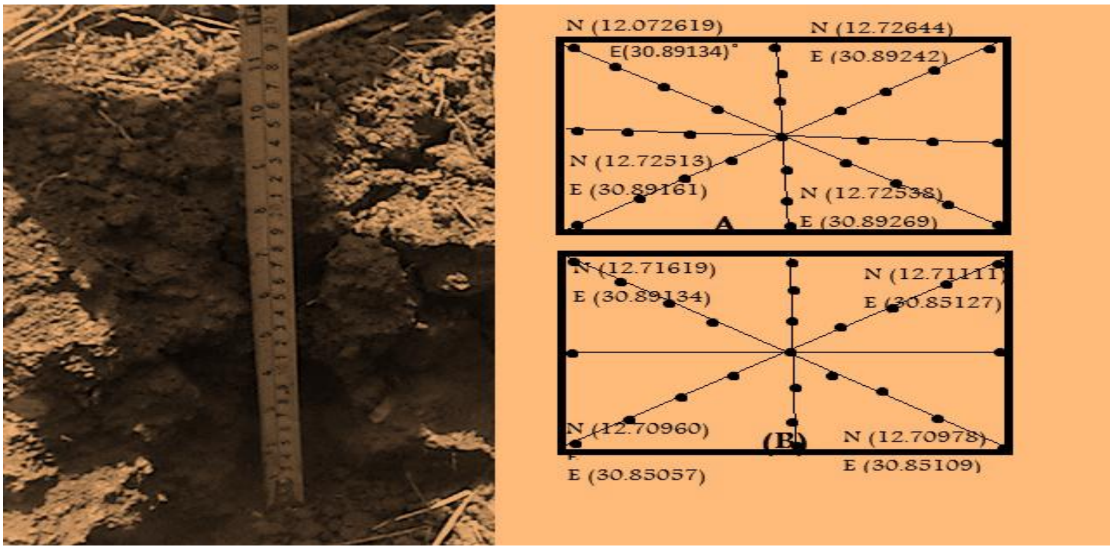


Plate 3.1: depth and lay out of soil pits with GPs points. A) Soil pit, B) pits lay out

Tubers were collected from each of the soil layers 0 – 10, 10 – 20 and 20 – 30 cm (Plate 3.2). The tubers, in each layer, were counted and subsequently kept in a fridge at 4 ˚C till used. A sample of tuber was randomly picked and divided into sets comprising 8 tubers, each. The Tubers were assayed for moisture content, sprouting ability, heat tolerance and viability using the TTC test. For each measurement 4 replicates were used.

Plate 3.2. Tubers collected from difference layers depth.

Plate 3.3 Recovery of *C. rotundus* from soil pits

3.2.2. Tuber moisture contents

Tubers collected from the different soil depths were made into sets as in 3.2.1. The sets, replicated 4 times each, were weighed and subsequently placed in an oven set at 70 ºC (Plate 3.4). The tubers were incubated in the oven and monitored for constant weight every 10 h up to 40 h. where a constant weight was attained.

Plate: 3.4. Tubers sets placed in paper bags.

3.2.3. Effects of heat on tuber moisture loss

Tubers sets were prepared and replicated as above and their initial weight recorded and subsequently placed in an oven set at 70 ˚C. The tuber sets were retrieved at different time intervals (1-32h), placed in a dissector, allowed to cool to room temperature and re-weighed. Moisture loss was determined by the method of difference.

3.2.4. Effects of heat on tuber sprouting and viability

Tuber sets prepared and replicated as above were placed in an oven set at 70 ˚C. The tubers were retrieved at different times as above (1-32 h). Assessment of sprouting capacity was made in a screen house using plastic pots (31 cm i.d.), with perforations at the bottom, filled with soil sand mixture (2:1 v/v). *C. rotundus* tubers (8) were sown at 2 – 3 cm soil depth in each pot (Plate 4.1). The pots were irrigated immediately. Subsequent irrigations were made every two days. Emerged *C. rotundus* shoots were counted 3, 6, 9, 12, 15, 18 and 21 days after sowing (DAS).

Plate 3.5: Tuber planting

After the last observation on sprouting (21 DAS) the non sprouting tubers, exhumed, thoroughly washed with tap water, were cut longitudinally and assessed for viability employing the Tetrazolium test. Tetrazolium chloride 2, 3, 5-triphenyl tetrazolium chloride (TTC) 0.5 g was dissolved in water and brought to volume (100 ml). The cut tubers were immersed in 25ml of the TTC solution for 6 h and observed for red colour development. Tubers developing red colour were considered viable.

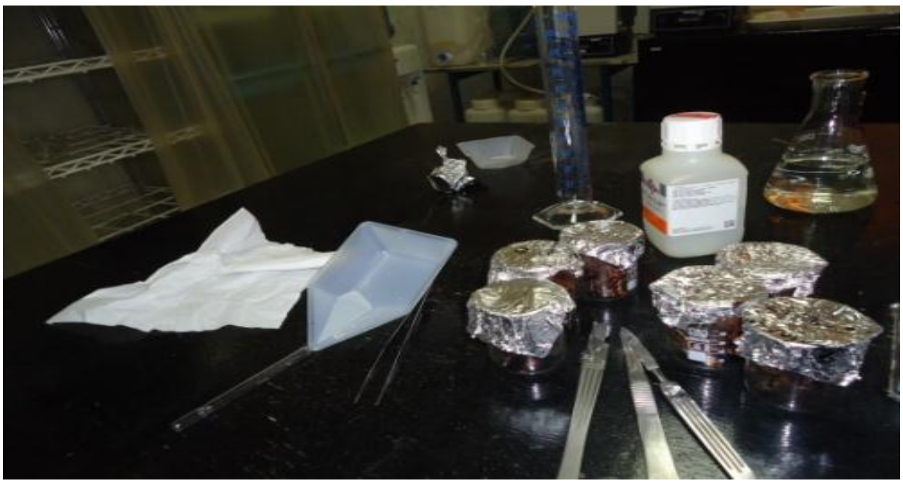


Plate 3.6: Preparation of TTC solution

3.3. Field Experiments

3.3.1 General

Four field experiments were conducted at EAS in season 2013/14 and 2014/15. The first experiment was undertaken to study the effects of exposure time on the soil surface on tuber sprouting capacity. The second experiment was conducted to access root development of *C. rotundus* with time after emergence. The third and fourth experiments were designed to evaluate the efficacy of selected cultural and chemical treatments on *C. rotundus* and their effects on cotton growth and yield.

3.3.2. First season

3.3.2.1. Effects of exposure on soil surface on tuber moisture contents and sprouting

Tubers (*ca* 400) were collected, randomly, from a deep ploughed (>30cm) field at EAS in mid April. Four sets of tubers, comprising 5 tubers each, were made, had their initial weight determined and subsequently placed in air-tight polythene bags and kept in a refrigerator at 4°C to curtail dehydration. The rest of the tubers were returned back to the field and placed on the soil surface. The tubers were randomly sampled, 4 sets comprising 5 tubers each, at a time, over a period of 16 days and placed in a refrigerator as above. The tuber sets, weighted, were subsequently planted in 2L plastic bags filled with soil and immediately irrigated. Subsequent irrigations were made as needed. At termination (3 WAS) tubers were retrieved and examined for sprouting.

3.3.2.2. Root development

Thirty six plants were selected, randomly, on the first day of their emergence and tagged using flags. Twelve plants selected randomly, at 7, 14 and 21days after emergence were carefully dug, washed off and the length of the longest root was measured using a tape.

Plate 3.7: *C. rotundus* roots measurements

3.3.2.3. Effects of cultural and chemical methods on *C. rotundus* control and cotton growth and yield

The treatments comprised deep blading (>30 cm), achieved by a Felico blade, designed and developed by the technical team in Agricultural Section of the EAS (Appendix1), deep ploughing (30 cm) using a disc plough, undertaken on mid April 2013/14, and urea and glyphosate applied at cotton planting. For spate irrigation water was admitted into the field in the last week of July and withdrawn 2-3 weeks later. Cotton (*G. hirsutum*) Bt was manually planted in rows in 4 cm deep holes, 2-3 seeds per hole, at spacing of 50 cm between rows and 30 cm between holes, one week after water withdrawal. The herbicide glyphosate (1.52 kg ae. fed^{-1}) and urea (50 kg fed^{-1}) were applied at cotton sowing. Glyphosate was applied as an aqueous spray using a knapsack sprayer at a volume rate of 100 L fed^{-1}. Urea was applied as broadcast by hand. Subplot size was 25 × 25 m. Treatments were arranged in a randomized complete block design with 5 replicates. Treatment effects were assessed by counting the number of *C. rotundus* over ground shoots in 2 quadrates ($1m^2$ each) taken randomly in each sub-plot, at sowing and 2 and 3 weeks later. Cotton height, open and total number of bolls were determined 17 WAS. Seed cotton yield was determined at harvest. The harvested area was 23 x 23 m.

3.3.3. Second season

3.3.3.1 Effects of selected cultural and chemical treatments on *C. rotundus* and cotton growth and yield

The experiment was conducted in season 2014/15. Sub-plot size and experimental design were as in section 3.3.2.3. Treatments, comprising disc harrowing and deep ploughing were conducted in April as above. Some of the ploughed sub-plots received glyphosate (1.5 kg ae fed^{-1}) at 4 weeks after spate irrigation. Another set of sub-plots received a tank mix of glyphosate (1.5 kg ae. fed^{-1}) and pendimethalin (0.5 kg a.i. fed^{-1}). Cotton sowing and assessment of treatment effects were conducted as previously described in section 3.3.2.3.

3.4. Statistical Analysis

The data collected were analyzed by descriptive statistics (mean, percentage, standard error, regression analysis) and by analysis of variance whichever relevant. The computer package STATISTICX 8, a menu-driven programme with broad applicability to a variety of data analysis, was employed.

CHAPTER FOUR

RESULTS

4.1. Laboratory Experiments

The laboratory experiments comprise assessment of spatial field distribution of *C. rotundus* tubers in the soil profile, effects of soil depth on tuber fresh weight, moisture contents and effects of heat on moisture loss and tuber viability.

4.1.1. *C. rotundus* tuber distribution and fresh weight as influenced by soil depth.

The number of *C. rotundus* tubers decreased with soil depth (Table 4.1).The highest number of tubers (32 m-2) was displayed in the top soil layer (0-10 cm soil depth) followed in descending order by the second (10 – 20 cm) and third layers (20 – 30 cm). Fresh weight of tubers mirror imaged the tuber distribution in soil. Fresh weight of tubers was 58.1, 20.0 and 11.6 g. The fresh weight per tuber was 1.82, 1.04 and 0.885g at the top, middle and bottom soil layer, respectively.

Table 4.1 *C. rotundus* tuber distribution and fresh weight as influenced by soil depth

Treatments (soil depth cm)	Weight (g/m^{-2})	Number (tuber m^{-2})
0 – 10cm	58.1a	32.0a
10-20cm	20.0b	19.3b
20-30cm	11.6b	13.6c
S.E.±	5.05	2.78

Means within a column followed by the same letter(s) are not significantly different at P≤ 0.05 according Duncan Multiple Range Test (DMRT).

4.1.2. Tuber moisture contents as influenced by soil depth

Tuber water content varied with soil depth from where the tubers were exhumed (Table 4.2). Tubers at top soil layer (0- 10 cm) had the highest water content (30.3%) followed in descending order by tubers collected from the second (10 -20 cm) and third (20 – 30 cm) soil depth.

Table 4.2 *C. rotundus* tuber water contents as influenced by soil depth

Soil depth (cm)	**Moisture (%)**
0 - 10cm	30.3a
10 - 20cm	13.1b
20 - 30cm	4.5c
S.E.±	2.2

Means within a column followed by the same letter(s) are not significantly different at P≤ 0.05 according DMRT

4.1.3. Effects of heat on tuber moisture loss

Tubers at the top soil layer (0-10 cm) showed less than 1% moisture loss up to 2 h following exposure to 70˚C (Table 4.3). An increase in exposure time to 4 h increased moisture loss by about 4-fold. A further increase in exposure time to 8 h did not cause a further significant loss in moisture content. However, at 16 and 32 h moisture loss increased by 1 to over 2-fold. Tubers collected from the second soil layer (10-20 cm) showed slightly different pattern of moisture loss. Tuber moisture loss was less than 1% subsequent to 1 h of exposure to 70˚C. Increasing exposure time to 2 and 4 h increased moisture loss by about 1.3 and 2.8-fold, respectively. However, differences between the two treatments were not significant. A further increase in exposure to heat for 8 h increased moisture loss significantly. An increase in heating time to16 h increased moisture loss to 7.4%. A further increase in heating time to 32 h resulted in slight non-significant increase in moisture loss. Tubers at 20-30 cm soil depth displayed a progressive increase in moisture loss (Table 4.3).

Exposure to heat for 1 h resulted in about 1% loss in moisture contents. Increasing exposure time to 2 h resulted in a significant increase in moisture loss. A further increase in heating time to 4-16 h increased moisture loss, albeit not significantly. However, a further increase in exposure time to 32 h resulted in a significant increase in moisture loss in comparison to exposure times of 1-4 h, but not for the 8-16 h where only non-significant increments were realized (Table 4.3).

Table 4.3 Tuber moisture loss as influenced by time and soil depth

Exposure time (h)	**Moisture loss (%)** **Soil depth (cm)**		
	0 -10 cm	**10 -20 cm**	**20 -30 cm**
1	0.9d	0.8d	1.1c
2	1.0d	1.8cd	2.3b
4	5.6c	2.9c	2.3b
8	5.8c	4.4b	2.4ab
16	10.1b	7.4a	2.5ab
32	18.8a	8.4a	2.6a
S.E.±	0.88	0.60	0.14

Means within a column followed by the same letter(s) are not significantly different at P≤ 0.05 according DMRT.

4.1.4. Effects of heat on tuber sprouting and viability

Tubers harvested from the 0-10 cm soil depth showed 84.4% sprouting. However, on exposure to heat for 1 -2 h sprouting was reduced to 9.4% (Table 4.4). A further extension of the heating time to 4 h or more resulted in complete suppression of sprouting. Tubers collected from the 10-20 cm soil depth showed 21.9% sprouting. Tuber exposure to heat for 1 h had no effect on sprouting. However, sprouting was completely suppressed when the tubers were exposed to heat for 2 h or more. Tubers collected from the 20-30 cm soil depth showed 15.2% sprouting. However, sprouting was completely suppressed on exposing the tubers to heat for 1 h or more (Table 4.4, Plate 4.2).

Table 4.4 *C. rotundus* tuber sprouting as influenced by heat and soil depth

Exposure time (h)	Sprouting (%) Soil depth (cm)		
	0 -10 cm	**10 -20 cm**	**20 -30 cm**
0	84.4a	21.9a	15.6a
1	9.4b	21.9a	0.0b
2	9.4b	0.0b	0.0b
4	0.0b	0.0b	0.0b
8	0.0b	0.0b	0.0b
16	0.0b	0.0b	0.0b
32	0.0b	0.0b	0.0b
S.E.±	5.62	5.07	4.2

Means within a column followed by the same letter(s) are not significantly different at P≤ 0.05 according DMRT.

Plate 4.1. Effects of heat *on C. rotundus* tuber sprouting

4.1.5. Effects of heat on tuber viability

Viability of the tubers failing to sprout (Table4.4) as indicated by the TTC test was influenced by both soil depth and time of exposure to heat (Table 4.5, Plate.4. 3. A-D). Tubers collected from the top soil layer and not exposed to heat showed 75% viability. On exposure to heat at 70 ºC for 1 h a slight non-significant increase in viability was observed. A further increase in time of exposure to 2 h decreased viability to 43.8%. Tubers exposed to 70 ºC for 4 h or more showed complete loss of viability as indicated by the TTC test. Tubers collected from the middle soil layer (20-30 cm) and not exposed to heat or exposed to heat for 1 h displayed 78.1% viability. A further exposure to heat for 2 h or more resulted in complete loss of viability. Tubers collected from the bottom soil layer, when not exposed to heat displayed 84.4% viability. However, on exposure to heat for 1 h or more a complete loss in viability was realized.

Table 4.5 *C. rotundus* tuber viability as influenced by heat, exposure time and soil depth

Exposure time (h)	**Viability (%)** **Soil depth (cm)**		
	0 -10 cm	**10 -20 cm**	**20 -30 cm**
0	75.0ab	78.1a	84.4a
1	92.3a	78.1a	0.0b
2	43.8b	0.0b	0.0b
4	0.0c	0.0b	0.0b
8	0.0c	0.0b	0.0b
16	0.0c	0.0b	0.0b
32	0.0c	0.0b	0.0b
S.E.±	16.66	5.07	4.20

Means within a column followed by the same letter(s) are not significantly different at P≤ 0.05 according DMRT.

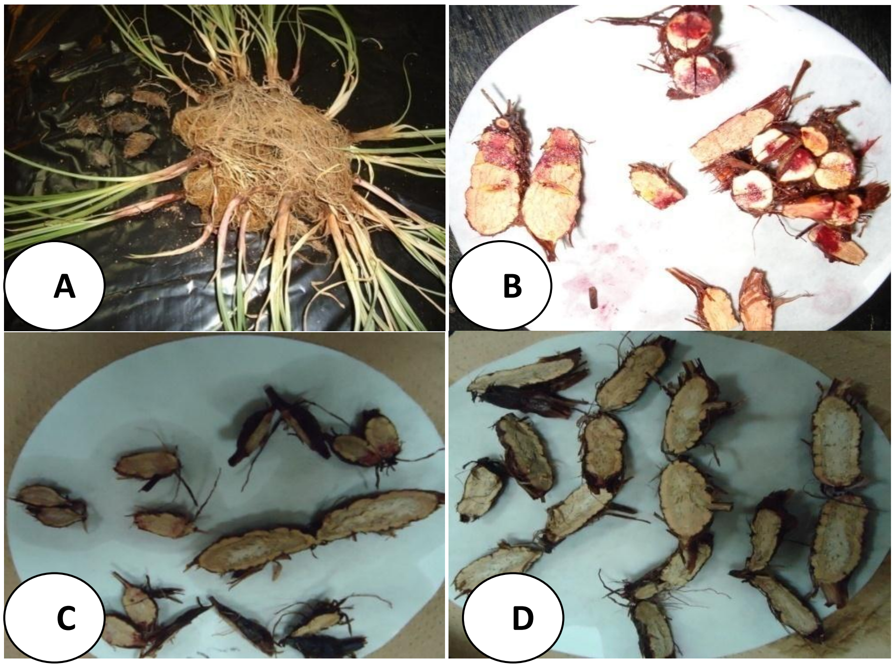


Plate 4.2. Effects of heat treatment on tuber viability as indicated by sprouting and the TTC test. A) Untreated control, B) TTC treated un-sprouted tubers from untreated control, C) 2 h heated TTC treated tubers and D) 4 h heated TTC treated tubers.

4.2. Field Experiments

Two experiments were undertaken in two seasons to study, i) effects of exposure time on the soil surface on *C. rotundus* tuber sprouting and ii) the effects of cultural and chemical control methods on *C. rotundus* and cotton growth and yield.

4.2.1. First season

4.2.1.1 Effects of exposure time on soil surface on tuber moisture contents and sprouting

Air temperature during the study period (16 days) was 35.95- 39.8 ºC. Tubers exposed on the soil surface for 1 an 2 days displayed 4.4 and 5.5 % moisture loss, respectively (Table 4.6). A further increase in exposure time to 4 and 8 days increased moisture loss to 10.6 and 13.7%, respectively. On further increase of exposure time tubers displayed 20% loss in moisture content.

Tubers collected from the field at same time as the others, but kept in a fridge at 4 °C showed 75% sprouting (Table 4.6, Plate 4.4). Exposure on surface soil for 1 or 2 days showed similar sprouting (75%). However, increasing exposure time to 4 and 8 days reduced sprouting to 50 and 20%, respectively (Table 4.6). A further increase in exposure time to 16 days resulted in complete inhibition of sprouting.

Table 4.6 *C. rotundus* moisture loss and sprouting as influenced by time of exposure on the soil surface

Exposure time (days)	**Moisture loss (%)**	**Sprouting (%)**
0	-	75.0a
1	4.4c	75.0a
2	5.5c	75.0a
4	10.6c	50.0b
8	13.7b	20.0a
16	20.0a	0.0
S.E.±	1.68	15.25

Means within a column followed by the same letter(s) are not significantly different at P≤ 0.05 according DMRT.

Plate 4.3. Effects of exposure time on the soil surface on *C. rotundus* tuber sprouting capacity.

4.2.1.2 Roots development as influenced by time after spate irrigation

One week after emergence *C. rotundus* seedlings showed an average root length of 20 cm. At 2 and 3 weeks after emergence root length increased by 33 and 66% respectively.

Table.4.7. *C. rotundus* root development with time (main root)

Time after emergence (weeks)	Roots length (cm)
1	20.6c
2	27.4b
3	34.2a
S.E.±	2.12

Means within a column followed by the same letter(s) are not significantly different at P≤ 0.05 according DMRT.

4.2.1.3. Effects of cultural and chemical methods on *C. rotundus* control

C. rotundus counts made at cotton sowing (one weeks after water withdrawal) showed that disc ploughing, and deep-blading reduced *C. rotundus* population density by 93.3% and 84.3%, respectively in comparison to the untreated plots (Table 4.8). However, at two weeks after sowing plots treated with urea showed the highest *C. rotundus* population density. Disc ploughing, deep-blading and glyphosate reduced *C. rotundus* population density by 90, 63.5 and 98%, respectively in comparison to the urea treatment. At 3 weeks after sowing the urea treatment sustained the highest *C. rotundus* population density. Disc ploughing, deep-blading and glyphosate reduced population by 81, 62.6 and 97.3%, respectively in comparison to the urea treatment (Table 4.8).

Table 4.8 Effects of cultural treatments and glyphosate on control of *C. rotundus*.

Treatment	**Number of *C. rotundus* (Plants m^{-2})**		
	One week[**]	**Two weeks**[**]	**Three weeks**[**]
Deep blading	1.5b	19.7b	35.8b
Urea	9.6[*]a	54.1a	95.8a
Disc ploughing	0.6b	5.4bc	18.1bc
Glyphosate	9.5a	1.1c	2.6c
S.E.±	1.91	6.86	8.13

Means within a column followed by the same letter(s) are not significantly different at $P \leq 0.05$ according DMRT, * = untreated at time of observation, **= timed after water withdrawal, S.E±= Standard error

4.2.1.4. Effects of cultural and chemical methods on control of *C. rotundus* and common weeds at harvest.

Despite lack of significant differences between treatments, the data showed that glyphosate resulted in the lowest *C. rotundus* dry weight followed in descending order by deep blading, disc ploughing and the fertilizer treatment (Table 4.9). The dry weight of weeds other than *C. rotundus* followed the same trend and was maximal in plots receiving the fertilizer treatment. Glyphosate reduced dry weight by 54.1% in comparison to the fertilizer treatment. The corresponding reduction figures for deep blading and disc ploughing were 25.7 and 27.02%, respectively.

Table 4.9. Effects of cultural treatments and glyphosate on dry weight of *C. rotundus* and common weeds in cotton

Treatment	Dry weight (g m^{-2})	
	C. rotundus	**Other weeds**
Deep blading	4.1a	27.5a
Urea	7.2a	37.0a
Disc ploughing	5.5a	27.0a
Glyphosate	4.0a	17.6a
S.E.±	2.04	9.00

Means within a column followed by the same letter(s) are not significantly different at P≤ 0.05 according DMRT

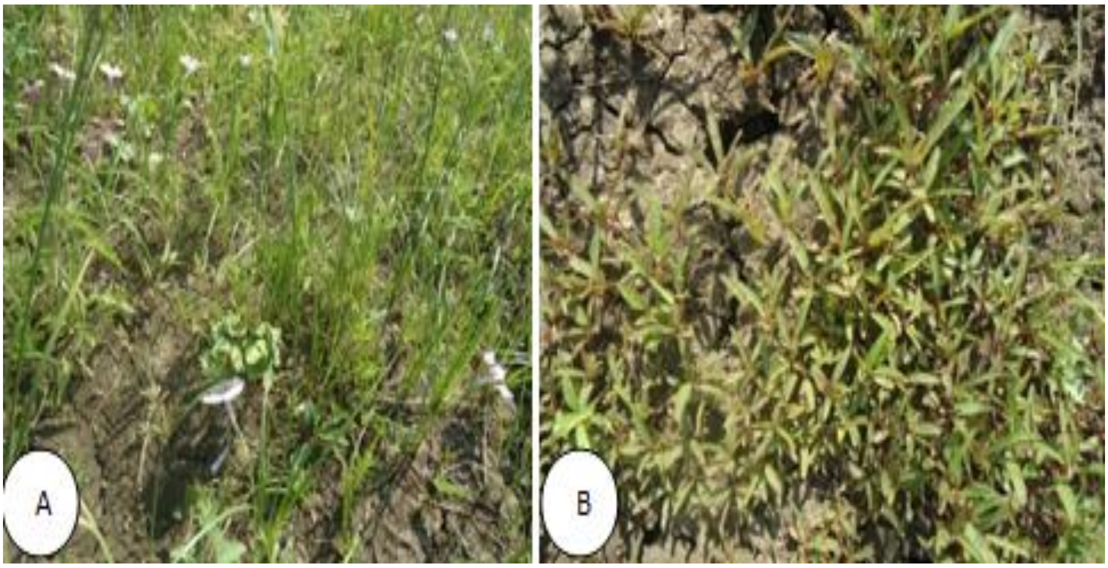


Plate 4.4. Effects of treatment on weed composition A) urea treated sub-plot and B) glyphosate treated sub-plot (One month after treatment)

4.2.1.5. Effects of cultural and chemical methods on *C. rotundus* control and cotton growth and yield

Cotton height measured 120 days after sowing (DAS) was maximal (56.32 cm) in plots treated with glyphosate (Table 4.10). Disc ploughing yielded cotton height comparable to the glyphosate treatment. Deep blading resulted in cotton height lower by 19.3% than the glyphosate treatment. Total number of bolls per plant, measured 120 DAS was maximal (9.14) for the glyphosate treatment followed in descending order by disc ploughing, deep blading and the fertilizer treatment. Number of open bolls per plant measured 120 DAS was maximum (2.1) for the disc ploughing treatment and was1.9, 1.1 and 0.2, for glyphosate, deep blading and the urea treatments, respectively. Seed cotton weight per 5 bolls measured 120 DAS was significantly the highest for glyphosate followed in descending order by deep blading, disc ploughing and the fertilizer treatment. The latter resulted in the lowest seed cotton yield (Table 4.10).

Table 4.10 Effects of cultural treatments and glyphosate on selected cotton growth and yield attributes.

Treatment	Plant height (cm $^{-1plant}$)	Total number of bolls (Bolls$^{-1plant}$)	Open bolls (Bolls$^{-1plant}$)	SCW (g$^{-5bolls}$)
Deep blading	45.5b	3.6b	1.1bc	16.9b
Urea	28.0c	1.7b	0.2c	7.4c
Disc ploughing	54.5a	5.1b	2.1a	15.7b
Glyphosate	56.3a	9.1a	1.9ab	22.2a
S.E.±	3.76	1.6	0.39	1.55

Means within a column followed by the same letter(s) are not significantly different at P≤ 0.05 according DMRT, SCW= Seed Cotton weight per 5 bolls

Plate 4.5 Effects of treatment on weed control A) glyphosate treated sub-plot and B) urea treated sub-plot

4.2.1.6. Effects of cultural and chemical methods of *C. rotundus* control on seed cotton yield.

Sup-plots receiving urea gave the lowest seed cotton yield (58.2 kg fed^{-1}) followed in ascending order by deep blading, disc ploughing and glyphosate. The latter treatment effected a seed cotton yield of 251.8 kg fed-1 (Table 4.11).

Table 4.11. Effects of cultural treatments and glyphosate on seed cotton yields.

Treatment	Seed cotton weight (kg fedan^{-1})
Deep blading	139.1b
Urea	58.2c
Disc ploughing	148.9b
Glyphosate	251.8a
S.E.±	22.65

Means within a column followed by the same letter(s) are not significantly different at P≤ 0.05 according DMRT

4.2.2 Second season

4.2.2.1. Effects of cultural and chemical methods on *C. rotundus* control

At one week after water withdrawal, the time where cotton was planted, the number of emerged *C. rotundus* plants was highest in sub-plots receiving the standard treatment (disc harrowing) (Table 4.12). Disc ploughing reduced population density of *C. rotundus* by 63%, in comparison to the standard disc harrowing treatment. At two weeks *C. rotundus* population density was (2.45 plants m^{-2}) in the standard treatment (Disc harrowing). Disc ploughing, disc ploughing plus a subsequent glyphosate treatment and disc ploughing plus pendimethalin and glyphosate tank mix reduced C. rotundus population density by 57.1, 91.8 and 91.8%, respectively. At 3 weeks after water withdrawal C. rotundus population density was 3.6 plants m-2 in the standard treatment. Disc ploughing, disc ploughing plus a subsequent glyphosate treatment and disc ploughing plus pendimethalin and glyphosate tank mix reduced C. rotundus population density by 6.9, 89 and 89%, respectively.

Table 4.12. Effects of cultural treatments and herbicides on control of *C. rotundus*

Treatment	**Number of *C. rotundus* (Plants m^{-2})**		
	One week**	**Two weeks****	**Three weeks****
DH+W	1.9*a	2.5*a	3.6*a
DP	0.6b	1.1b	3.4a
DP+G	0.7b	0.2c	0.4b
DP+G+P	0.8b	0.2c	0.4b
S.E.±	0.20	0.26	0.57

Means within a column followed by the same letter(s) are not significantly different at P≤ 0.05 according DMRT, * = untreated at time of observation, **= timed after water withdrawal, S.E±= Standard error, DH= disc harrowing, W= hand weeding, DP= disc ploughing, DP = disc ploughing, G= glyphosate.

4.2.2.2. Effects of cultural and chemical methods on control of *C. rotundus* and common weeds.

At harvest maximum *C. rotundus* dry weight (6.7g m^{-2}) was realized from sub-plots receiving the standard treatment of disc harrowing and subsequent weeding. Disc ploughing reduced *C. rotundus* dry weight by 70% (Table 4.13). Disc ploughing followed by a subsequent glyphosate treatment further reduced *C. rotundus* dry weight by 90.7% in comparison to the standard treatment. However, the attained reduction was not significant in comparison to disc ploughing alone. Disc ploughing followed by pendimethalin in tank mixture with glyphosaate applied at sowing further decreased *C. rotundus* dry weight by 94.4% in comparison to the standard treatment (disc harrowing plus weeding). For weeds other than *C. rotundus*, despite the lack of statistical significance between treatments, disc ploughing followed by glyphosate effected the highest weed dry weight (40.9 m-2), followed in descending order by disc ploughing, disc harrowing plus weeding and disc ploughing followed by pendimethalin and glyphosate tank mix (Table 4.13). The latter effected 55% reduction in dry weight of weeds other than *C. rotundus* in comparison to the least effective disc ploughing plus glyphosate treatment (Table 4.13).

Table 4.13. Effects of cultural treatments and herbicides on dry weight of *C. rotundus* and common weeds in cotton

Treatment	**Dry weight (g m^{-2})**	
	C. rotundus	**Other weeds**
DH+W	6.7a	27.8a
DP	2.0b	32.8a
DP+G	0.6bc	40.9a
DP+G+P	0.4c	18.4a
S.E.±	0.64	12.72 **NS**

Means within a column followed by the same letter(s) are not significantly different at P≤ 0.05 according DMRT, DH= disc harrowing, W= hand weeding, DP= disc ploughing, DP = disc ploughing, G= glyphosate.

4.2.2.3. Effects of cultural and chemical methods on *C. rotundus* control and cotton growth and yield

Cotton in sub-plots receiving the standard treatments, disc harrowing plus supplementary weeding 4 WAS, displayed the shortest plants (Table 4.14). Disc ploughing increased cotton height, albeit not significantly. A further, but insignificant increase in plant height was attained on supplementing disc ploughing with a glyphosate treatment. The combination disc ploughing, glyphosate and pendimethalin resulted in maximum cotton height. The crop height effected by the latter treatment was significantly different from those realized in sub-plots receiving the standard harrowing and weeding treatment and ploughing alone. However, it was not significantly different from that attained from sub-plots receiving ploughing and a subsequent glyphosate treatment. The treatment comprising disc ploughing, pendimethalin and glyphosate tank mix effected the highest number of bolls per plant (Table 4.14). Disc ploughing followed by glyphosate effected a lower number of bolls, albeit not significantly. The standard treatment (disc harrowing + weeding) resulted in a significantly less number of bolls. Disc ploughing alone, affected the least number of bolls among all treatment. Despite the lack of significant differences boll opening was highest in sub-plots where ploughing was not supplemented by glyphosate.

Table 4.14. Effects of cultural treatments and herbicides on selected cotton growth and yield attributes.

Treatment	**Plant height** (cm $^{-1plant}$)	**Total number of bolls** (Bolls$^{-1plant}$)	**Open bolls** (Bolls$^{-1plant}$)	**SCW** (g$^{-5bolls}$)
DH+W	50.8b	11.7b	1.7a	19.0b
DP	54.6b	7.9b	2.0a	19.1b
DP+G	57.9ab	16.6a	1.9a	21.9ab
DP+G+P	66.6a	20.1a	1.3a	24.4a
S.E.±	4.49	2.06	0.63	1.45

Means within a column followed by the same letter(s) are not significantly different at P≤ 0.05 according DMRT, SCW= Seed Cotton weight per 5 bolls, DH= disc harrowing, W= hand weeding, DP= disc ploughing, DP = disc ploughing, G= glyphosate.

The standard treatment (disc harrowing + weeding) resulted in a significantly less number of bolls. Disc ploughing, alone, effected the least number of bolls among all treatment. Despite the lack of significant differences boll opening was highest in sub-plots where ploughing was supplemented by glyphosate.

The standard treatment disc harrowing plus weeding and the disc ploughing treatment gave comparable seed cotton yield per 5 bolls. Ploughing plus glyphosate increased seed cotton yield, albeit not significantly (Table 4.14). Disc ploughing plus the tank mix pendimethalin plus glyphosate increased seed cotton yield significantly, however, the yield attained was comparable to the disc ploughing plus glyphosate treatment.

4.2.2.4. Effects of cultural and chemical methods on *C. rotundus* control on seed cotton yield

The standard disc harrowing plus weeding gave seed cotton yield of 180.7 kg fed^{-1}. Disc ploughing alone reduced seed cotton yield by 20.3% in comparison to disc harrwing plus supplementary weeding. Disc ploughing plus glyphosate increased yield significantly over the standard disc harrowing plus weeding treatment. Ploughing plus pendimethalin and glyphosate out yielded all treatments significantly and the attained yield was 303.3 kg fed-1

Table 4.15 Effects of cultural treatments and herbicides on seed cotton yields

Treatment	**Seed cotton weight (kg fedan^{-1})**
DH+W	180.7c
DP	144.0d
DP+G	226.1b
DP+G+P	303.3a
S.E.±	22.65

Means within a column followed by the same letter(s) are not significantly different at P≤ 0.05 according DMRT. DH= disc harrowing, W= hand weeding, DP= disc ploughing, DP = disc ploughing, G= glyphosate.

CHAPTER FIVE

DISCUSSION

Tubers distribution showed distinct variability with soil depth. Of the total number of tubers 49.33, 29.72 and 20.95% was found in the 0-10cm. 10-20 cm and 20-30 cm soil depth, respectively. This finding is consistent with previous reports on tuber distribution within the soil profile (Andrews, 1940). Further, the observed spatial distribution corroborates the report by Riemens *et al* (2008) that rhizomes do not penetrate deep in heavy soils and tend to grow laterally thus leading to accumulation of tubers in the top soil. The tubers fresh weight was 58.1, 20.0 and 11.6 g/m^2 in the 0-10 cm, 10-20 cm and 20-30 cm soil depth. The corresponding fresh weight per tuber was 1.81, 1.03 and 0.85 g, whereas the dry weight per tuber was 1.39, 0.91 and 0.81 g. These results suggest that translocation of assimilates down the chain is slow and that most of assimilates accumulate in tubers at the upper soil layers. Translocation of assimilates is known to follow a sink source relationship and thus it concurred that tubers in the top soil are more metabolically active than those down the soil profile. Metabolic activity is known to be influenced by the state of dormancy of organisms and temperature. Fluctuations in soil temperature are known to decrease with soil depth and that sprouting in *C. rotundus* tubers, is known to be broken by alternating temperature (Miles *et al*, 2002).

Tuber moisture content followed the same trend and was highest (30.3%) and lowest (4.5%) for those at the 0-10 cm and the 20-30 cm depth, respectively. The high moisture contents displayed by tubers at the top soil layer may be attributed to absorption of water from the surrounding soil by the extensive roots and rhizomes in the top soil layer. However an upwards movement of water, driven by differences in osmotic pressure between the relatively metabolically active tubers at the topsoil layers and their quiescent and/or dormant congeners at the lower soil depths cannot be ruled out.

Heat induced an initial gradual loss in moisture contents in all tubers. However, a progressive increase in moisture loss occurred with time. Further, the relative rate in loss in moisture contents was highest for tubers at the top soil layer. The notable increase in moisture loss with time suggests an alteration and/or breakdown of the matrix of tuber covers. The relatively higher rate of moisture loss displayed by the tubers exhumed from the top soil layer may indicate differential permeability and/or vulnerability to heat of the outer covering of tubers. However, the possibility of differential binding of the water molecules to cellular constituents of the tubers cannot be refuted. It is noteworthy that tubers at the top soil layer had higher moisture contents and the water molecules may be loosely bound to cellular constituents and hence could easily be lost on heating.

The results of the TTC test when taken in conjunction with the sprouting test undertaken in the green house indicates clearly the existence of tuber dormancy in exhumed tuber prior to heating (Plate 4.3, Table 4.5). Further, loss in sprouting capacity on short exposure to heat could be a result of both loss in viability and heat induced dormancy. Dormancy, be it innate or induced, leads to irregular emergence of *C. rotundus*, increases its persistence and precludes its eradication. In this respect tubers buried by agricultural operations or those inside clods ma y be less vulnerable to heat and help preserving the weed. It is intriguing that tubers population density at or near the soil surface is the highest, they have the highest moisture contents and they showed the highest sprouting capacity. Emergence from the top soil will be more rapid and less energy demanding than emergence from deep soil layers. Omezine and Harzallah (2009) reported that emergence from greater soil depth needs more carbohydrates and that there is an inverse relationship between emergence and soil depth and a direct relation between soil depth and emergence time. Thus rapid emergence and less consumption of carbohydrates ensure more vigorous growth and higher competitive capacity for plants arising from tubers at or near the soil surface. In general weed interference is invariably more intense if they emerge before the crop. In EAS early rains induce sprouting, emergence and establishment of *C. rotundus* before the onset of spate irrigation. Established *C. rotundus* is tolerant to water logging. Early establishment of the weed, incontestably, leads to intense competition and greater losses in crop yield. Further, the results revealed that tubers at or near the soil surface if properly managed through tillage and exposed on the surface soil for adequate time will be vulnerable to heat and lose viability. However, if disc harrowing or disc ploughing are delayed to the advent of the rainy season tubers from the top soil layer, by sheer number, rapid sprouting and emergence will colonize more areas in and /or around the mother plants (batch effect) and with repeated ploughing at the wrong time, increase and become more problematic. In *C. rotundus* the top bud in a tuber or the top tuber in a chain exert a correlative inhibition over the other buds in a tuber or tubers in a chain (Omezine and Harzalla, 2009). Removal of apical dominance by severing tubers chain allows for sprouting of tubers and if conditions are permissible a heavy and persistent infestation develops.

Counts of *C. rotundus* made one week after cotton planting and urea and glyphosate treatments, showed that disc ploughing and deep blading effected excellent suppression (.>80%) of the weed. However, considerable resurgence of the weed was evident at 2 and 3 weeks after crop sowing (Table 4.8). The resurgence of the weed could be attributed to the inherent rapid multiplication of the tubers which escaped being killed by the treatment. Tubers are renowned for their ability to multiply and a single tuber is reported to produce over 100 tubers or basal bulbs in three months (Hauser, 1962b; Rao, 1968). Counts made in the urea treated plots at 2 weeks after treatment showed a surge in *C. rotundus* population density where the number of emergent shoots was increased to about 6-fold. Counts made at three weeks showed almost an increase of about 9-fold over the initial count made at one week after treatment. The very high infestation of the urea treated sub-plots may be attributed, apart from the inherent rapid multiplication of the tubers to the high initial infestation of the sub-plots before treatment. Glyphosate on the other hand showed the highest suppression of the weed. Visual observation made 4 weeks after herbicide treatment showed that the herbicide maintained its excellent suppression of the weed, however the sub-plots were heavily infested by *Corchorus olitouris* (Plate 4.5-B). Glyphosate is a foliar applied systemic none selective, primarily phloem mobile herbicide which moves, readily, in the symplast from source to sink following the same routes established for assimilates (Pereria and Crabtree, 1967). However, apoplastic movement has also been prescribed for the herbicide and considerable quantities could move from the phloem to the xylem and thus glyphosate could move with the transpiration stream (Stoller and Sweet 1987; Smith and Fic, 1937 and Nishimoto 2001). Phloem and xylem mobility together with prolonged persistence in plants could confer plasticity on the herbicide and may explain its high and lasting activity against *C. rotundus*. Re-infestation of the glyphosate treated sub-plots by *Corchorus olitouris* is consistent with the lack of residual activity of the herbicide as reported by Eliason *et al*. (2004); Jordan *et al*. (1998) and Street and Mueller (1993) in similar situations.

In the second season, based on *C. rotundus* population density, all treatments gave initial significantly better control than the standard practice of disc harrowing during the first two weeks after crop sowing. However, on the third week after crop sowing disc ploughing showed *C. rotundus* population density comparable to the disc harrowing treatment while disc ploughing supplemented by either glyphosate alone or in a tank mixture with pendimethalin maintained over 90% suppression of the weed. Dry weight of *C. rotundus* determined at harvest showed that the standard treatment of disc harrowing supplemented by hand weeding 4 weeks after crop sowing displayed the highest *C. rotundus* biomass (Table 4.13). Disc ploughing alone reduced *C. rotundus* biomass by 68%, while disc poughing supplemented by glyphosate or glyphosate tank mix with pendimethalin maintained over 90% reduction in *C. rotundus*.

Based on weeds, other than *C. rotundus*, biomass determined at harvest, despite lack of statistical significance, deep ploughing supplemented by glyphosate sustained the highest biomass (40.95g). Disc harrowing supplemented by hand weeding 4 weeks after cotton sowing and disc ploughing sustained reduced weed biomass by 31 and 20%, respectively. However, disc ploughing supplemented by the tank mix of glyphosate and pendimethalin effected the highest reduction (55%). The observed pattern of reduction in weeds, other than *C. rotundus* biomass, which is at variance with treatments efficacy on *C. rotundus* (Tables 4.13) suggests the need for residual herbicides to be mixed with glyphosate to curtail infestation by other weeds. The need for a soil acting herbicide to be applied in a tank mix with glyphosate is supported by the observed higher reduction of the biomass of weeds other than *C. rotundus,* by the tank mix of glyphosate with pendimethalin. Removal of C. rotundus, which is the dominant and suppressive weed (Appendix 12-D) affects both quality and intensity of light at the ground level and may encourage germination and subsequent infestation by phytoblastic weeds (Nkomo, and Kambizi,2009; Ologundudu et al., 2013). It deserves mentioning that *C. olitouris* germination is promoted by light. Further, *C. olitouris* is a broad leaf and a broadleaved weed killer such as diuron would have been the proper choice.

Data on cotton growth and yield revealed that in the first season among all treatments urea effected the least cotton growth, the least number of bolls, the least number of open bolls and the least seed cotton weight (Table 4.10). Deep blading increased cotton height and seed cotton weight significantly over the urea treatment. However, it yielded comparable number of bolls and similar boll opening to the urea treatment. Disc ploughing, increased cotton height significantly over the deep blading treatment. However, it showed comparable seed cotton yield per 5 bolls. Glyphosate showed comparable cotton height and number of open bolls to the disc ploughing treatment, however, the total number of bolls and seed cotton yield per 5 bolls were significantly higher.

In ESA seed cotton yield is generally low. The average seed cotton yield over the last 10 years was 200 kg fed^{-1}. Urea, deep blading, disc ploughing and glyphosate effected 29.11, 69.56, 74.46 and 125.91 % of average EAS yield. In the second season the total seed cotton yield per feddan followed the same trend. The yield attained by disc harrowing supplemented by hand weeding, disc ploughing, disc ploughing supplemented by glyphosate and disc ploughing supplemented by the tank mix of glyphosate and pendimethalin was 90.35, 72.01, 113.07and 151.65% of the 10 years average seed cotton yield of the EAS.

In the second season the standard treatment (disc harrowing supplemented by hand weeding) effected the lowest growth parameters (Table 4.14). Disc ploughing showed comparable effects, however, when supplemented with glyphosate a significant increase in total number of bolls was achieved. However, the other parameters (cotton height and boll opening) were increased, albeit not significantly. Disc ploughing when supplemented by the tank mix of glyphosate and pendimethalin, significantly all the measured parameters in comparison to the standard treatments.

Disc ploughing in April fallowed by glyphosate alone, applied at sowing proved to be effective in suppressing *C. rotundus*. However, other weeds, presumably emerging after cotton planting make it a necessity to include a soil acting residual herbicide. Inclusion of glyphosate as a supplementary treatment in a tank mix with the residual herbicide should be left to the jurisdiction of the farmer whose decision is to be based on the degree of *C. rotundus* control and on the presence of other weeds. Further experiments on type of tillage, timing of the tillage operation, the residual herbicide to be used, effects of tillage on soil structure and erosion and economic returns have to be undertaken.

The use of modern herbicide application technologies should be considered. Recently technologies have been developed to spray or wipe non-selective herbicides on target weeds with special equipment e.g. directed sprayers, hooded sprayers, re-circulating sprayers, shielded, sensing devices and rope-wick applicators. Further glyphosate resistant cotton adapted to Sudan conditions should be considered as resistant crops allow over –the-top application of none selective herbicides.

Conclusions and recommendations:

Conclusions:

- *Cyperus rotundus* tuber population density decreased with soil depth. Of the retrieved tubers 20.95, 29.72 and 49.33% were recovered from 20-30 cm, 10-20 cm and 0-10 cm soil depth, respectively. Tubers at 0-10 cm soil depth showed the highest sprouting capacity.
- *C. rotundus* tubers completely lose sprouting capacity in 1-4 h on exposure to70 °C in the laboratory and in 16 days when exposed on the soil surface under field conditions.
- Deep blading, disc ploughing and disc harrowing applied in April prior to cotton planting, glyphosate applied at planting in July and supplementation of disc ploughing by glyphosate reduced *C. rotundus* infestation, however, heavy infestation by annual weeds occurred early in the season. Among all treatments disc ploughing supplemented by a tank mix of glyphosate and pendimethalin showed the highest efficacy against all weeds including *C. rotundus* and effected the highest seed cotton yield.

Recommendations:

- Because of high reproductive capacity season long management of *C. rotundus* is essential to curtail proliferation over time.
- As tubers are the main agent for propagation and spread of *C. rotundus* depletion of tuber reserves in soil, curtailment of tuberization and prevention of spread within and between fields should be preludes for any plausible management strategy.

- Disc ploughing in April followed at planting by a tank mix of glyphosate and a soil acting residual herbicide together with improvement of crop husbandry practices to ensure rapid canopy closure is a plausible system for further evaluation for weed management in cotton at EAS and other spate irrigated areas in the country.

References

Andrews, F. W. (1940). A study of nut grass (*Cyperus rotundus* L.) in the cotton soil of the Gezira. I. The maintenance of life in the tuber. *Annual of Botany*. **4:** 177–193

Anderson, W. P. (1999). *Perennial Weeds: Characteristics and Identification of Selected Herbaceous Species*. 1st ed. Ames, Iowa: Iowa State University Press. **228p**

Babiker, A. G. T. (1976). *Behavior and Fate of Pesticides in Plant Soil-System*. Ph.D Thesis. University of Glasgow, Scotland U. K. 232

Bangarwa, S. K. Norsworthy, J. K. Jha, P. and Malik, M. S. (2008). Purple nutsedge (*Cyperus rotundus*) management in an organic production system. *Weed Science*, **56**:606–613.

Barberi. (2002) Weed Management in Organic Agriculture. *Weed Research*. **42**:177-193.

Bewick, T. A. K. Stall, W. M. and Olson, S. M. (1995). Tomato (*Lycopersicon esculentum*) cultivar and weed sensitivity to DPX-E9636. *Weed Technology*. **9**:499–503.

Bhowmik, P. C. (1997). Weed Biology: Importance to weed management. *Weed Science*,**45**: 349-356

Brecke, B. J. Stephenson, D. O. and Unruh, J. B. (2005). Control of purple nutsedge (*Cyperus rotundus*) with herbicides and mowing. *Weed Science* **19**: 809–814.

Burke, I. C., Shawn, C; Troxler, J. W; Wilcut, and Smith, W. D. (2008). Purple and Yellow nutsedge (*Cyperus rotundus* and *C. esculentus*) Response to post emergence herbicides in cotton. *Weed Technology*. **22**:615–621.

Chase, C. A. Sinclair, T. R. and Locascio, S. J. (1999). Effects of soil temperature and tuber depth on *Cyperus spp*. control. *Weed Science*. **47**: 467–472.

Chauhan, B. S. and Johnson, D. E. (2010). Opportunities to improve cultural approaches to manage weeds in direct-seeded rice. in: Seventeenth Australasian Weeds Conference. Christchurch, New Zealand: *New Zealand Plant Protection Society*. P 40–43.

Chauhan, B. S. (2012). Weed ecology and weed management strategies for dry-seeded rice in Asia. *Weed Technology*, **26**:1-13.

Chellemi, D. O; Olson, S. M; Mitchell, D. J; Secker, I. and McSorley, R. (1997). Adaptation of soil Solarization to the integrated management of soil borne pests of tomato under humid conditions. *Phytopathology,* **87**:250–258.

Cheema, P. (2015). A comprehensive evaluation of *Cyperus rotundus* Linn. *Indian Journal of Plant Science,* **4**:35-41.

Cirujeda, A. Anzalone, A. Aibar, J. Moreno, M. M. C. Zaragoza. C. (2012). Purple nutsedge (Cyperus rotundus L.) control with paper mulch in processing tomato. *Crop Protection,* **39**: 66-71.

Costa, J. and Appleby, A. P. (1976). Response of two yellow nutsedge varieties to three herbicides. *Weed Science,* **24**: 54–58.

Davis, C. H. (1942). Responses of *Cyperus rotundus* L. to five moisture levels. *Plant Physiology,* **2**: 311-6.

Davis, A. S. and Liemman, M. (1999). Integration of soil, crop and weed management in low-external-input farming systems. *Weed Research*, **40**, 27- 47.

Doll, D. J. and Piedrahita, W. (1982). Effect of glyphosate on the sprouting of *Cyperus rotundus L*. tubers. *Weed Research*, **22**:123–128.

Eliason, R. Schoenau, J. J. Szmigielski, A. M. and Laverty W. M. (2004). Phytotoxicity and persistence of flucarbazone-sodium in soil. *Weed Science*, **52**: 857–862.

Fischer, A. Brouquisse, R. and Raymond, P. (1995a). Organic nitrogen reserves and their mobilization during sprouting of purple nutsedge (*Cyperus rotundus*) tubers. *Journal Experimental Botany*, **46**:1803–1808.

Fischer, A. Caseley, J. C. Varsane, R. Negbi, M. and Rubin B. (1995b). Factors affecting benfuresate activity against purple nutsedge (*Cyperus rotundus* L.). *Weed Research*, **35**:279–287.

Garg, D. K.; Bendixen, I. E. and Anderson, S. R. (1967).Rhizome differentiation in yellow nutssedge. *Weeds*, **15**:124-128.

Gifford, E. M. and Bayer, D. E. (1995). Development anatomy of *Cyperus sculentus* (yellow nutsedge) *International Journal of Plant Sciences*, **156**: 622-629.

Glaze, N. C. (1987). Cultural and mechanical manipulation of *Cyperus spp*. *Weed Technology*, **1**:82–83.

Govaerts, R. (2014) World checklist of zingiberaceae. Royal botanic gardens, kew, Richmond. http://apps.kew.org/wcsp/ access date 10/4/2017

Hauser, E. W. (1962a). Establishment of nutsedge from space-planted tubers. *Weeds*, **10**:209–212.

Hauser, E. W. (1962b). Development of purple nutsedge under field conditions. *Weeds*, **10**: 315–321.

Holm, L. G. Plucknett, D. L. Pancho, J. V. and Herberger, J. P. (1977a). The *World's Worst Weeds. Distribution and biology*. Honolulu, University of Hawaii, 609p.

Holm, L. G. Plucknett, D. L. Pancho, J. V. and Herberger, J. P. (1977b). *The Geographical Atlas of World Weeds*. New York USA: John Willy and Sons. 1156p.

Holm, L. G. Plucknett, D. L. Pancho, J. V. and Herberger, J. P. (1991). *The World's Worst Weeds: Distribution and biology*. Malabar, FL: Kriegen. 609p.

Horak, M. J; Holt, J. S and Ellstrand, N. C. (1987). Genetic Variation In Yellow nutsedge (*Cyperus esculentus*). *Weed Science* **35**: 506–512.

Horowitz, M. (1972). Growth, tuber formation and spread of *Cyperus rotundus* from single tubers. *Weed Research*. **12**:348–363.

Horowitz, M. Regev, Y. and Hertzlinger, G. (1983). Solarization for weed control. *Weed Science*. **31**:170–179.

Igbal, J. Hussain, S., ALi A. Javaid, A. (2012). Biology and management of nutsedge (*Cyperus rotundus* L.). *The Journal of Animal & Plant Sciences*, **22**: 384-389.

Itamar, F. S and Luis, W. (2004). *Weed Management Under no Tillage Systems In Tropical Regions*.Pp.329-343.

James, P. G. and Bielinski, M. S. (2005). Purple Nutsedge (*Cyperus rotundus*) Control with Fumigant and Pebulate Combinations in Tomato. *Weed Technology*, **19**: 575-579

Javaid A, Bajwa,R., Rabbani, N. and Anjum, T. (2007). Comparative tolerance of rice (*Oryza sativa* L.) genotypes to purple nutsedge (*Cyperus rotundus* L.) allelopathy. *Allelopathy Journal*, **20**: 157-166

Joel, E. M., Osamu, K. and Nishimoto, R. K. (2002). Modeling purple nutsedge sprouting under soil Solarization. *Weed Science*. **50**: 64-71

Jordan-Molero, J. E. and Stoller, E. W. (1978). Seasonal development of yellow and purple nutsedges (*Cyperus rotundus* and *C. esculentus*) in Illinois.*Weed Science*. **26**: 614–618.

Jordan, D. L. (1996). Adjuvants and growth stage affect purple nutsedge (*Cyperus rotundus*) control with chlorimuron and imazethapyr. *Weed Technology*. **10**:359–362.

Jordan, D. L., Bollich P. K., Burns A. B. and Walker D. M. (1998). Rice (*Oryza sativa*) response to clomazone.*Weed Science*. **46**: 374–380.

Julien, M. H. and Griffiths, M. W. (1998). Biological control of weeds: *World Catalogue of Agents and Their Target Weeds. 4th ed., CAB International, Wallingford, Oxon, UK. 223 p.*

Kadir, J. B. and Charudattan, R. (2000). *Dactylaria higginsii*, a bioherbicide agent for Prple nutsedge (*Cyperus rotundus*). Biology Control. *Weed Science*. **48**:61–68.

Katan, J. Greenberber, A. Alon, H. and Grinstein A. (1976). Solar heating by polyethylene mulching for the control of diseases caused by soil borne pathogens. *Phytopathology*. **66**:683–688.

Keeley, P. and R. Thullen. (1975). Influence of yellow nutsedge competition on furrow-irrigated cotton. *Weed Science*, **23**:171–175.

Keeley, P. E. Thullen, R. J. Miller, J. H and Carter, C. H. (1983) Comparison of Six Cropping Systems for Yellow nutsedge (*Cyperus esculentus*) Control. *Weed Science* **31**: 63–67.

Keeley, P. E. (1987). Interference and interaction of purple and yellow nutsedges (*Cyperus rotundus* and *Cyperus esculentus*) with crops. *Weed Technology*. **1**: 74-81.

Kim, K. U. and Nakayama, H. (1984). Effect of growth regulators on tuberization of purple nutsedge. *Weed Research* (Japan), **29**: 55-60.

Lati, R. N. Filin, S. and Eizenberg, H. (2011). Temperature- and radiation-based models for predicting spatial growth of purple nutsedge (*Cyperus rotundus*). *Weed Science*. **59**: 476–482.

Locascio, S. J. Gilreath, J. P. Dickson, D. W. Kucharek, T. A. Jones, J. P. and Noling, J. W. (1997). Fumigant alternatives to methyl bromide for polyethylene- mulched tomato. *Horticulture Science*. **32**:1208–1211.

Loustalot, A. J., Muzik, T. J. and Gruzado, H. J. (1954). Studies on nutgrass (*Cyperus rotunndus* L.) and its control. *Fedral Experimental Station in Puerto Rico of the United States Department of Agriculture, Mayguez, Puerto Rico, Bullein* **22**.P9

Mahajan, G. and Chauhan , B. S. (2011). Effects of planting pattern and cultivar on weed and crop growth in aerobic rice system. *Weed Technology*. **25**:521–525.

Mahmoud. H. A. (1987). Soil Tillage and seedbed preparation. *Mechanization of field experiments in semi-arid areas conference*. Aleppo, Syria. P 26-31.

McCarty, L. B. Everest, J. W. Hall, D. W. Murphy, T. R. and Yelverton , F. (2008). *Color Atlas of Turfgrass Weeds*. 2nd ed. Hoboken, N. J: J. Wiley. 432p.

McGiffen, M. E., Cudney, Jr., Ogbuchiekwe, D. W. E. J., Baameur, A. and Bell, C. E. 1997. Management alternatives for purple and yellow nutsedge (*Cyperus rotundus* and *Cyperus esculentus*). *HortScience* **32**: 431.

Menashe, H. (1972). Growth, tuber formation and spread of *Cyperus rotundus* L. from single tubers. *Weed research*. **12**:348-363.

Metcalfe, C. R. (1971). *Anatomy of the Monocotyledons. V. Cyperaceae*. Oxford, Clarendon Press: 597P.

Miles, J.E. Nishimoto, R. K. and Kawabata, O. (1996). Diurnally alternating temperatures stimulate sprouting of purple nutsedge (*Cyperus rotundus*) tubers. *Weed Science*. **44**: 122–125.

Miles, J. E., O. Kawabata, and R. K. Nishimoto. (2002). Modeling purple nutsedge sprouting under soil solarization. *Weed Science*. **50**:64–71.

Moody, K. (1977). Weed control in multiple cropping. In Cropping System *Research and Development for the Asian rice farmer*. IRRI, Manila. 281P.

Motis, T. N. Locascio, S. J and Gilreath, J. P. (2002). Efficacy of 1,3-dichloropropene 1 chloropicrin and metam-Na on yellow nutsedge tubers planted at varying growing stages. Proceedings florid State *Horticulture Society*. **115**: 189– 192.

Motis, T. N. Lacascio, S. J. Gilreath, J. P and Stall, W. M. (2003). Season long interference of yellow nutsedge (*Cyperus esculentus)* with polyethylene-mulched bell pepper (*Capsicum annuum*). *Weed Technology*. **17**:543–549.

Neeser, C. Aguero, R. and Swanton, C. J. (1997). Survival and Dormancy of Purple nutsedge (*Cyperus rotundus*) Tubers. *Weed Science*. **45**: 784–790.

Nishimoto, R. K. (2001). Purple nutsedge tuber sprouting. *Weed Biology and Management* **1**:203–208.

Nkomo, M. and Kambizi, L. (2009). Effects of pre-chilling and temperature on seed germination of Corchorus olitorius L. (Tiliaceae) (Jew's Mallow), a wild leafy vegetable. *African Journal of Biotechnology* 8 (6), pp. 1078-1081

Ologundudu, A. F.; Adelusi, A. A.; Adekoya, K. P. (2013). Effect of light stress on germination and growth parameters of *Corchorus olitorius*, *Celosia argentea*, *Amaranthus cruentus*, *Abelmoschus esculentus* and *Delonix regia*, *Notulae Scientia Biologicae* **5**: 68-75

Omezine and Harzallah. S. (2009). Biological behavior of *Cyperus rotundus* in relation to agro-ecological conditions and imposed human factors. *The African Journal of Plant Science and Biotechnology* **3**: 63-69.

Parsons, W. T. Cuthbertson, E. G. (1992). *Noxious Weeds of Australia*. Melbourne, Australia: Inkata Press. 692p.

Patterson, D. T. (1998). Suppression of purple nutsedge (*Cyperus rotundus*) with polyethylene film mulch. *Weed Technology*. **12**:275–280.

Pereira, W. and Crabtree, G. (1967). Translocation, and toxicity of glyphosate and oxyfluorfen in yellow nutsedge (*Cyperus esculentus*). *Weed Science.* **34**: 923 – 929.

Quayyum, H. A. Mallik, A. U., Leach, D. M. Gottardo, C. (2000). Growth Inhibitory effects of nutgrass (*Cyperus rotundus*) on rice (*Oryza sativa*) seedlings. *Journal of Plant Protection Research*. **26**: 2221–2231.

Rao, J. (1968). Studies on the development of tubers in nutgrass and their starch content at different soil depths. *Madras Agriculture*. **55**: 19–23.

Richards, M. C. and Whytock, G. (1993). Varietal competitiveness with weeds. *Aspects of Applied Biology*. **34**: 345–354.

Riemens, M. M. Dueck T. Kempenaar, C. A. P. Lotz, . Kropff M. J. K. (2008). Sublethal effects of herbicides on the biomass and seed production of terrestrial non-crop plant species, influenced by environment, development stage and assessment date. *Environmental Pollution*. **157**: 2189-2586

Rubin, B. and Benjamin, A. (1983). Solar heating of the soil: effect on weed control and on soil-incorporated herbicides. *Weed Science*. **31**:819–825.

Rubin, B. and Benjamin, A. (1984). Solar heating of the soil: involvement of environmental factors in the weed control process. *Weed Science*. **32**: 138–142.

Santos, B. M. Morales-Payan, J. P. Stall, W. M. and Bewick, T. A. (1997). Influence of tuber size and shoot removal on purple nutsedge (*Cyperus rotundus*) regrowth. *Weed Science*. **45**: 681–683.

Santos, B. M. Morales-Payan, J. P., Stall, W. M. and T. A. Bewick, T. A. (1998). Influence of purple nutsedge (*Cyperus rotundus*) density and nitrogen rate on radish (*Raphanus sativus*) yield. *Weed Science*, **46**: 661-664.

Schneider, S. M. Rosskopf, E. N. Leesch, J. G. Chellemi, D. O., C. T. and Mazzola M. (2003). U.S. Department of Agriculture -Agricultural Research Service. Research on alternatives to methyl bromide: Pre-plant and Post-harvest. *Pest Management Science* **59**: 814–826.

Senarathne, S. H. S., Bamdara, D. M. B. M and Sangakkara, U. R. (2012). Germination characteristics of rhizomes of major monocotyledonous weeds in coconut plantation of *Sir Lanka*. *Korwan Journal of Weed Science*, **32**: 180-187.

Shamsi, S. R. A., Al-Ali, F. A., and Hussain, S. M. (1978). Temperature and light requirements for the sprouting of chilled and unchilled tubers of the purple nutsedge, *Cyperus rotundus*. *Physiology Plantarum*. **44**:193–196.

Singh, N. B. Pandey, B. N. and Singh, A. (2009). Allelopathic Effects of *Cyperus rotundus* extract in vitro and ex vitro on banana, *Acta Physiologiae Plantarum* **31**: 633-638.

Siriwardana, G. and Nishimoto, R. K. (1987). Propagules of purple nutsedge (*Cyperus rotundus*) in soil. *Weed Technology*. **1**:217–220.

Smith, E. V. and Fic, C. L. (1937). Nutgrass eradication studies- Relation of the life history of nutgrass (*Cyprus rotundus*) to possible methods of control. *Journal of the American society of Agronmoy*, **29**: 1007-1013

Smith, E. and Mayton, E. (1938). Nut grass eradication studies. 2. Eradication by certain tillage treatments. *Journal American Society Agronomy*. **30**: 18–21.

Stall, W. M. and Gilreath, J. (2001). Estimated effectiveness of recommended herbicides on selected common weeds in Florida vegetables. In: *Weed Management in Florida Vegetables and Fruits*. (W. M. Stall, ed.) FL. Gainesville, University of Florida Cooperative Extension Service, Institute of Food and Agricultural Science. Pp 59– 61.

Stoller, E. W. and Sweet, R. D. (1987). Biology and life cycle of purple and yellow nutsedges (*Cyperus rotundus* and *Cyperus esculentus*).*Weed Technolology*. **1**: 66–73.

Street, J. E. and Mueller, T. C. (1993). Rice (*Oryza-Sativa*) weed-control with soil applications of quinclorac.*Weed Technology*. **7**: 600–604

Summerlin, J. R. Coble, Jr. H. D. and Yelverton , F. H. (2000). Effect of mowing on perennial sedges. *Weed Science*. **48**: 501–507.

Tumbleson, M. E. and Kommedahl, T. (1961). Reproductive potential of *Cyperus esculentus* by tubers. *Weeds* **9**: 646–653.

USDA-ARS (2014) Germplasm resources information network (GRIN). Beltsville, Maryland, USA: national germplasm resource laboratory. http://www.ars-grin.gov access date 10/4/2017

Webster, T. M. (2005). Patch expansion of purple nutsedge (*Cyperus rotundus*) and yellow nutsedge (*Cyperus esculentus*) with and without polyethylene mulch. *Weed Science*. **53**:839–845.

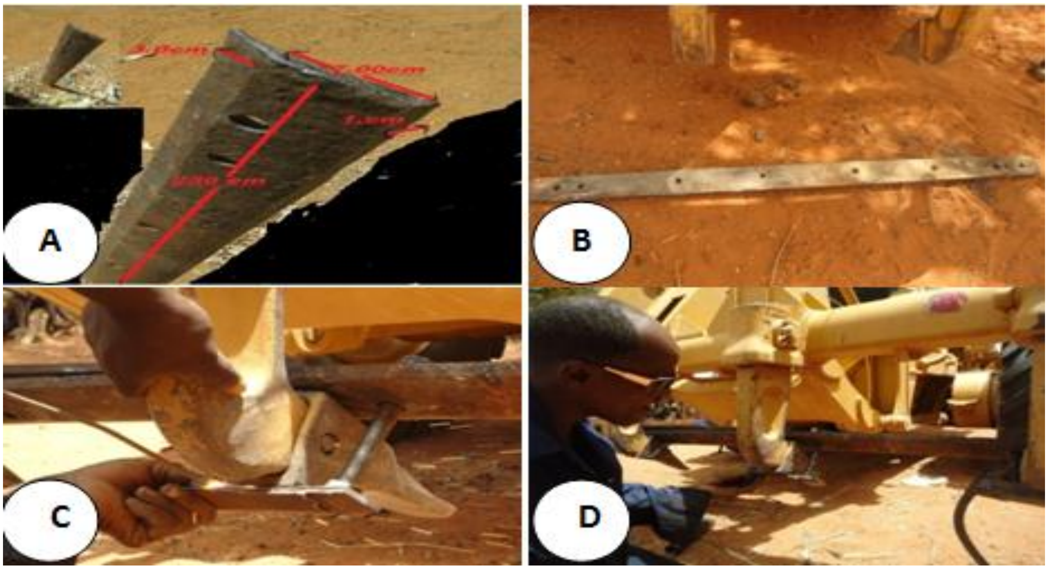
Wills, G. D. and Briscoe, G.A. (1970). Anatomy of purple nutsedge. *Weed Science*. **18**: 631-635.

Wills, G.D. (1987). Description of purple and yellow nutsedge (*Cyperus rotundus* and *C. esculentus*). *Weed Technology* **1**: 2 -9.

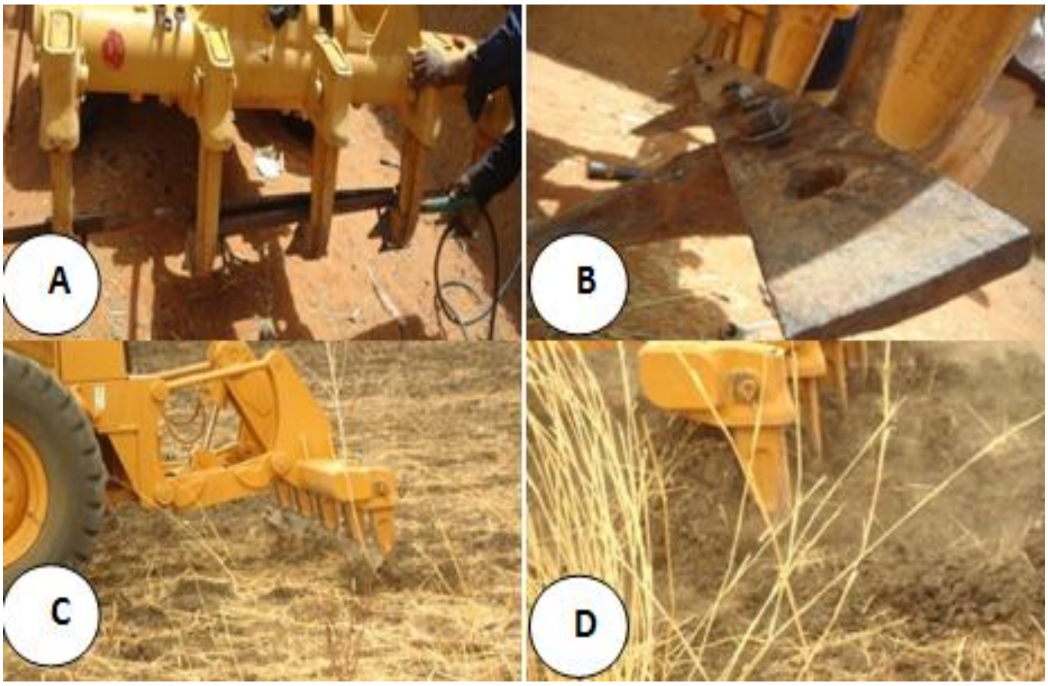
Zandstra, B. H. and Nishimoto, R. K. (1977). Movement and activity of glyphosate in purple nutsedge. *Weed Science*. **25**: 268–274.

Zohaib, A., Tasawer, Abbas, T.; Tahira, T. (2016). Weed cause losses in field crops through allelopathy. *ProQuest*. P.**48**: 56.

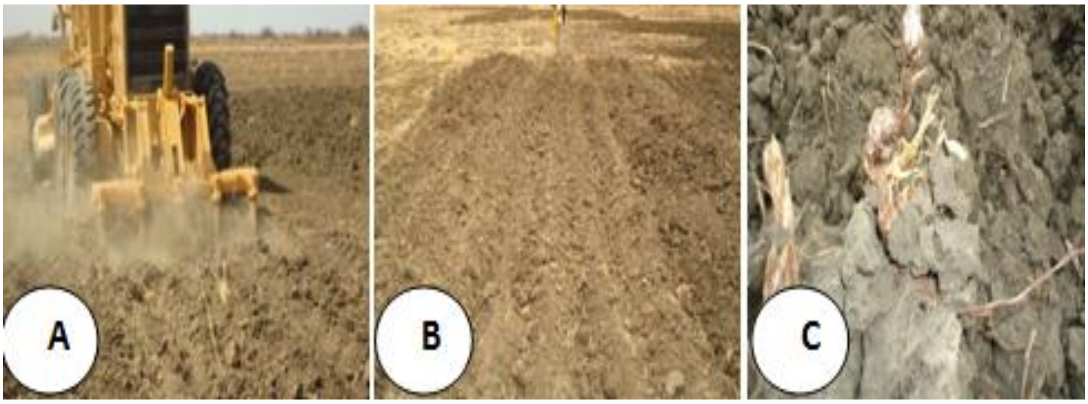
Appendixes



Appendix 1. Modefications of a motor grader to a deep blader. A) metal bars(2.30 m length, 10 cm width and 1 cm thick), B) metal bar with drilled holes, C and D) metal bars fixed to the machine tines.

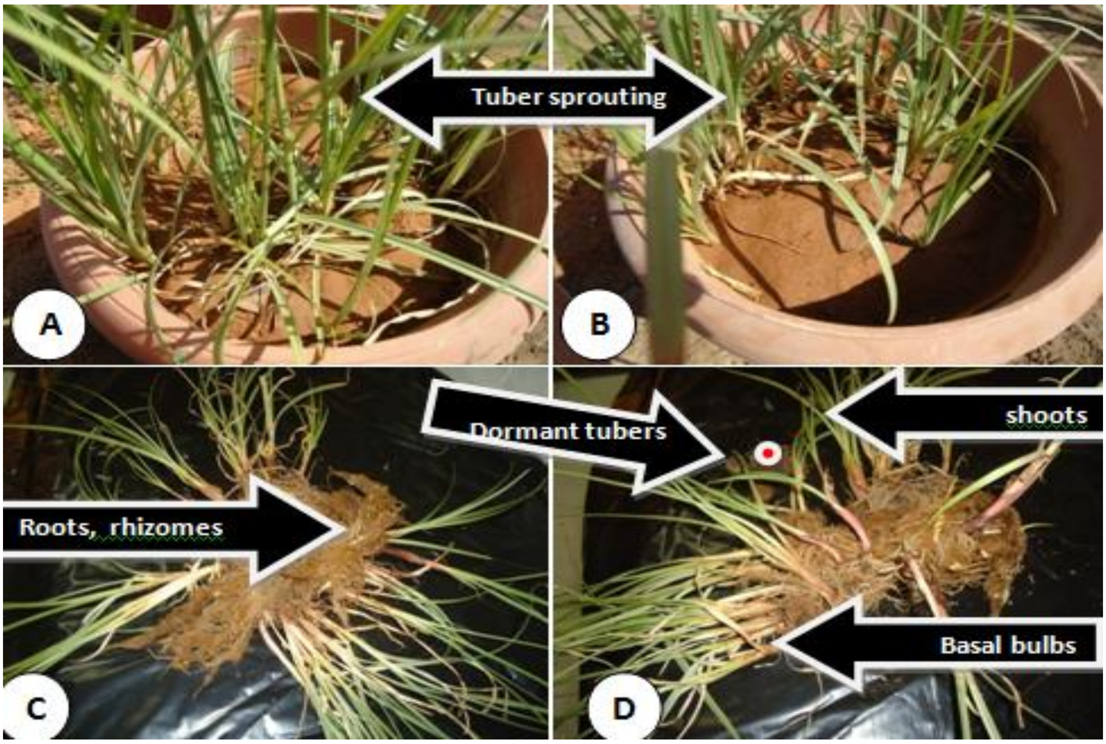


Appendix 2. Fixed metal bars. A) back view B) front view C) side view and D) side view indicating penetration depth in soil .



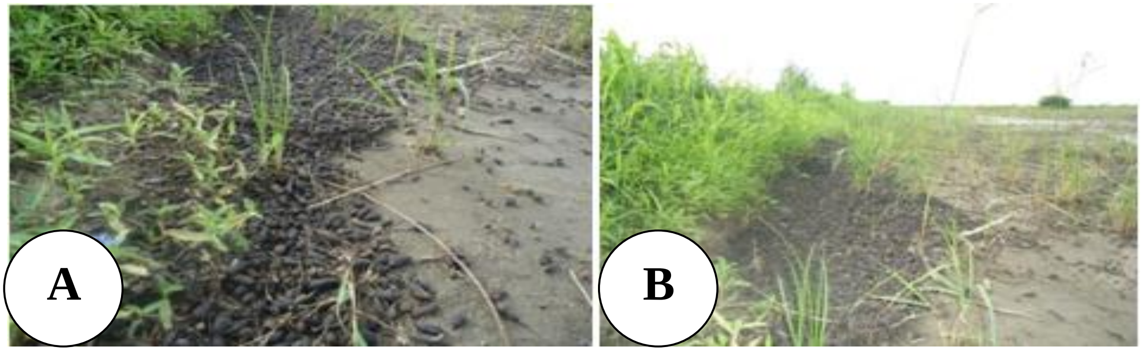
Appendix 3. Modefied machine. A) in action, B)soil surface after blading and C) tubers in a clod

Appendix 4. Tuber chains exhumed by deep blading

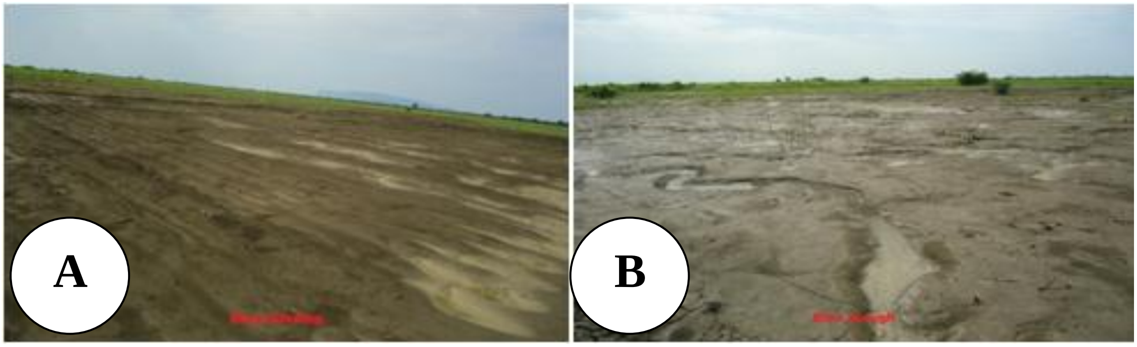


Appendix 5. Tubers sprouting. A- B) sprouted tubers, C) roots with rhizomes and D) basal bulbs with shoots ant dormant tuber.

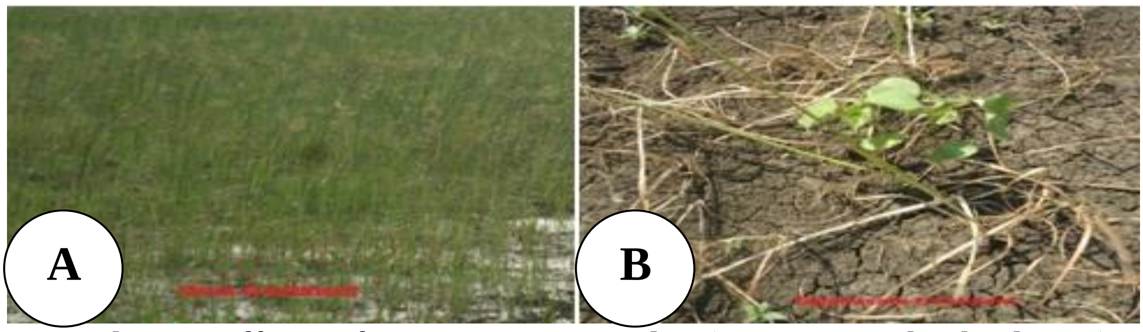
Appendix 6. Devolepment of main root. A) main root one WASI, B) main root two WASI, C) main root three WASI and D) root length measurment



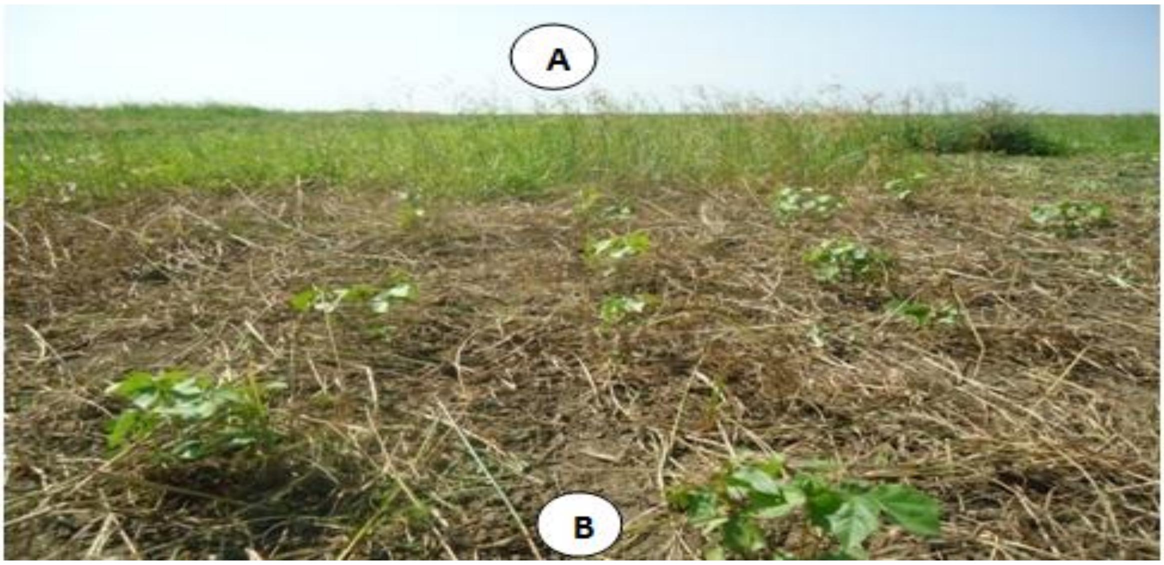
Appendix 7. Dead tubers. expoused by(A), deep ploughig and (B) deep blading, drafted by flood water.



Appendix 8. Effects of treatment on weeds A) deep blading, B) deep ploughing (after water residing)



Appendix 9. Effects of treatment on weeds A) urea treated sub-plot, B) glyphosate treated sub-plot (3 weeks after treatment)



Appendix 10. Effects of glyphosate on weed control and surface mulch. A) un treated B) treated.

Appendix 11. Effects of deep ploughing supplemented by glyphosate plus pendimethalin. A) two weeks after herbicide treatment (WAHT), B) three WAHT, C) 12 WAHT and D) 16 WAHT.

Appendix 12, Effects of treatment on bolls opening, A) disc harrow plus weeding, B) deep ploughing, C) deep ploughing plus glyphosate and D) disc ploughing plus glyphosate plus pendimethalin (Note: redness and senescence in leaves).