CONTROL OF NUTGRASS (CYPSRUS RØTUNDUS L.) WITH HERBICIDES

BY

KOLAWOLE OWOLABI ADEJONWO
B.Sc. (AGRIC) AHMADU BELLO UNIVERSITY, ZARIA, NIGERIA

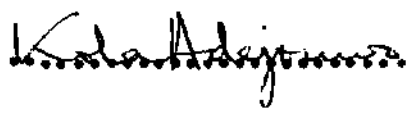
A thesis submitted to the Department of Agriculture, University of Aberdeen, in partial fulfilment of the requirements for the Degree of Master of Science.

University of Aberdeen
September, 1979

DECLARATION

I declare that this work was carried out and written by the undersigned and none of the work here recorded has been presented in any previous application for a degree.

All quotations have been marked by quotation marks, sources of information indicated by references and help given by others in this work has been quoted in the acknowledgements.



SUMMARY

The control of nutgrass (Cyperus rotundus L.) with three herbicides - glyphosate, paraquat and cyperquat was investigated.

Glyphosate gave 100% kill of aerial growth of nutgrass at 8 and 16 litres/ha 20 days after application although 97.2% kill of aerial growth was achieved at a lower rate of 4 litres/ha after the same time.

100% kill of aerial growth was achieved by paraquat at 2 litres/ha rate of application within 4 to 8 days after spraying. All higher rates of application gave similar results and there was no measurable difference in activity of the herbicide between the lowest rate of 2 litres/ha and the highest rate of 16 litres/ha.

Cyperquat achieved 50% kill of aerial growth at 16 litres/ha 20 days after spraying. From this result, cyperquat appears to be much less effective than the other herbicides in controlling the aerial growth of nutgrass.

The plants exposed to light in all the three herbicide treatments had higher per cent kill of aerial growth of nutgrass than the plants in the dark. This shows that light has an effect on the activities of these herbicides in nutgrass.

In experiments designed to investigate the time taken for glyphosate to translocate and prevent regrowth of nutgrass tubers, it was found that the number of days after spraying had a significant effect on the per cent regrowth of tubers. The longer the treated plants are left for translocation to occur, the less are the chances of regrowth of the tubers.

Statistically, there was no significant effect between rates of application of glyphosate and the per cent regrowth of tubers. However, rates of application have some influence on the effect of days after spraying on the per cent regrowth of nutgrass tubers.

CONTENTS

		Page Number
I	Introduction	1
II	Biology of Cyperus rotundus L.	5
a.	Morphology	5
b.	Reproduction and spread	6
c.	Effect of temperature	7
d.	Photoperiodic effects	8
e.	Effects of oxygen and carbon dioxide	9
f.	Relationship to soil type and soil moisture	9
g.	Effect of cultivation on nutgrass	10
III	Literature review of herbicides performance	12
a.	Past work	12
b(i)	Recently introduced herbicides	15
(ii)	Glyphosate	16
IV	Experiment 1	21
a.	Objective	21
b.	Methods and materials	21
c.	Results	22
d.	Discussion and conclusion	35
V	Experiment 2	38
a.	Objective	38
b.	Methods and materials	38
c.	Results and conclusion	38
VI	Experiment 3	39
a.	Objective	39
b.	Methods and materials	39
c.	Results	39
d.	Discussion and conclusion	44
VII	General discussion and conclusions	46
	Acknowledgements	48
	References	49
	Appendix 1	52

I INTRODUCTION

Cyperus rotundus L. which is commonly called nutgrass, nutsedge or purple nutsedge belongs to the family Cyperaceae. It is now recognised as one of the most serious perennial weed species in world agriculture. Its distribution is pantropical extending into sub-tropical and other warmer regions of the world. It is now a problem in Central and South America, Euro-mediterranean, Africa, India, Australia and the Far East (Holm, 1968). See figure 1. Its range at increasing latitudes in both hemispheres is limited by cold and it is intolerant of sub zero temperatures. Apart from this limitation, it grows vigorously in almost every soil type, elevation, humidity, soil moisture and pH and can survive the highest temperatures encountered in agriculture. It is found in cultivated fields, on road-sides, in neglected areas and the edges of woods and it may cover the banks of irrigation canals and streams.

C. rotundus is reported to be a weed in 52 crops in 92 countries (Holm et al, 1977). Where it is found, nutgrass competes seriously with cotton, rice, maize, sorghum, soyabean, vegetables, sugarcane to mention a few. Nutgrass was found to have reduced cotton yield by 34% during a growing season (Keeley and Thullen, 1975). Similar adverse effects were also observed in upland rice which gave 41 and 43% reduction in grain yield in drilled and broadcast sowings respectively (Sierra and Mercado, 1975). Williams and Warren (1975) found that crop losses due to purple nutsedge competition with some vegetables during the entire cropping season were as follows - okra 62%, green bean 41%, cabbage 35%, tomato 53% and cucumber 43%. Attention has been drawn to the way in which a plant of such small stature as C. rotundus can cause severe harm by competition to a larger plant such as sugarcane - a crop which may grow to 4 meters in height and which at harvest yields a greater bulk tonnage than any other world crop. Experiments in Argentina, for example, showed that in extreme cases the weed caused a reduction in cane harvest of 75% and sugar yields

of 65%. It was suggested that the cause of the yield reduction was competition for moisture at stooling time so that fewer canes are produced (Chapman, 1966). In Panama, vegetable culture in the area is extremely difficult because the rhizomes of nutgrass which pierce the roots and underground storage organs of crops. In some areas of Australia and Italy tobacco growing has been discontinued because the costs of hand weeding and crop yield reduction due to nutgrass has made it unprofitable. In Kenya, the weed is very competitive in coffee and some scientists believe that it may cause the death of coffee trees (Holm et al, 1977). In addition to competing for moisture, the weed withdraws and holds large quantities of nutrients in its massive underground system and these are not available to a competing crop (Bhardwaj and Verma, 1968).

Apart from its direct competitive effects, substances toxic to other plants may be produced by decay of dead residues of C. rotundus (Horowitz and Friedman, 1971). Nutgrass serves as a nematode reservoir. Examination of the nutgrass roots by Bird and Hogger (1973) indicated that it is a host for Meloidogyne incognita and Hoplolaimus columbus. Both of these nematode species are serious pathogens of cotton. In China, the weed has been traditionally used for medicinal purposes and a recent report from that country concerns its use in landscaping (Holm et al, 1977).

Nutgrass is a particularly serious weed in row crops because many common husbandry practices appear to stimulate growth and spread of the weed. For example, hand weeding or mechanical cultivation and most pre-plant incorporated and pre-emergence herbicides currently used for weed control in vegetables and field crops appear to reduce competition from other weeds and often allow a more rapid increase in nutgrass population. Lack of success with manual, mechanical and cultural methods, has focussed attention on the use of translocated herbicides that will move to all parts of the plant. In this thesis the properties and uses of such herbicides will be examined in detail.

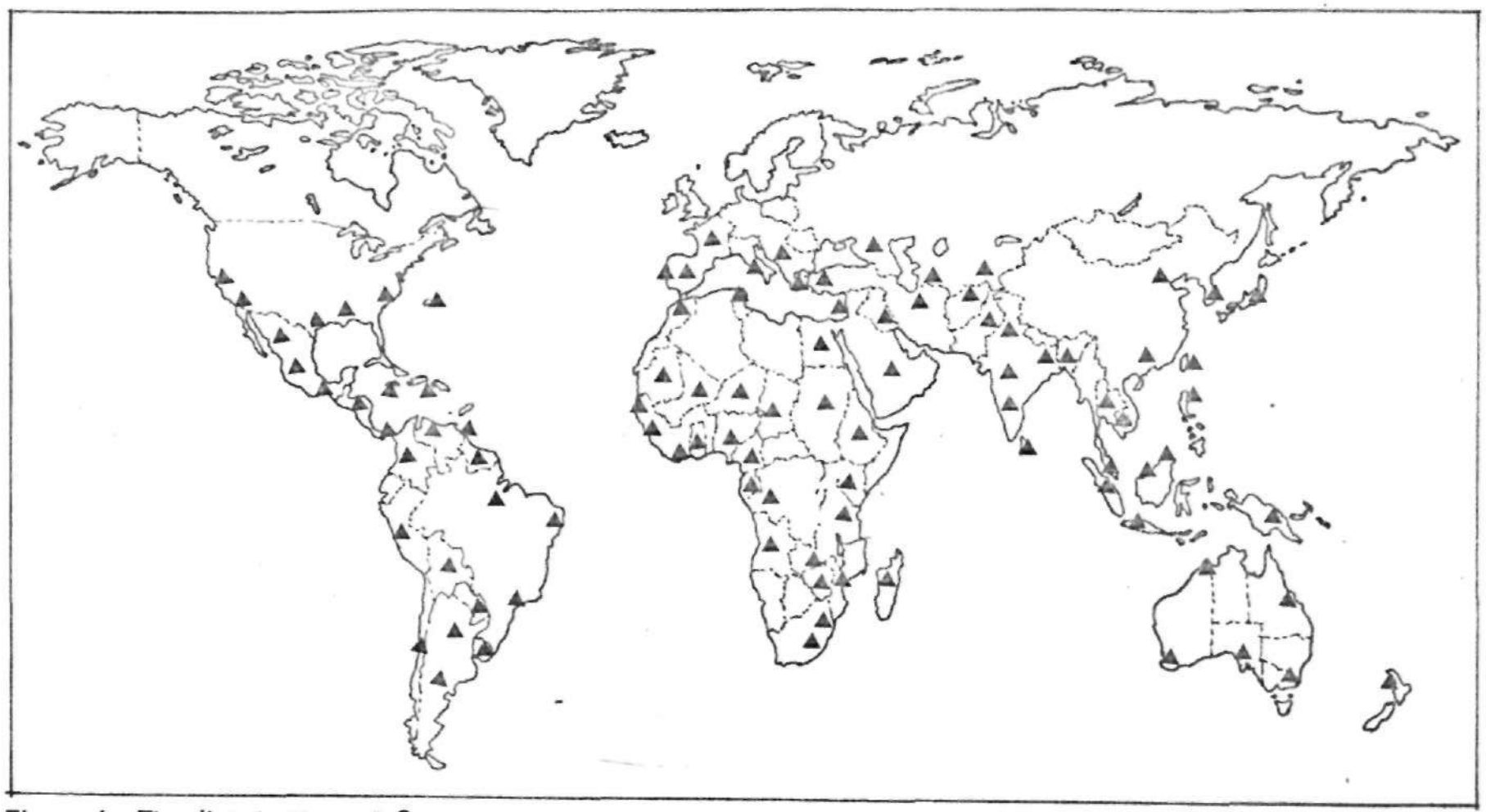


Figure 1 – The distribution of Cyperus rotundus L. across the world (after Holm et al,1977)

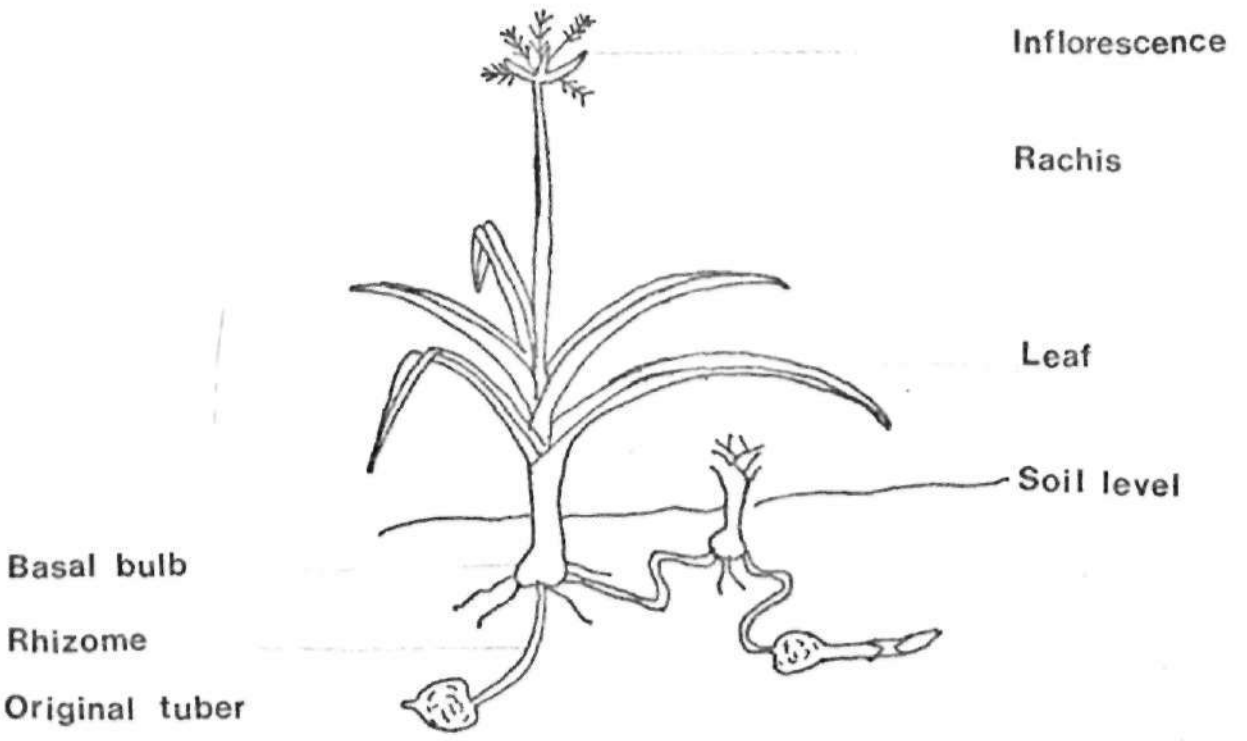


Figure 2 -- Diagram of purple nutsedge developing from a single tuber

II BIOLOGY OF CYPERUS ROTUNDUS L.

Before considering herbicide performance it is necessary to understand the biology of nutgrass.

a. Morphology

C. rotundus is an erect, persistent, glabrous perennial monocotyledonous herb which is capable of vegetative propagation indefinitely under favourable conditions. See figure 2. The roots are fibrous, extensively branched and clothed with hairs. The weed spreads by extensive horizontal, slender rhizomes which are white and fleshy and covered with scale leaves when young but which become brown, fibrous or wiry when old. Axillary buds are not present on the rhizomes. Rhizomes give rise at intervals of 5 to 25 cm to underground tubers which continue to proliferate forming tuber chains that extend to a considerable length and depth in the soil. The tubers are variable in shape, up to 2.5 cm in diameter, white and succulent when young turning coarse fibrous brown or almost black with age. Aboveground stem arises from a swelling on the rhizome described as a basal bulb or a tuberous bulb and this structure later forms a swollen or thickened plant base. The stem is erect, unbranched, 10 to 60 cm high and usually taller than the basal leaves. The leaves are grasslike, linear, up to 50 cm long and 8 mm wide, smooth, shiny and dark green. The upper leaf surface consists of a single layer of large epidermal cells covered by a thick cuticle. Stomata occur only in the lower surface. The vascular bundles vary from collateral to amphivasal as they pass from the leaves through the tuberous bulb into the rhizomes and tubers. The inflorescence is a loose umbel on the stem apex subtended by two to four leaflike bracts. There are three to nine slender, three-sided peduncles of unequal length near the ends of which are clustered the narrow spikelets. The spikelets consist of 10 to 40 florets which are a reddish brown or purple brown

colour. It is from this that the weed derives its name purple nutsedge.

b. Reproduction and Spread

Nutgrass is perpetuated in the short term by lateral growth of shoot forming rhizomes and in the longer term by the production and dissemination of tubers. Reproduction by seed is of little significance as few viable seeds are produced. Justice and Whitehead (1946) tested seeds of nutgrass in an incubator with alternating temperatures immediately after harvest but the seeds did not germinate for 3 to 4 months. Germination continued to increase during the 13 month test. The highest germination recorded was 15 per cent but most lots averaged only 3 to 5 per cent. Hammerton (1975) supported this claim.

Speed and numbers of tubers produced are of major importance in nutgrass spread. Rao (1968) in India found that one tuber could produce 99 new tubers in 90 days and calculated that on this basis, the weed could produce 8 million tubers per hectare in cultivated areas and 4.8 million per hectare in uncultivated areas. Work by Hammerton (1974) showed that new tubers were produced as soon as 16 days after shoots appeared above-ground. At this time shoots had only six leaves. From then on a new tuber was formed approximately every 4 days. His data suggests that no more than 14 days should elapse between shoot emergence and cultivation or chemical treatment if tuber formation is to be prevented. It is believed that there are no buds at the nodes of the rhizomes of nutgrass and that little or no propagation is possible from fragments of these organs. The apical bud of a tuber inhibits growth of any other bud. The tuber at the morphological apex of a rhizome tuber chain prevents sprouting of others in the chain but this control is not as strong as the dominance of buds within one tuber (Smith and Fick, 1937; Holm et al, 1977). The breaking

of apical dominance explains in part why cultivation frequently appears to increase the infestation of nutgrass. The plough and other implements break many connecting rhizomes and free the proximal tubers of the system from the suppressing effects of the terminal tubers. Mulligan and Junkins (1976) noted that the spread of nutgrass from uncultivated areas to agricultural fields seems to be largely due to tubers carried by cultivation implements.

Man and his agricultural activities are the major disposal agents for weeds but natural agencies and appropriate modifications of the plant which aid disposal are also important. The tubers are moved in mud on the feet of men and animals and by transport on cultivation machinery. They may be seen floating and drifting with wind propulsion in flooded rice. They are also brought into new areas when streams flood after storms and they are distributed in surface irrigation water.

c. Effect of Temperature

Temperature is one of the important factors controlling germination of tubers. Japan is one of the coolest areas of nutsedge infestation and Ueki (1969), in experiments, obtained 95 per cent germination of tubers at 30° to 35°C with no sprouting above 45°C or below 10°C. Horowitz (1972), working in Israel, found that the seasonal growth variations of C. rotundus observed in experiments appear closely related to temperature changes. He noted that aerial and subterranean growth was very rapid in the warm season. During cool season most aerial shoots of established plants withered but most of their subterranean organs remained alive and active regrowth took place in the following spring. He found minimum temperature for tuber formation to be approximately 20°C.

Stoller (1973) observed that less than 10 per cent C. rotundus tubers survived at 2°C for 12 weeks whereas more than 95 per cent of the closely related C. esculentus tubers survived this treatment. Exposure to -2°C for

4 hours or longer killed 50 per cent C. rotundus tubers whereas -6.5°C was required to kill 50 per cent of C. esculentus tubers. Therefore C. rotundus distribution is restricted to regions where the soil seldom freezes. Survival of C. esculentus tubers in soil which frequently freezes probably accounts for its distribution in colder regions like Canada and northern parts of America.

The possibility that tillage operations can raise the dormant tubers of nutgrass to the surface where they are subject to extremes of temperature and drying has attracted the attention of many workers. Others have attempted simply to desicate the tubers by allowing fields to become as dry as possible. (Smith and Fick, 1937; Andrews, 1940 and Ueki, 1969). Smith and Fick (1937) placed tubers on the surface of dry soil in full sun. They found that the tubers were desicated beyond recovery in 4 days in the sun. In experiments approximating to field conditions, tubers were planted at 5 and 10 cm in dry soil that was protected from rain but was exposed to direct sunlight. At 5 cm 80 per cent of the tubers were killed in 8 days and all were dead at 12 days. All of the tubers at 10 cm were killed in 16 days.

d. Photoperiodic effects

Light has been found to influence several stages of nutsedge growth and development. Musik and Cruzado (1953) found extensive sprouting of nutsedge tubers in the light but little in darkness. Ueki (1969) in Japan obtained results which showed that sprouting was about the same whether the light provided was red, green, blue or white. Berger and Day (1969) applied short (10 hour) and long (18 hour) photoperiods to nutsedge. They found that short photoperiods induced flowering and tuber production, stimulated formation of salicylic acid, inhibited bud growth of tubers and reduced foliage growth causing the foliage to grow horizontally. Long photoperiods inhibited flowering, reduced tuber production and formation of salicylic acid, enhanced tuber bud growth and induced vertical foliage

growth. Salicyclic acid, isolated from foliage and sprouted tubers is thought to be the major controlling agent of seasonal dormancy in nutsedge. In a recent study, Williams (1978) found that flowering occurred only at the 12 hour photoperiod. Thus, purple nutsedge is intermediate in flowering response to daylength. He also showed that although the total dry weight varied with amount of light, the relative amount of dry weight (as per cent of total weight) partitioned between shoots, roots, rhizomes and tubers was constant.

Purple nutsedge is very sensitive to low light intensity. Hauser (1962) found that continuous shading gave a 10 to 57 per cent reduction in the numbers of tubers and bulbs formed. In tree orchards and plantations, top growth of C. rotundus begins to decline as heavy shading develops due to tree growth. This does not mean that the infestation has been destroyed. For, as soon as openings are created by diseases or tree felling, the weed infestation quickly regenerates. Similarly, in sugar-cane, the tall crop plants eventually shade out the top growth of C. rotundus but the tubers become quiescent and foliage quickly reappears after harvest and during tillage of the fields.

e. Effects of Oxygen and Carbon Dioxide

The importance of an optimum level of oxygen and its significance in controlling morphological development are often implied in the literature, but, apart from general agreement on the need for some oxygen in the soil, there is very little information available. Palmer and Porter (1959) investigated the possibility that dormancy of tubers in the soil was due to lack of aeration. They found that tuber sprouting was most active at high oxygen and low carbon dioxide concentration. Low oxygen and high carbon dioxide levels inhibited germination.

f. Relationship to soil type and soil moisture

Nutgrass grows actively in almost every soil type and at widely variable soil moistures and pH. Ranade and Burns (1925) reported that it cannot

tolerate soils with high salt content. Ueki (1969) found no germination in fields which were under water and suggested that, at the latitude of Japan, fields must be quite dry to obtain tuber sprouting. However, excess moisture does not necessarily destroy the tubers, for some that had been held in water for 200 days gave satisfactory germination when removed from the water and placed in suitable growing conditions. Fuentes and Doll (1976) observed that highest aerial dry matter production, shoot, inflorescence and tuber numbers were obtained with soil moisture levels above 75 per cent of field capacity. Results of soil moisture trials they conducted varied with different soil textures. 81 per cent more aerial dry matter was produced on heavy soils with high water holding capacity than on light soils with low water holding capacity.

g. Effect of cultivation on nutgrass

In the tropics and sub-tropics weed problems are in many ways more severe than in temperate zones. Some measure of this is seen by comparing the differences in the speed and size of regrowth of vegetation on bare ground in the two types of climatic zones. The effect of this difference on the growth of a crop is very marked and it makes weed control very essential if any crop is to give an economic return (Ashby and Pfeiffer, 1956).

Perennial weeds like nutgrass present a more difficult problem because their tenacious nature is due to their efficient methods of vegetative propagation by means of both overground and underground organs and also, because they may reproduce by fertile seeds.

The habit of growth of perennials ideally fits them to resist eradication by conventional cultivation methods. The different cultivation practices in operation in a crop particularly that of mechanical cultivation could aggravate the problem of perennial weeds such as nutgrass. In fact by this method the perennating organs are cut into pieces and disseminated in the field by the agricultural implement. The

practice of hand weeding perennial weeds is a costly and ineffective method. It has the disadvantage of disturbing and damaging the developing root system of the crop. Moreover, the encroachment of freshly weeded areas soon become re-infested by the underground and overground organs of the perennial from the edges of the unweeded areas. For satisfactory results frequent weedings are necessary and this can be achieved only in countries where cheap labour is available (Rechecouste, 1969).

III LITERATURE REVIEW OF HERBICIDES PERFORMANCE

a. Past work

A lot of work had been done in the past two decades in trying to find herbicides which can effectively control Cyperus rotundus. Parker et al (1969) reported that since 1958 fifty experiments had been conducted first by the A.R.C. Unit of Experimental Agronomy and later by the A.R.C. Weed Research Organization. A total of 174 compounds had been tested for their effects on nutgrass as pre and/or post-emergence treatments. Many of the chemicals used are now obsolete but some of those which are currently available as commercial or experimental herbicides will be mentioned.

Experiments with benzonitriles and related compounds namely dichlobenil and chlorthiamid showed that they were highly active as incorporated soil treatments. Very prolonged control can be obtained under glasshouse conditions but tubers were not usually killed and the continued effect may depend upon persistence of the herbicides in the soil. These herbicides were not usually persistent enough under tropical conditions to give this prolonged effect. In any case selectivity would not be possible in annual crops. The hydroxybenzonitriles, ioxynil and bromoxynil, which have a contact, foliar mode of action were virtually inactive.

Parker et al (1969) also tried the bipyridillium herbicides - diquat and paraquat for controlling nutgrass. Diquat was introduced by ICI in 1957 and paraquat in the following year. Diquat and paraquat are mainly post-emergence compounds with no soil activity under normal circumstances. This is due to their strong absorption on to soil particles, particularly the clay minerals. They are generally non-selective and act within the plant by reduction to a free radical during photosynthesis. This is oxidised in the presence of oxygen to hydrogen peroxide, which destroys

the plant tissue and the free ion is thus recycled to repeat the process. Under low light intensity some translocation may occur but in darkness no symptoms develop. Symptoms of paraquat and diquat treatment are a characteristic rapid scorch and desication of sprayed leaves. Mammalian toxicity is high (Fryer and Makepeace, 1977). Parker et al (1969) found that diquat had some scorching action but paraquat is much more active and capable of killing young plants including their underground parts. The general experience of paraquat under field conditions is that C. rotundus makes very rapid recovery and the repeated sprayings required are uneconomic in most situations.

Amongst the phenoxy-aliphatic acids, Parker et al (1969) reported that 2, 4-D and MCPA were not very thoroughly tested in this series of experiments but limited results suggest comparable performance to that expected in the field, that is, temporary control by 1.12 kgae./ha post-emergence or at rather higher doses pre-emergence. Hammerton (1974) found that treatment with 2, 4-D or paraquat at 34 days after emergence severely checked shoot growth but tuber production appeared to be only temporarily checked. He noted that the impact on tuber production was comparatively small and a delay in tuber production of 10 days or so appeared to be followed by resumption of production at a rate similar to the original. A somewhat similar sequence followed treatment with paraquat. Musik and Crusado (1953) reported very slow movement of 2, 4-D in nutgrass systems resulting in a limited kill. Standifer (1974) reported that emerged plants of nutgrass and their parent tubers were killed by four or five applications of paraquat and up to three applications of 2, 4-D afforded almost complete control.

In benzoic and phenylacetic acids, Parker et al (1969) found that 2, 3, 6-TBA had only mild effects as a post-emergence treatment but were active pre-emergence. The dose of 1.12 to 2.24 Kg/ha which is required limits their selectivity and the period of control was also rather

variable. Chlorfenac, on the other hand, gave consistently prolonged control as a pre-sowing treatment but tubers were not killed even at very high doses although root development was inhibited and shoots were greatly weakened at low doses for periods of up to several months. Dicamba and chloramben can be effective but only at rather high doses pre-sowing.

As regards the carbamates, Parker et al (1969) observed that the non-sulphur containing carbamates, for example, asulam are consistently inactive both as pre and post-emergence treatments. In their effects on Cyperus rotundus, the thiocarbamates are strikingly distinct from other carbamates. EPTC activity had been confirmed in several pot tests at doses down to 0.56 Kg/ha. Even at high doses of 6.72 Kg/ha however, tubers were not killed and there was eventually healthy recovery. Prolonged control appeared to depend on persistence in the soil. Most of the related compounds had similar effects but none were as active as EPTC itself. Di-allate and tri-allate were much less active at low doses on a short term basis. Hammerton (1974) reported that soil incorporated butylate, EPTC and vernolate had only small effects on nutgrass shoot numbers and the germination of recovered tubers. However, Williams et al (1976) observed satisfactory control of C. rotundus at 2 Kg/ha EPTC during the dry season and 4 Kg/ha or more during the wet season. They found that EPTC persisted longer when applied to air dry soil and incorporated with a rototiller than when incorporated into moist or wet soil.

Rincorn and Warren (1978) working on the effect of five thiocarbamates on purple nutsedge found that the most effective reduction in the number of sprouts aboveground was given by butylate, EPTC and vernolate followed by pebulate and molinate. No effect was observed on the number of tubers which sprouted. Current knowledge on the metabolism and mode of action of thiocarbamate herbicides is rather limited. In general, these herbicides inhibit growth of shoots rather than roots. Prolonged control appears to

depend on persistence in the soil which is affected by volatility, leaching and microbial breakdown. (Gray and Weierich, 1965, 1968).

C. rotundus had an apparent resistance to the majority of substituted areas e.g. diuron and linuron which were tested on it (Parker et al, 1969).

The triazines in general had only moderate activity on C. rotundus and rather high doses were required for satisfactory control. Under ideal conditions, 3.36 Kg of simazine or atrazine per hectare were successful in pot tests carried out by Parker et al (1969) but higher doses are likely to be needed in the field. The methyl thiotriazines (ametryne, prometryne) had considerable post-emergence activity but again high doses were needed and recovery usually occurred (Parker et al, 1969).

Aminotriazole was well known to have some useful action against C. rotundus but high doses were required and kill was rarely achieved. Among the miscellaneous group, dalapon gave some suppression but even at high doses no lasting control was achieved (Parker et al, 1969).

Williams and Warren (1975) observed that night applications of nitrofen (1, 2 and 4 Kg/ha) in water and an herbicidal oil alone (100, 200 and 400 l/ha) suppressed C. rotundus foliage by 60% or more. Combinations of nitrofen in the herbicidal oil were more effective in suppressing C. rotundus than either herbicide applied alone. Generally night applications were said to be more effective than day applications. It should be noted, however, that the suppression of nutgrass referred only to the foliage and no mention was made of the tubers which are vital organs of regeneration.

b(i) Recently introduced herbicides

Cyperquat (1-methyl-phenyl-pyridinium chloride) is a recent introduction by Gulf Oil Company. It belongs to the pyridines group and it is mainly a post-emergence compound with no soil activity due to its strong absorption on to soil particles. Cyperquat is apparently specific to a few species with selectivity in a number of crops. Cyperquat symptoms are less

dramatic than those of other members of its group like paraquat and scorch is minimal and slower to develop. Paleness of foliage or chlorosis develops before death. This can also occur in the regrowth of perennial weeds treated with cyperquat. Mammalian toxicity is high in cyperquat (Fryer and Makepeace, 1977).

Cyperquat has been suggested for post-emergence control of Cyperus rotundus in a wide range of crops. Johnson (1974) reported that purple nutsedge was controlled during the initial year of treatment with single applications of 3.4 and 5.6 Kg/ha rates of S - 21634 which is cyperquat. He noted further that S - 21634 resulted in top kill of purple nutsedge when applied at 3.4 Kg/ha rate. Hammerton (1975) reported that cyperquat killed top growth and reduced germination of recovered tubers in both field and pot trials but he added that whether cyperquat caused tuber death was not clear from the reported work.

b(ii) Glyphosate

Chemical methods of control of Cyperus rotundus were not very effective before the discovery of glyphosate a few years ago. Glyphosate, the common name of N-(phosphonomethyl) glycine is a relatively new post-emergence translocated herbicide discovered by Monsanto Company. Roundup is the trademarked name for the formulation containing the isopropylamine salt of glyphosate. It is formulated as a water soluble concentrate containing 480 g/litre of the isopropylamine salt of glyphosate or 360 g acid equivalent per litre (Strbac, 1976).

Glyphosate controls a broad spectrum of annual, biennial and perennial grasses, sedges and broadleaved weed species. It is applied as a post-emergence foliar absorbed material and it is slowly translocated throughout the plant system giving out standing destruction of underground roots and rhizomes thereby controlling many deep rooted perennial species (Spurrier, 1973). The isopropylamine salt of glyphosate is a non-selective, broad spectrum herbicide. A moderate concentration of it will

destroy desirable as well as undesirable plants. Selective control of weeds in certain agricultural or horticultural crops may be achieved by direct spray applications but low crop selectivity is a problem that must be considered (Spurrier, 1973). Soil persistence of the herbicide is negligible. Sprankle et al (1974) postulated that the initial inactivation of glyphosate in soil is by reversible absorption to clay and organic matter through the phosphonic acid moiety. This assertion was later supported by Hensley et al (1978) who found that mineral soils significantly reduced the inhibitory effects of glyphosate on root growth.

Glyphosate, the parent compound, has a low mammalian toxicity and it is classified as only slightly toxic by oral ingestion with an acute LD_{50} to rats of 4320 mg/Kg. The isopropylamine salt of glyphosate has an acute oral LD_{50} of 4900 mg/Kg to rats (Spurrier, 1973). Excellent handling characteristics of the formulation make it very safe and convenient to apply with hand sprayers. Further strong evidence of low toxicity to bees and wildlife should encourage acceptability under conditions where environmental safety is important.

Based on limited investigations, Jaworski (1972) postulated that glyphosate interferes with the biosynthesis of phenylalanine and more specifically with the metabolism of chorismic acid in the aromatic amino acid biosynthesis pathway. Initial activity is fairly slow after application, and depending on the species treated, obvious herbicidal response may not be visible for two to four days for annual species and up to ten days or longer for perennials. Visible effects are manifested as gradual wilting and yellowing of the treated plant which advances to complete browning, deterioration of plant tissue and ultimate decomposition of the underground root or rhizome system (Spurrier, 1973). Zandstra et al (1974) treated purple nutsedge plants in the greenhouse and field with glyphosate. They found that the fresh weight of leaves and shoots per original tuber and sprouts per new tuber were reduced by 4 Kg/ha glyphosate in the greenhouse.

In the field, after several applications, glyphosate at 2 and 4 Kg/ha reduced the number of plants per unit area. Abu-Irmaileh and Jordan (1978) reported that glyphosate caused significant reductions in the chlorophyll and carotenoids content of purple nutsedge leaves. Based on levels in untreated plants, carotenoid content was reduced more rapidly than chlorophyll in glyphosate treated plants.

Many researchers have reported that glyphosate activity is affected by environmental factors including relative humidity, temperature, rainfall, soil moisture, photoperiod and light intensity (Spurrier, 1973; Jordan, 1977 and Wills, 1978). The stage of maturity of weed species to be treated is also a primary consideration for obtaining best results (Spurrier, 1973; Zandstra and Nishimoto, 1977). Jordan (1977) observed that at both 22 and 32°C translocation of the ^{14}C - glyphosate out of the treated leaf into the plant was five to six times greater at 100% RH than at 40% RH. Likewise, he found that more ^{14}C of glyphosate was translocated at 32°C than at 22°C at 40% RH. However, there was no difference in the amount of translocation of the ^{14}C label at 100% RH. Wills (1978) found in studies with ^{14}C-glyphosate applied to cotton under various combinations of temperature, relative humidity and surfactant that absorption and translocation of ^{14}C were affected most by variations in RH. When temperature and surfactant remained constant, an increase in RH from 40 to 100% resulted in approximately 3 to 6 fold increase in absorption and translocation of the ^{14}C label. At constant RH, he stated that an increase in temperature from 22 to 32°C or in surfactant from 0 to 1% resulted in either no significant effect or less than a 1-fold increase in absorption or translocation of ^{14}C.

In an earlier work for the manufacturer of glyphosate, Spurrier (1973) observed that rainfall occurring up to six hours after application reduced the effectiveness of the treatment depending on the intensity and duration of the rain. Thus to be certain of benefit spraying should be avoided when rain is imminent or forecast.

Moosavi-Nia and Dore (1979) gave three different soil moisture regimes - field capacity, moderate stress and extreme stress to established greenhouse grown plants of purple nutsedge followed 6 weeks later by glyphosate applications to shoots at 1.12 Kg/ha. They found that glyphosate applied at field capacity decreased shoot dry weight and total number of tuber bulbs in Cyperus rotundus. In contrast, at extreme soil moisture stress, glyphosate showed reduced activity which appeared to be related to the physiological and morphological behaviour of the plants arising from the drought treatment. They stated further that application of water to the roots of the plants grown at soil moisture stress, 1 week before and 1 week after glyphosate spraying, enhanced glyphosate activity, probably because of the recovery of processes disturbed by the soil moisture deficit.

Caseley(1972) found that if treatments are made under shade or extremely cloudy conditions it may take longer for visible effects on certain weed species to appear but the ultimate results are normally comparable to treatments made in sunlight.

As regards the stage of maturity of weed species, Spurrier (1973) observed that the most effective destruction of certain deep rooted perennials appears to be when treatments are made at early bud or bloom stage for broadleaved species or at the late boot or early head stage for grasses and sedges. Very early treatment of perennial vegetation is usually less effective as many plants will not have emerged sufficiently to receive the spray. Perennial weeds must have adequate leaf area e.g. six to eight leaves to permit absorption and translocation of glyphosate into the plant tissue and root system. Zandstra and Nishimoto (1977) found that with increasing plant age, specific activity of glyphosate decreased in both tubers and leaves. As purple nutsedge grew older, total ^{14}C translocated increased in tubers and decreased slightly in leaves. Thin layer chromatography showed no evidence of glyphosate metabolism in purple nutsedge.

Shaner (1978) reported that foliar application of glyphosate reduced transpiration rates but the time required for the effect to take place depended upon the species and the concentration of glyphosate used. First, the lower the concentration of glyphosate sprayed on the leaves, the longer the time required before transpiration was affected. Second, the age of the treated leaves affected the length of time before transpiration began to decrease after treatment. The younger plants responded before the older plants but the ultimate decrease was nearly the same after 29 hours. The three plant species used by Shaner (1978) in this experiment were pea (Pisum sativum L.), sunflower (Helianthus annus L.) and bean (Phaseolus vulgaris L.).

Published information have shown that certain herbicides can reduce the activity of glyphosate when applied as a tank mix. Appleby and Somabhi (1978) found antagonistic effect of atrazine and simazine on glyphosate activity. This antagonism was more pronounced at threshold levels of glyphosate and was overcome by increasing the glyphosate rate. Their conclusion was that the reduction in glyphosate phytotoxicity from mixing with atrazine or simazine wettable powders was due to a physical binding within the spray solution rather than from biological interactions within the plant. Therefore, manufacturer's instructions must always be followed before any tank mix is made.

IV EXPERIMENT 1

Effects of glyphosate, paraquat and cyperquat as influenced by rate of application, light and time after treatment on the control of the aerial growth of Cyperus rotundus

a. Objective

This experiment was designed to investigate the effectiveness of the three herbicides mentioned above on the control of the aerial growth of nutgrass and to find out at what rates of application they are most effective. The effects of covering some of the treated nutgrass plants thereby reducing light entry on the activity of these herbicides was also investigated.

b. Methods and Materials

This work was carried out in a greenhouse with pot grown plants of Cyperus rotundus. The original tubers came from the Chesterford Park Research Station, Essex, England. Good growth was obtained in the greenhouse and tuber development was typical of that obtained under field conditions.

For this post-emergence spraying experiment, single unsprouted tubers of nutgrass were planted in a sand/peat mixture in 20 cm diameter pots and grown to the 6 to 12 leaf stage before spraying. At this stage rhizome development is usually just beginning and no new tubers have been formed so the plants are at a relatively very susceptible stage. Greenhouse temperature ranged from 18 to 24°C (65 to 75°F). Supplementary light was provided at night by warm white fluorescent tubes during this growth period. Pots were placed on the ground and spraying was carried out by walking over the pots with a knap-sack sprayer using two overlapping nozzles. Rates of application of herbicide selected varied from 0 to 16 litres/ha. All the three herbicides were applied in a volume of application equivalent to 600 litres of water per hectare. Standard commercial formulations of

these herbicides were used. Randomised block design with four replications was used and comparisons made with untreated plants as control. After post-emergence treatment, half of the plants were covered with non-transparent polythene sheets to reduce light. The plants were grown on for three weeks during which they were assessed for damage and to permit full symptoms and/or recovery to be shown. Assessments were made visually on a 0 to 9 scale for leaf kill (aerial growth) with 0 representing no control and 9 representing complete death of foliage and other aerial parts. Assessments were made at 4 days interval from date of treatment to 3 weeks after treatment. All assessments were taken into consideration in arriving at the figures shown in the Tables.

c. Results

The analysis of variance of the data collected showed that effects of herbicide type, rates of application, light treatment and time after spraying were significant at 0.1% level. Also, all the first and second order interactions were significant at 0.1% level (see appendix 1). However, replicates were found not to be significant.

The assessment of visual kill on the 0 - 9 scale for leaf kill (aerial growth) were converted to per cent kill of aerial growth for the different tables as follows:

Table 1

$$\text{Treatment score divided by } \frac{\text{Total score}}{\text{df + 1 of herbicides x rates}} \times 100$$

Table 2

$$\text{Treatment score divided by } \frac{\text{Total score}}{\text{df + 1 of herbicides x dark/light}} \times 100$$

Table 3

$$\text{Treatment score divided by } \frac{\text{Total score}}{\text{df + 1 of herbicides x dark/light}} \times 100$$

Table 1

Effects of the rates of application on the activities of the three herbicides in purple nutsedge as influenced by time.

TIMES (days after spraying)	RATES (litres/ha) 0			2			4			8			16			
	GLY	CYP	PAR	GLY	CYP	PAR	GLY	CYP	PAR	GLY	CYP	PAR	GLY	CYP	PAR	
4	0	0	0	2* (2.7)+	6 (8.3)	68 (94.4)	3 (4.1)	6 (8.3)	68 (94.4)	2 (2.7)	5 (6.9)	68 (94.4)	1 (1.3)	5 (6.9)	68 (94.4)	302
8	0	0	0	2 (2.7)	20 (27.7)	72 (100)	5 (6.9)	20 (27.7)	72 (100)	12 (16.6)	20 (27.7)	72 (100)	15 (20.8)	20 (27.7)	72 (100)	402
12	0	0	0	16 (22.2)	20 (27.7)	72 (100)	32 (44.4)	20 (27.7)	72 (100)	32 (44.4)	20 (27.7)	72 (100)	32 (44.4)	20 (27.7)	72 (100)	480
16	0	0	0	34 (47.2)	24 (33.3)	72 (100)	62 (86.1)	24 (33.3)	72 (100)	64 (88.8)	24 (33.3)	72 (100)	64 (88.8)	24 (33.3)	72 (100)	608
20	0	0	0	38 (52.7)	24 (33.3)	72 (100)	70 (97.2)	32 (44.4)	72 (100)	72 (100)	32 (44.4)	72 (100)	72 (100)	36 (50)	72 (100)	664
	0	0	0	92	94	356	172	102	356	182	101	356	184	105	356	2456

* Visual score for kill of aerial parts (total of four replicates)

\+ Per cent kill of aerial parts in brackets

Table 2

Effects of dark and light treatments on the activity of the three herbicides in purple nutsedge as affected by time.

TIMES (days after spraying)	HERBICIDE: Glyphosate dark	Glyphosate light	Cyperquat dark	Cyperquat light	Paraquat dark	Paraquat light	
4	8* (4.4)+	0	6 (3.3)	16 (8.8)	128 (71.1)	144 (80)	302
8	17 (9.4)	17 (9.4)	32 (17.7)	48 (26.6)	144 (80)	144 (80)	402
12	28 (15.5)	84 (46.6)	32 (17.7)	48 (26.6)	144 (80)	144 (80)	480
16	104 (57.7)	120 (66.6)	48 (26.6)	48 (26.6)	144 (80)	144 (80)	608
20	120 (66.6)	132 (73.3)	64 (35.5)	60 (33.3)	144 (80)	144 (80)	664
	277	353	182	220	704	720	2456

Table 3

Effects of dark and light treatments on the three herbicides and their rates of application

RATES (litres/ha)	HERBICIDE: Glyphosate dark	Glyphosate light	Cyperquat dark	Cyperquat light	Paraquat dark	Paraquat light	
0	0	0	0	0	0	0	0
2	32* (17.7)+	60 (33.3)	42 (23.3)	52 (28.8)	176 (97.7)	180 (100)	542
4	79 (43.8)	93 (51.6)	46 (25.5)	56 (31.1)	176 (97.7)	180 (100)	630
8	82 (45.5)	100 (55.5)	45 (25)	56 (31.1)	176 (97.7)	180 (100)	639
16	84 (46.6)	100 (55.5)	49 (27.2)	56 (31.1)	176 (97.7)	180 (100)	645
	277	353	182	220	704	720	2456

* Visual score for kill of aerial parts (total of four replicates)

\+ Per cent kill of aerial parts in brackets

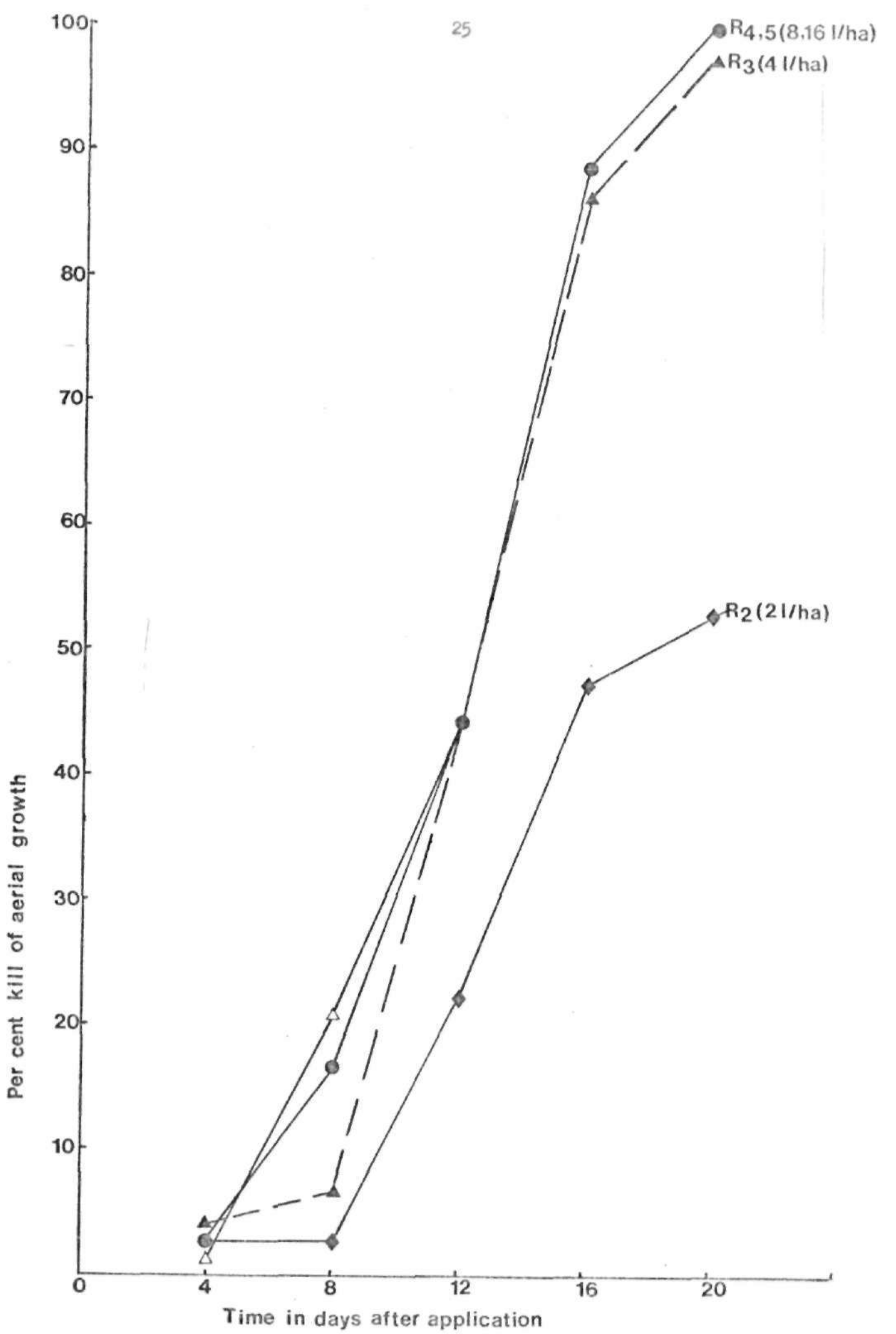


Figure 3: Effects of the different rates of application of glyphosate on the control of aerial growth of nutgrass with time

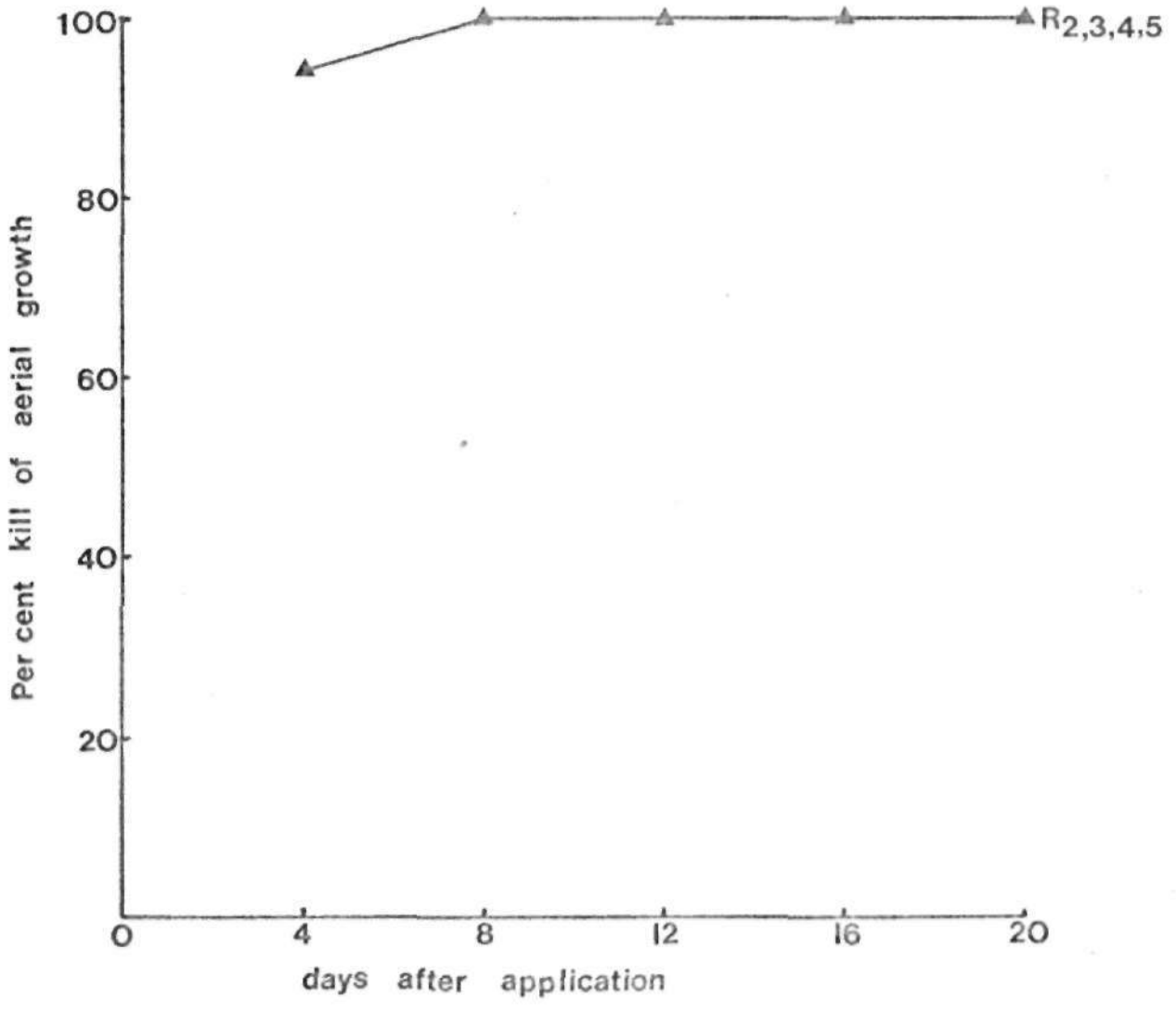


Figure 4: Effects of the different rates of application of Paraquat on the control of the aerial growth of nutgrass with time

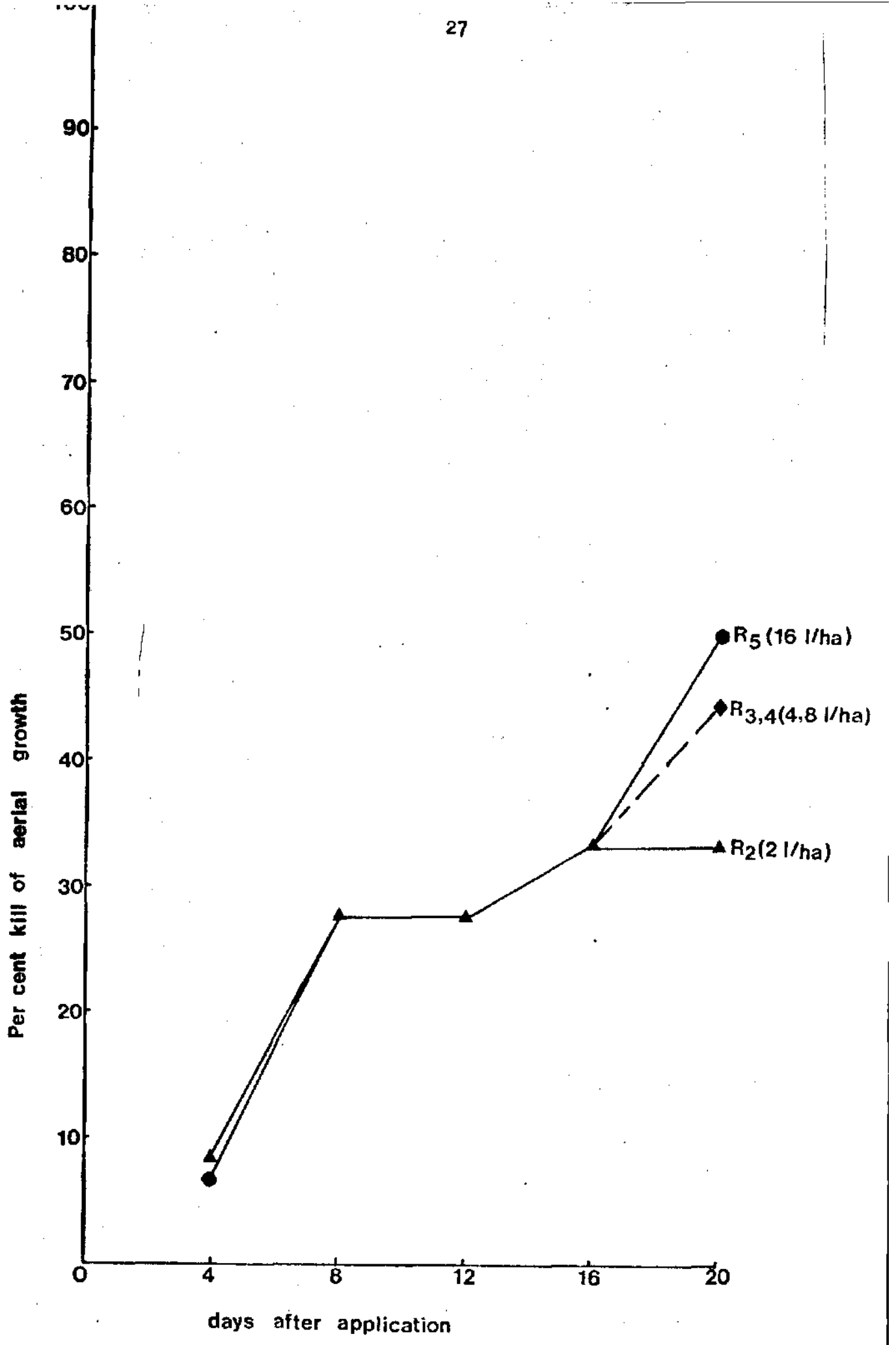


Figure 5: Effects of the different rates of application of Cyperquat on the control of the aerial growth of nutgrass with time

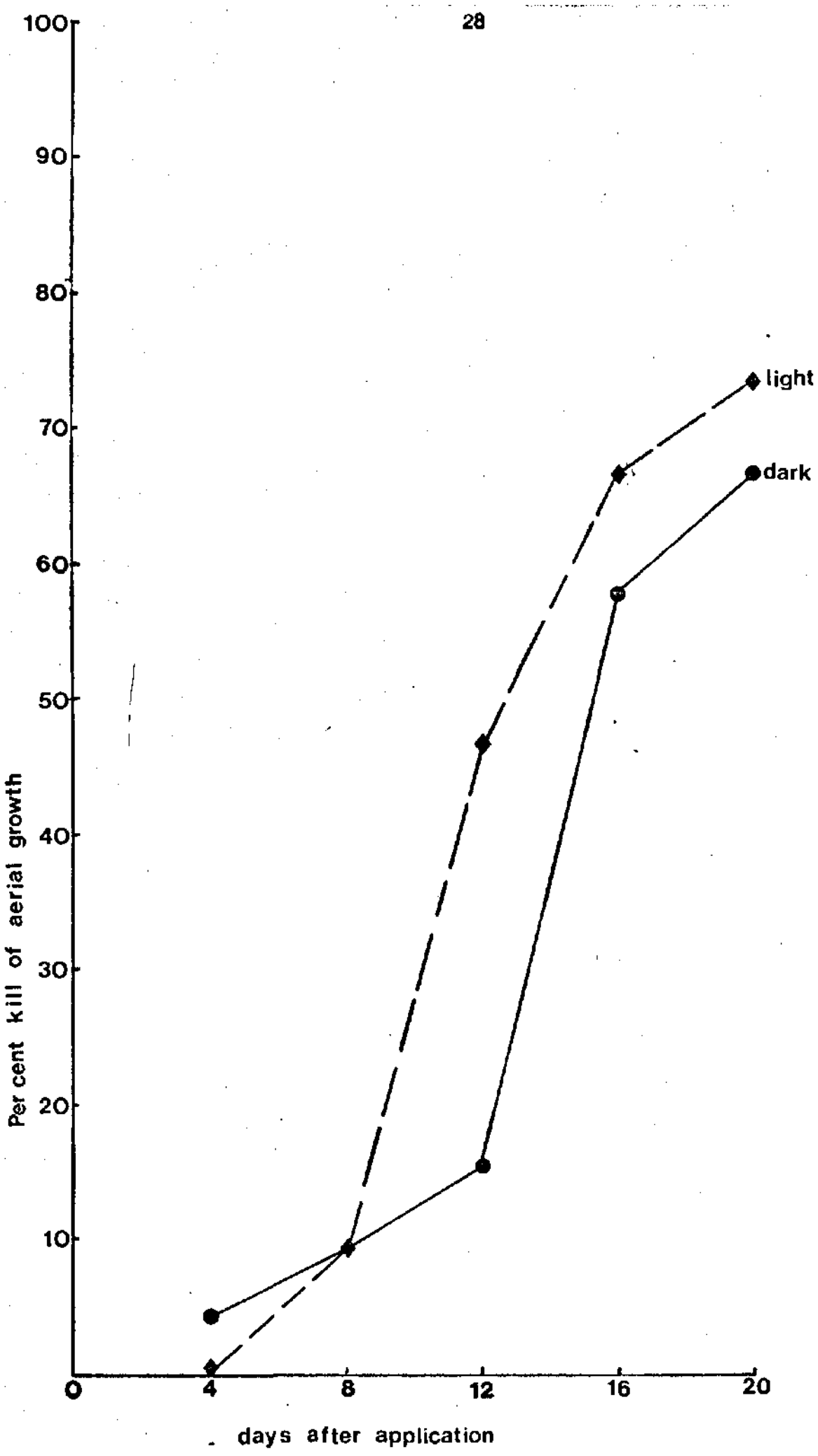


Figure 6: Effects of light and dark treatments on the activity of glyphosate in C. rotundus as affected by time

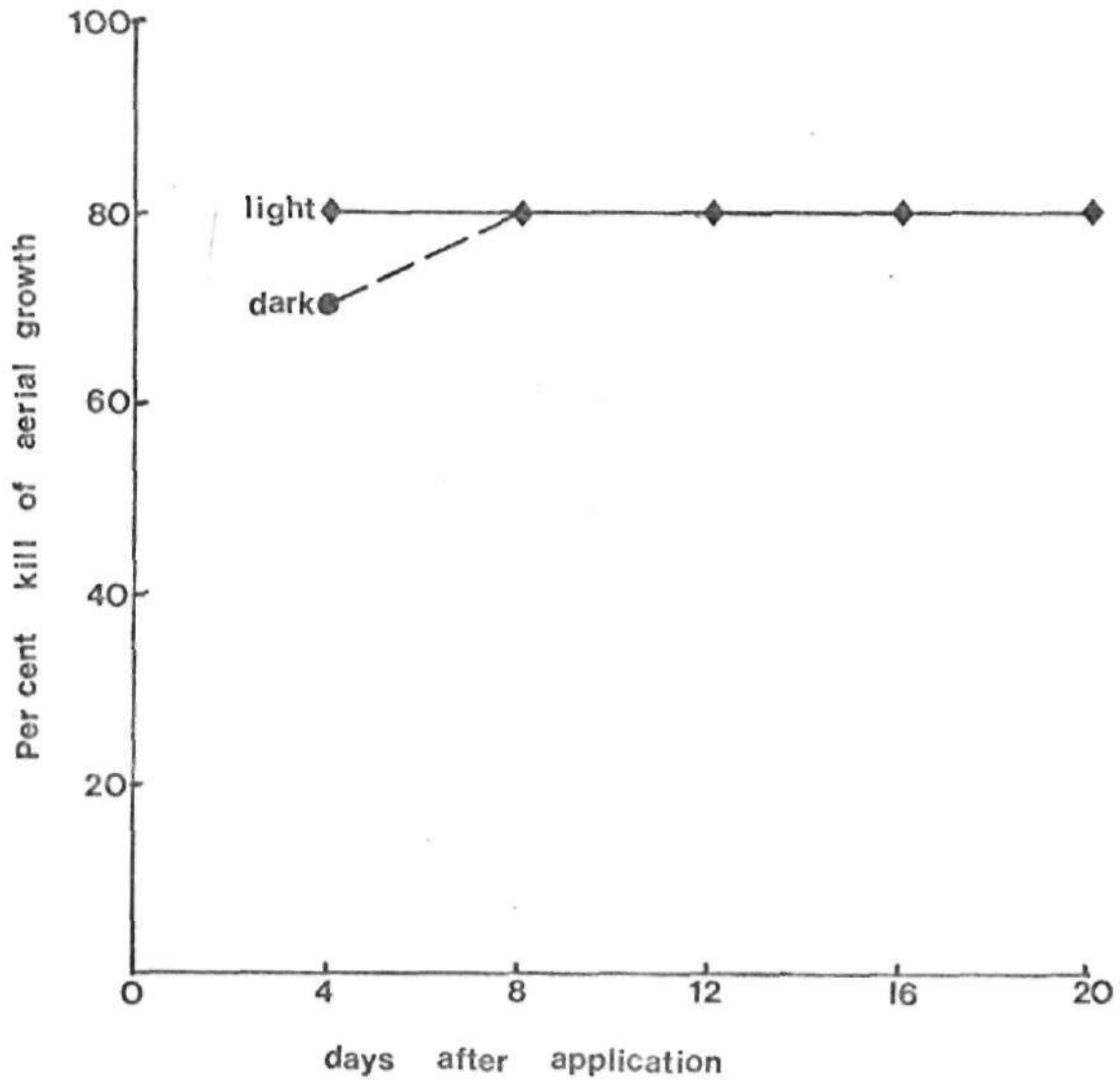


Figure 7: Effects of light and dark treatments on the activity of paraquat in C. rotundus as affected by time

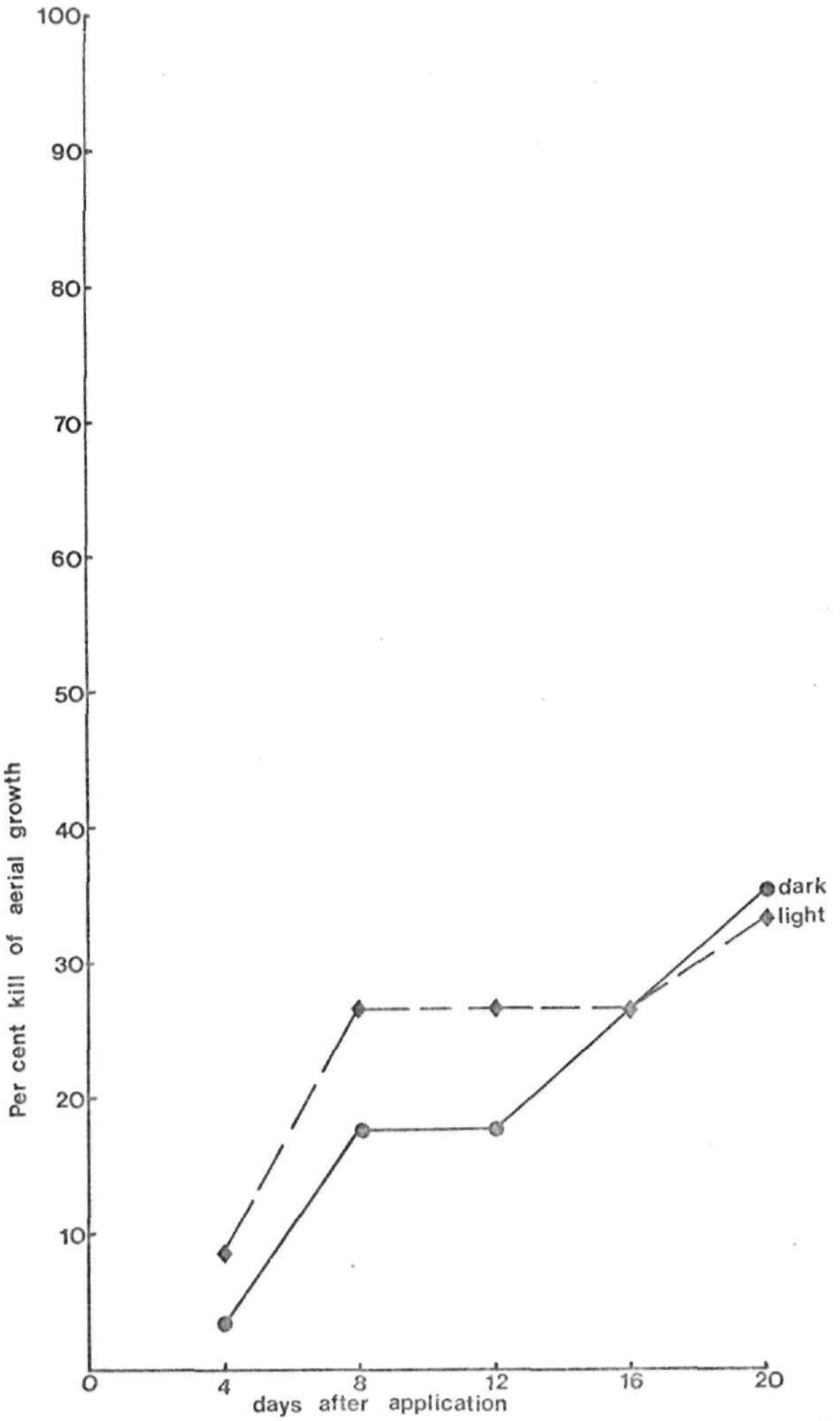


Figure 8: Effects of light and dark treatments on the activity of Cyperquat in C. rotundus as affected by time

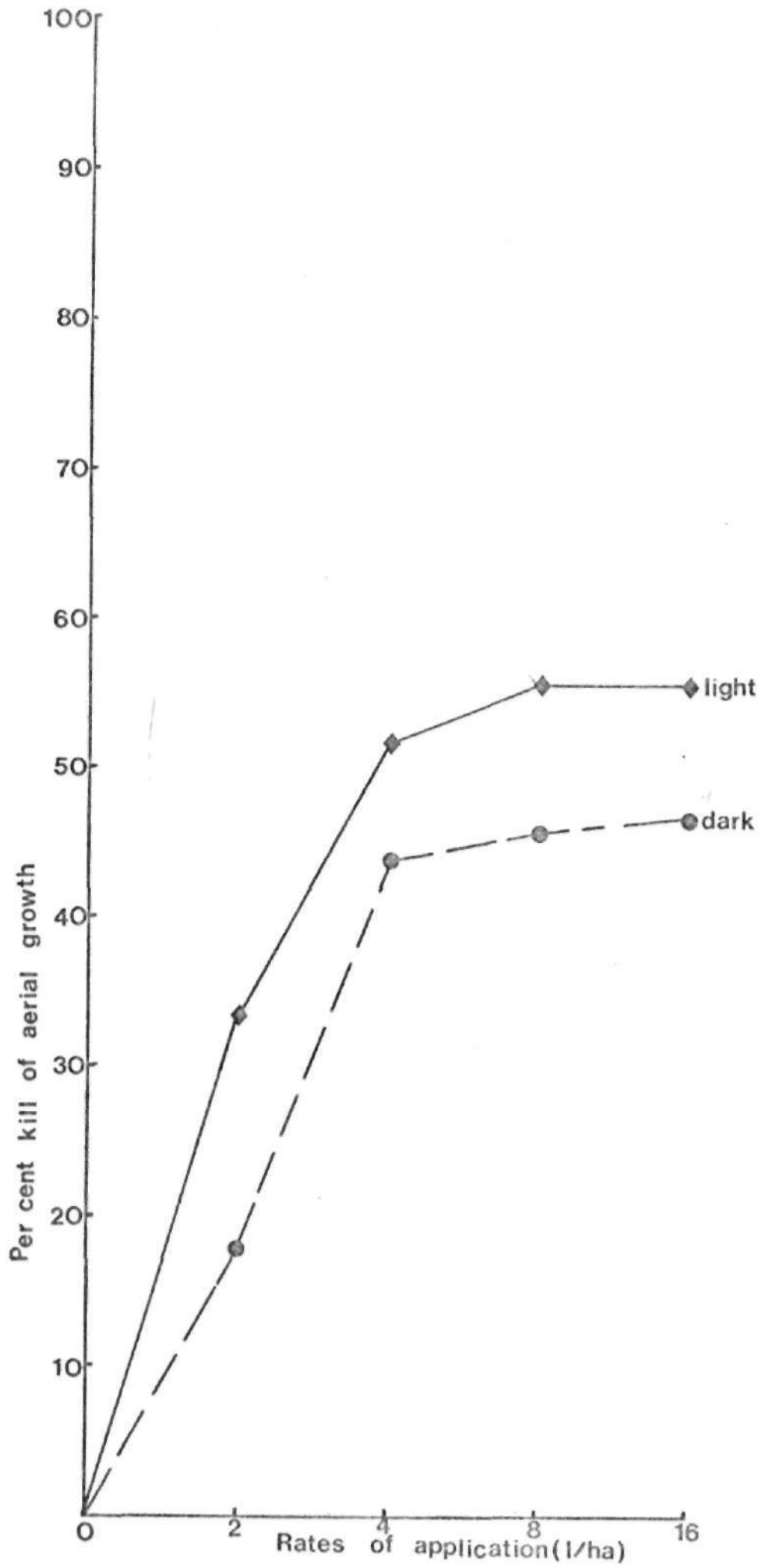


Figure 9: Effects of light and dark treatments on the rates of application of glyphosate in killing the aerial growth of nutgrass

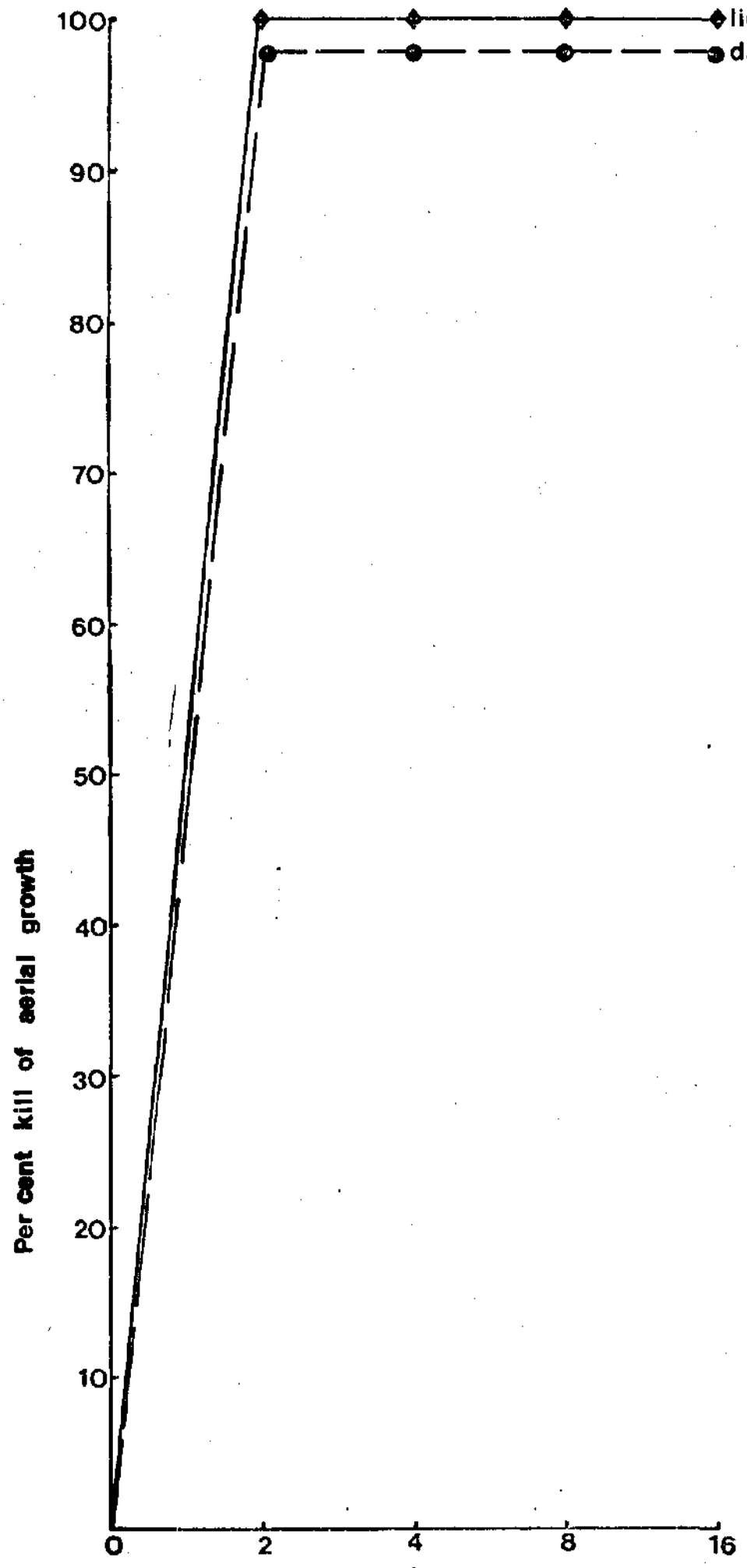


Figure 10: Effects of light and dark treatments on the rates of application of paraquat in killing the aerial growth of nutgrass

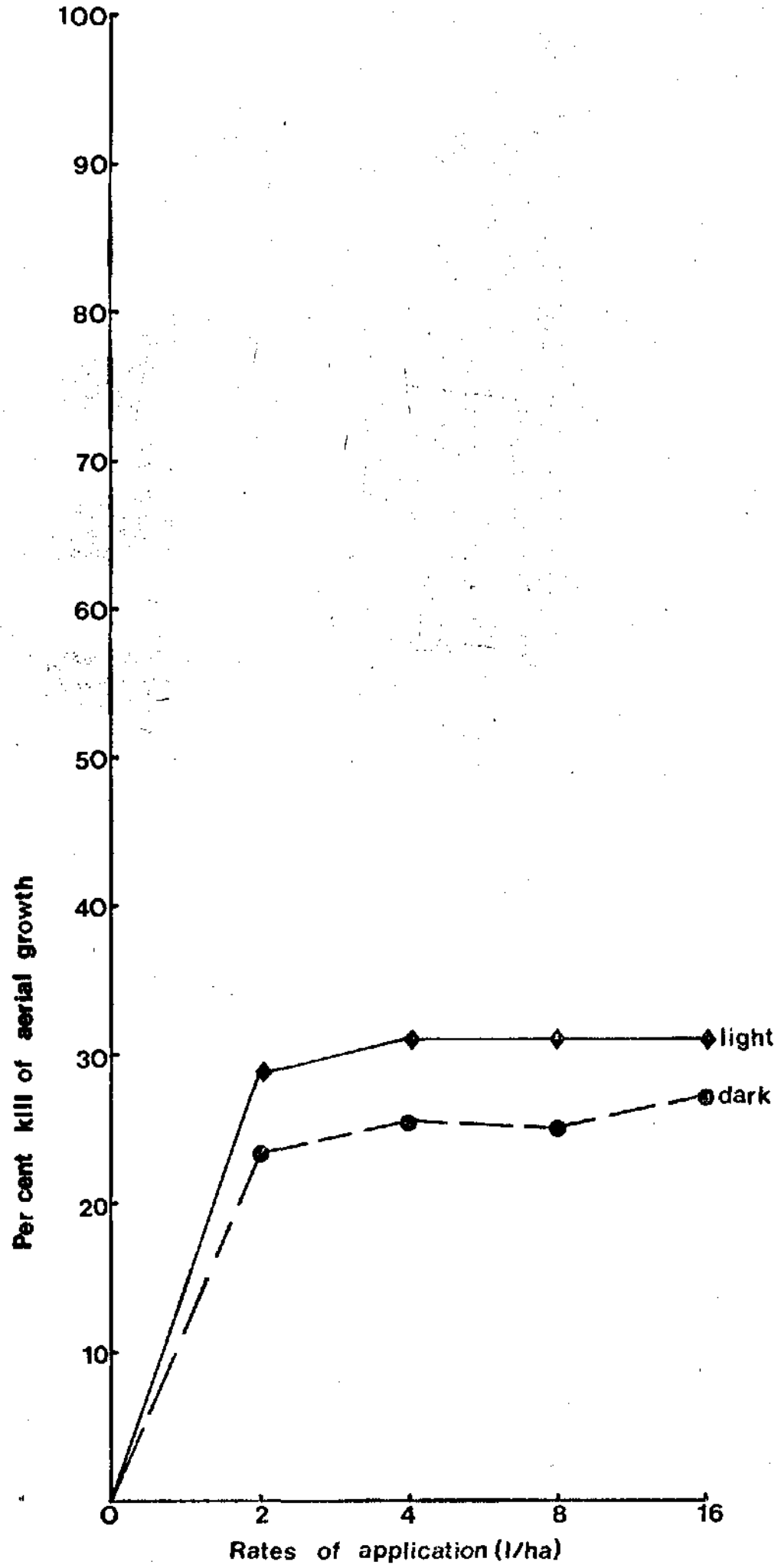


Figure 11: Effects of light and dark treatments on the rates of application of Cyperquat in killing the aerial growth of nutgrass

Table 1 (Herbicides x rates x time)

This table shows the effect of herbicides and rates of application as influenced by time. Rate 1 was taken as the control with no herbicides used and other treatments were compared with it.

(i) Glyphosate (Fig. 3)

In the case of this herbicide, 100% kill of aerial growth was achieved by rate 4 (8 litres/ha) and rate 5 (16 litres/ha) at 20 days after spraying. Even at rate 3 (4 litres/ha), 97.2% of aerial parts were killed at 20 days after application of herbicide.

(ii) Paraquat (Fig. 4)

100% kill of aerial growth was achieved quickly at rate 2 (2 litres/ha) in 4 to 8 days after spraying. All higher rates of application gave similar results and there was no measurable difference in activity of the herbicide between the lowest rate of 2 litres/ha and the highest rate of 16 litres/ha.

(iii) Cyperquat (Fig. 5)

The highest per cent kill of aerial growth achieved by this herbicide was 50% at 16 litres/ha rate 20 days after spraying, the lowest being 8.3% kill at 4 litres/ha in 4 days. From this result, cyperquat appears to be much less effective than the other herbicides in controlling the aerial growth of nutgrass.

Table 2 (Herbicides x light/dark x time)

This table shows the interaction between herbicides and light/dark treatment as affected by time.

(i) Glyphosate (Fig. 6)

The effect of light did not start to show until 8 days after spraying. At 20 days after spraying, 73.3% of the aerial growth of nutgrass exposed to light was killed compared with 66.6% in the dark treatment.

(ii) Paraquat (Fig. 7)

There was 71.1% kill of aerial growth of nutgrass under the dark treatment 4 days after spraying compared with 80% kill of the light treatment at the same time. However, there was no difference in the per cent kill of dark and light treatments as from 8 days after spraying.

(iii) Cyperquat (Fig. 8)

The light treatment had 8.8% kill of aerial growth compared with 3.3% kill by the dark treatment 4 days after spraying. This trend continued until 20 days after spraying when dark treatment had a slightly higher per cent kill of 35.5% against 33.3% kill of plants under light.

Table 3 (Herbicides x rates x light/dark)

When the interactions between herbicides, light and dark treatments as well as rates of application were taken into account, a different picture emerges. Here, the plants exposed to light in all the three herbicide treatments had higher per cent kill of aerial growth of nutgrass than the plants under the dark. This shows that light has an effect on the activities of these herbicides in nutgrass (Figs. 9, 10 and 11).

d. Discussion and conclusion

The slow initial activity of glyphosate after spraying and the fact that it took 20 days for necrosis to be complete in nutgrass was supported by Spurrier (1973) who observed that herbicidal response of glyphosate may not be visible for up to 10 days or longer in perennial weeds.

The need for the high rate of application of 8 litres/ha to achieve complete control of the aerial parts of nutgrass may be due to environmental factors especially temperature and relative humidity. Jordan (1977) and Wills (1978) reported that glyphosate activity is

affected by temperature and relative humidity. Jordan (1977) observed further that less than 10% of the applied ^{14}C-glyphosate penetrated the treated bermudagrass leaf at 22°C and 40% RH whereas more than 70% penetrated the treated leaf at 32°C and 100% RH. This experiment was carried out in the greenhouse at a temperature range of 18 to 24°C (65 to 75°F) and 90 to 100% RH. During the night time temperature often dropped below 18°C before the completion of this work. This condition probably resulted in less glyphosate penetrating the leaves of nutgrass and therefore caused reduction in activity of the herbicide. Another reason why it took a high rate of application of glyphosate to be effective is that nutgrass plants used in this experiment were at least 5 weeks old before spraying started. In fact shoots did not emerge until 12 days after planting on the average because of low temperature at that time. This claim is in agreement with Zandstra and Nishimoto (1977) who reported that with increasing plant age specific activity decreased in both tubers and leaves and that as purple nutsedge grew older total ^{14}C translocated increased in tubers and decreased slightly in leaves. It is probably more economic to apply glyphosate at 4 litres/ha as the 97.2% kill of aerial growth achieved at this rate of application is just a little less than 100% kill produced by 8 litres/ha rate (Fig. 3).

The low difference between per cent kill of aerial growth of nutgrass in the dark and light treatments (Table 2) agreed with the observation of Caseley (1972) who said that if treatments were made under shade or extremely cloudy conditions it may take longer for visible effects on certain weed species to appear but the ultimate results are normally comparable to treatments made under sunlight.

In the case of paraquat which is quick acting, the complete kill of the aerial growth of nutgrass within 4 days after spraying agreed with Fryer and Makepeace (1977) description of its symptoms as being a

characteristic rapid scorch and desiccation of sprayed leaves. The rate of application of 2 litres/ha is as effective in killing the aerial growth of nutgrass as any other higher rate (Fig. 4). This is contrary to the findings of Zandstra et al (1974) who said that paraquat had no effect on nutsedge stand. The reason why nutgrass plants sprayed with paraquat and then covered with non-transparent polythene sheets gave the same per cent kill of aerial growth as those uncovered may be that the covering did not totally prevent the entry of light but may just have succeeded in reducing the light intensity. Fryer and Makepeace (1977) said that light is essential for the activity of paraquat but under low light intensity some translocation may occur but in darkness no symptoms develop.

From the low 50% kill of the aerial growth of nutgrass by cyperquat in this experiment, it is clear that this herbicide cannot bring about an effective control of nutgrass. This claim agrees with the observation of Fryer and Makepeace (1977) that cyperquat symptoms are less dramatic and scorch is minimal and slower to develop. On the contrary, Johnson (1974) said that cyperquat resulted in top kill of purple nutsedge which was supported by Hammerton (1975) who reported that cyperquat killed the top growth of nutgrass in both field and pot trials.

It should be noted that this experiment concerns itself with the effectiveness of the three herbicides in killing the aerial growth of nutgrass. Whether they are capable of killing the underground tubers was not investigated but with the known properties of both paraquat and cyperquat as contact herbicides, it is highly unlikely that they can have any considerable effect on the ability of the tubers to regenerate. However, glyphosate being a translocated herbicide is expected to reach the tubers and kill them (Spurrier, 1973; Johnson, 1974 and Hammerton, 1975) but how long it takes glyphosate to reach the tubers given the various environmental factors is the subject of consideration in the next experiment.

V. EXPERIMENT 2

a. Objective

To investigate whether different rates of application of glyphosate is able to translocate into and prevent regrowth of nutgrass tubers 21 days after spraying.

b. Materials and methods

In this experiment, nutgrass plants were sprayed with glyphosate at 2, 4 and 8 litres/ha and left at a temperature of 21°C (70°F) and 60% relative humidity in the laboratory. Untreated nutgrass plants serve as control. The plants were lifted from the pots 21 days after this post-emergence treatment and ten randomly selected tubers from each of the treatments and control were replanted in pots containing sand/peat mixture.

c. Results and discussion

All the tubers from the treated plants except the control failed to regenerate 21 days after treatment. This shows that glyphosate has translocated into the underground tubers of nutgrass plants thereby preventing their regrowth. The next experiment tries to find out whether glyphosate translocation and prevention of regrowth of underground tubers occurred within 7 days after spraying.

VI EXPERIMENT 3

a. Objective

To investigate whether glyphosate applied at different rates on nutgrass leaves prevents the regrowth of the underground tubers lifted within 7 days after treatment.

b. Methods and materials

Nutgrass plants grown in sand/peat mixture in 20 cm diameter pots for at least 3 months were used in this experiment. By this time the plants had a lot of foliage and tubers were well developed.

Randomised block design was used and comparison made with untreated plants as control. Pots were placed on the ground and spraying was carried out by walking over the pots with a knap-sack sprayer using two overlapping nozzles. Rates of application of glyphosate varied from 0 to 8 litres/ha. The herbicide was applied in a volume of application equivalent to 600 litres of water per hectare. A standard commercial formulation of glyphosate was used. Greenhouse temperature was about 15°C (59°F) and 100% relative humidity.

After this post-emergence treatment, the plants were lifted from the pots at 24 hour intervals for 7 days and ten randomly selected tubers from each of the treatments were replanted in pots containing sand/peat mixture. The percentage of the tubers which produced shoots was calculated and recorded as shown in Table 4.

c. Results

Table 4 shows that not all the tubers in the control treatment grew during the 7 days when they were under observation and there was wide day to day variation. At the rate of application of 8 litres/ha, 40% of the tubers regenerated 4 days after spraying compared with 100% on the 7th day. 50% regrowth of tubers was recorded on the 4th day while 30% regrowth occurred on the 7th day at 4 litres/ha rate of application

of glyphosate. At 2 litres/ha rate, 40% regrowth of the tubers on the 4th day compared with 30% on the 7th day.

Analysis of variance showed that days after spraying were significant at 5% level. This means that the longer nutgrass plants are left after spraying the lower the per cent regrowth of the tubers (Fig. 12). It was also established that rates of application have no significant effect on the regrowth of tubers.

The orthogonal polynomial method showed that the response curve of the relationship between days after spraying and per cent regrowth of tubers was linear (Fig. 12). Correlation coefficient analysis also showed that rates of application of glyphosate was significant and therefore closely correlated with the per cent regrowth of the tubers up to 4 days after spraying. The interactive effects between days after spraying and the rates of application of glyphosate was found to be significant by partial correlation coefficient analysis.

Table 4

Effects of the rates of application of glyphosate and days after spraying on the per cent regrowth of nutgrass tubers.

		Per cent regrowth							
	DAYS AFTER SPRAYING	1	2	3	4	5	6	7	
Rates of application (litres/ha)	0	70	30	80	40	50	0	60	330
	2	100	60	70	40	40	40	30	380
	4	90	20	50	50	70	10	30	320
	8	30	40	80	40	80	0	100	370
		290	150	280	170	240	50	220	1400

Analysis of variance of experiment 2

Source	Df	SS	MS	VR(F)
Days	6	10600	1766.7	3.37*
Rates	3	371.4	123.8	0.24 NS
Rates x Days	18	9428.6	523.8	
Total	27	20400		

Orthogonal polynomial analysis

x	1	2	3	4	5	6	7
y	290	150	280	170	240	50	220
Linear	-3	-2	-1	0	1	2	3
Quadratic	5	0	-3	-4	-3	0	5
Cubic	-1	1	1	0	-1	-1	1

	Linear	Quadratic
Q =	-450	310
K =	28	84
R =	4	4
SS = $\frac{Q^2}{K.R}$ =	1808.04	286.0
VR = $\frac{SS}{EMS}$ =	3.5*	0.55 NS

Correlation coefficient analysis

x_1 = Days after spraying

x_2 = Rates of application

$$r = \frac{xy}{(x^2)(y^2)}$$

ryx_1 = -0.4130*

ryx_2 = +0.3315 NS

	A				B			
Days	1	2	3	4	4	5	6	7
Total % regrowth	290	150	280	120	170	240	50	220
Rates	0	2	4	8	0	2	4	8
Total % regrowth	220	270	210	190	150	150	160	220

ry_1 = -0.4082* -0.0606 NS

ry_2 = -0.6165** +0.9276***

r1.2 = -0.3534 NS +0.2672 NS

Partial correlation coefficient

A. $ryl.2 = \dfrac{ry_1 - (ry_2)(r1.2)}{(1-r^2y_2)(1-r^2 1.2)}$

$$ryl.2 = \frac{-0.4082 - (-0.6165)(-0.3534)}{(0.6199)(0.8751)}$$

$$= \frac{0.6261}{0.7365}$$

$$ryl.2 = \underline{-0.8501}^{***}$$

B. $$ryl.2 = \frac{-0.0606 - (0.9276)(0.2672)}{(0.1396)(0.9286)}$$

$$= \frac{-0.3085}{0.3601}$$

$$ryl.2 = -0.8567^{***}$$

* = significant at 5% level

*** = significant at 0.1% level

NS = not significant

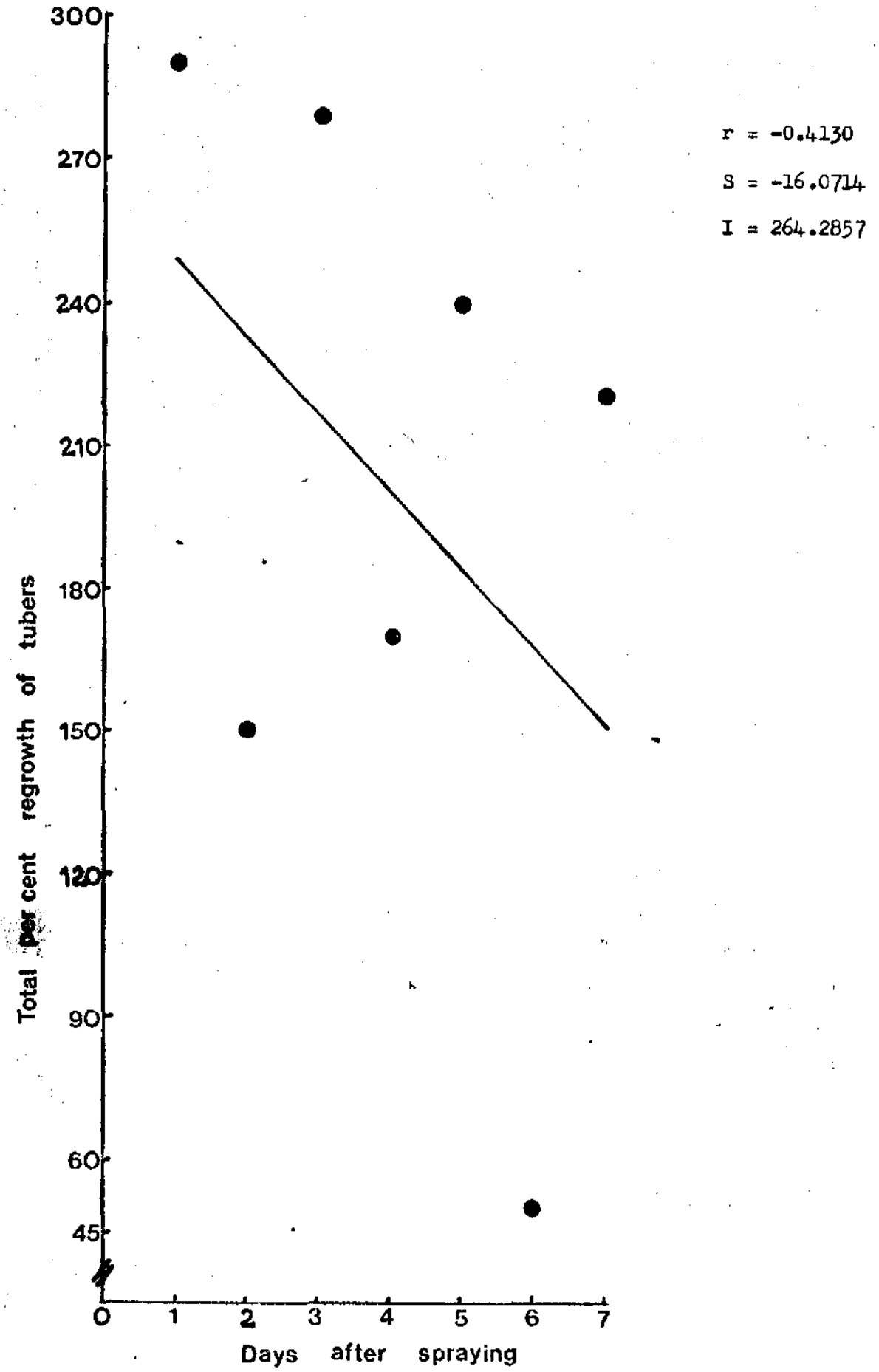


Fig. 12 - Effect of days after spraying on the total per cent regrowth of nutgrass tubers

d. Discussion and conclusion

The fact that not all the tubers in the control treatment grew was probably due to dormancy of the buds and environmental factors especially temperature. Temperature is one of the important factors controlling sprouting of tubers of nutgrass. Ueki (1969) obtained 95 per cent regrowth of tubers at 30 to 35°C with no sprouting above 45°C or below 10°C. The low temperature of 15°C prevailing at the time of this experiment may have reduced the chances of regrowth of these tubers.

There is a suggestion of a progressive decline in viability of tubers at 2 and 4 litres/ha. The results at 8 litres/ha seem anomalous but may be due to rapid kill of shoots and failure of translocation (Table 4). However, from the above analysis, it was found that the relationship between days after spraying and the regrowth of tubers depended on how long the treated plants were left for the herbicide to be translocated down to the underground parts of nutgrass. This shows that the longer the treated plants are left for translocation to occur the less are the chances of regrowth of the tubers.

The correlation coefficient analysis (Page 42) showed that the higher the rate of application the lower is the per cent regrowth at a shorter period of time of 4 days. At 2, 4 and 8 litres/ha rates of application of glyphosate only 40, 50 and 40% regrowth respectively was observed 4 days after spraying. This observation agrees with the work of Chase and Appleby (1979) who observed that after two applications of 2 Kg/ha of glyphosate to non-tilled nutgrass plants only 40% reduction in germination of the tubers occurred.

The partial correlation coefficient showed that the interactive effect of days after spraying and rates of application are significant at 0.1% level after the data has been partitioned into two groups of

days 1 to 4 and 4 to 7. From this analysis it could be said that effect of days after spraying on the regrowth of nutgrass tubers is influenced by the rates of application of glyphosate. Therefore, it could be concluded that using high rate of application of glyphosate, short number of days will be required to achieve low per cent regrowth while application of low rate of glyphosate will require long number of days to achieve low per cent regrowth of nutgrass tubers.

VII General discussion and conclusions

It is clear from published work and the experiments described in this thesis that glyphosate is an extremely promising herbicide for the non-selective control of nutsedge. It is capable of killing both the aerial parts and the underground tubers which is essential if more than temporary control is to be achieved. Absorption and translocation is rapid under favourable conditions especially high temperature and relative humidity which should make it more suitable for tropical than temperate conditions. It seems likely that soil cultivation can take place as soon as seven days after application without loss of tuber kill which means that little time is lost in preparation of the ground for the next crop. The absence of soil persistence is another characteristic of glyphosate of great value in crop production.

A serious drawback to effective control with glyphosate is its relatively slow adsorption by plant leaves which results in poor control when heavy rain follows soon after application or where impermeable cuticle is present. The addition of extra surface active agent or inorganic salts has been shown to sometimes have beneficial effects.

Already glyphosate is being used in weed control in tropical countries such as Nigeria although this is restricted mainly to research stations and other agricultural institutes. The limiting factor to the widespread use of this herbicide is the high cost of application. In Britain it costs £30 per hectare to apply glyphosate and there is no doubt that it will cost at least twice this amount in the developing countries of the tropics. With the establishment of Agricultural Credit Bank in Nigeria to give loans to farmers together with government subsidy of fertilisers, seeds and other agricultural

inputs, it is hoped that more farmers will be able to afford the purchase of glyphosate and other relatively costly herbicides which are essential for improved and high output crop production.

ACKNOWLEDGEMENTS

This work was conducted in the Agricultural Botany Division, University of Aberdeen. The author expresses his sincere gratitude and appreciation to Mr. E.B. Soragg of the Agricultural Botany Division who supervised this work.

I would like to thank Mr. A.D. McKelvie, former Head of Division, for his assistance and suggestions on experimental design and analysis of data.

Appreciation is also extended to Dr. G.F. Burnett, Head of Agricultural Zoology, for supplying me with the sprayer used in this work and to other members of staff of the Agricultural Botany Division for their help and co-operation especially Mr. John Douglas in the Craibstone farm.

I would also like to thank Dr. D.H.K. Davies of the Chesterford Park Research Station, Essex, England who supplied me with tubers of nutgrass and the Gulf Oil Chemical Company, Kansas, U.S.A. who sent me 1 litre of the herbicide cyperquat.

Many thanks are due to my wife for her support and understanding during the course of this work.

Finally, I would like to express my gratitude to the Nigerian Government and the authorities of Ahmadu Bello University, Zaria, Nigeria for granting me a study fellowship to undergo this course.

REFERENCES

ABU-IRMAILEH, B.E. & JORDAN, L.S. (1978) - Some aspects of glyphosate action in purple nutsedge. Weed Science 26(6) : 700-703

ANDREWS, F.W. (1940) The control of nutgrass in the Sudan Gezira. Emp. Journ. Expt. Agric. 8 : 215-222

APPLEBY, A.P. & MONTIEN SOMABHI (1978) Antagonistic effect of atrazine and simazine on glyphosate activity. Weed Science 26(2) : 135-139

ASHBY, D.G. & PFEIFFER, R.K. (1956) Weeds - a limiting factor in tropical agriculture. World Crops, June 1956, 227-229

BERGER, G. & DAY, B.E. (1969) Dormancy, growth inhibition and tuberization of nutsedge C. rotundus L. as affected by photoperiods. Proc. 1st Asian-Pacific Weed Contr. Int, 123.

BHARDWAJ, R.B.L. & VERMA, R.D. (1968) Seasonal development of nutgrass (Cyperus rotundus L.) under Delhi conditions. India J. Agric. Sci. 38 : 950-957

BIRD, G.W. & HOGGER, Ch. (1973) Nutsedges as hosts of plant parasitic nematodes in Georgia cotton fields. Plant Disease Reporter 57 : 402.

CASELEY, J. (1972) The effect of environmental factors on the performance of glyphosate against Agropyron repens. Proc. 11th Br. Weed Contr. Conf. 2 : 641-647

CHAPMAN, L.S. (1966) Prolific nutgrass growth. Cane Growers Quart. Bull. 30 : 16

CHASE, R.L. & APPLEBY, A.P. (1979) Effect of intervals between application and tillage on glyphosate control of Cyperus rotundus L. Weed Research 19 : 207-211

FRYER, J.D. & MAKEPEACE, R.J. (1977) Weed control handbook. Volume 1/ Principles. Sixth edition. Blackwell Scientific Publications, London

FUENTES, C. & DOLL, J. (1976) - The effect of soil humidity and texture on the growth and development of purple nutsedge (C. rotundus L.) Revista Comalfi 3(4) : 257-275

GRAY, R.A. & WEIERICH, A.J. (1965) Factors affecting the vapor loss of EPTC from soils. Weeds 13 : 141-147

GRAY, R.A. & WEIERICH, A.J. (1968) Leaching of five thiocarbamate herbicides in soils. Weed Sci. 16 : 77-79

HAMMERTON, J.L. (1974) Experiments with C. rotundus L. I. Growth and development and effects of 2,4-D and paraquat. Weed Research 14 : 365-369

HAMMERTON, J.L. (1975) Experiments with Cyperus rotundus L. II Effects of some herbicides and growth regulators. Weed Research 15 : 177-183

HAMMERTON, J.L. (1975) Experiments with Cyperus rotundus L. III Seasonal variation in growth. Weed Research 15 : 339-348

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

HENSLEY, D.L. et al (1978) The inactivation of glyphosate by various soils and metal salts. Weed Research 18 : 287-291

HOLM, L. (1968) Weed problems in developing countries. Weed Sci. 17 : 113-118

HOLM, L.G. et al (1977) The world's worst weeds - distribution and biology. University Press of Hawaii, Honolulu, U.S.A. (1977)

HOROWITZ, M. (1972) Growth, tuber formation and spread of Cyperus rotundus L. from single tubers. Weed Research 12 : 348-363

HOROWITZ, M. & FRIEDMAN, T. (1971) Biological activity of subterranean residues of Cynodon dactylon L. Sorghum halepense L. and Cyperus rotundus L. Weed Research 11 : 88-93

JAWORSKI, E.G. (1972) Mode of action of N-phosphonomethyl glycine : Inhibition of aromatic amino-acid biosynthesis. Journal Agric. & Food Chemistry 20 : 1195-1198

JOHNSON, B.J. (1974) Purple nutsedge control in Turfgrasses with S-21634 (1-methyl-phenyl-pyridinium chloride). Weed Sci. 22 : 549-552

JORDAN, T.N. (1977) Effects of temperature and relative humidity on the toxicity of glyphosate to bermunda grass (Cynodon dactylon). Weed Sci. 25(5) : 448-451

JUSTICE, O.L. & WHITEHEAD, M.D. (1946) Seed production, viability and dormancy in the nutgrass C. rotundus and C. esculentus. Journ. Agric. Res. 73 : 303-318

KEELEY, P.E. & THULLEN, R.J. (1975) Influences of yellow nutsedge competition on furrow irrigated cotton. Weed Sci. 23 : 171-175

MOOSAVI-NIA, H. & DORE, J. (1979) Factors affecting glyphosate activity in Imperata cylindrica and Cyperus rotundus. I. Effect of soil moisture. Weed Res. 19(2) : 137-143

MULLIGAN, G.A. & JUNKINS, B.E. (1976) The biology of Canadian weeds. 17. Cyperus esculentus L. Canadian Journ. Plant Sci. 56 : 339-350

MUZIK, T.J. & CRUZADO, H.J. (1953) The effect of 2,4-D on sprout formation in Cyperus rotundus. American Journ. Bot. 40 : 507-512

PALMER, R.D. & PORTER, W.K.Jr.(1959) The metabolism of nutgrass (Cyperus rotundus L.) I. The influence of various oxygen and carbon dioxide concentrations upon the germination and respiration of nutgrass. Weeds 7 : 481-490

PARKER, C. et al (1969) Herbicides for nutgrass control - conclusions from ten years of testing at Oxford. PANS 15 : 54-63

RANADE, S.B. & BURNS, W. (1925) The eradication of Cyperus rotundus L. (a study in pure and applied botany). Mem. Dep. Agric. India bot. ser. 13(5) : 99-192

RAO, J.S. (1968) Studies on the development of tubers in nutgrass and their starch content at different depths of soil. Madras Agric. Journ. 55 : 19-23

RECHECOUSTE, E. (1969) The problem posed by perennial weeds in Tropical plantation crops. Proc. 2nd Asian-Pacific Weed Contr. Int. 401-406

RINCORN, D.J. & WARREN, G.F. (1978) Effect of five thiocarbamate herbicides on purple nutsedge (Cyperus rotundus). Weed Sci. 26(2) : 127-131

SHANER, D.L. (1978) Effect of glyphosate on transpiration. Weed Sci. 26 : 513-516

SIERRA, J.N. & MERCADO, B.L. (1975) Competitive ability of C. rotundus L. with some associated crops. Proc. Third Indonesian Weed Science Conf, Bandug, 1975

SMITH, E.V. & FICK, G.L. (1937) Nutgrass eradication studies I. Relation of life history of nutgrass C. rotundus L. to possible methods of control Journ. Amer. Soc. Agronomy 29 : 1007-1013

SPRANKLE, P. et al (1974) Adsorption, mobility and microbial degradation of glyphosate in the soil. Weed Sci. 23 : 229-234

SPURRIER, E.C. (1973) Glyphosate - a new broad spectrum herbicide. PANS(C) 19 : 607-612

STANDIFER, L.C. (1974) Control of purple nutsedge with 2,4-D, Paraquat and Dinoseb. Weed Sci. 22 : 520-522

STOLLER, E.W. (1973) Effect of minimum soil temperature on differential distribution of C. rotundus and C. esculentus in the U.S. Weed Research 13 : 209-217

STRBAC, V. (1976) Performance of glyphosate on certain Mediterranean perennial weeds. Notiziaro sulle Malattie delle Piante 94-95 : 261-269

UEKI, K. (1969) Studies on the control of nutsedge C. rotundus L. on the germination of a tuber. Proc. 2nd Asian-Pacific Weed Contr. Int. 355-369

WILLIAMS, R.D. (1978) Photoperiod effects on the reproductive biology of purple nutsedge, Cyperus rotundus. Weed Sci. 26(6) : 539-542

WILLIAMS, R.D. & WARREN, G.F. (1975) Competition between purple nutsedge and vegetables. Weed Sci. 23 : 317-323

WILLIAMS, R.D. & WARREN, G.F. (1975) Suppression of Cyperus rotundus L. in carrots with night applications of nitrofen or herbicidal oil. Weed Res. 15 : 285-290

WILLIAMS, R.D. et al (1976) Seasonal activity of EPTC for Cyperus rotundus L. control in a tropical climate. Weed Res. 16 : 217-222

WILLS, G.D. & BRISCOE, G.A. (1970) Anatomy of purple nutsedge. Weed Sci. 18 : 631-635

WILLS, G.D. (1978) Factors affecting toxicity and translocation of glyphosate in cotton. Weed Sci. 26 : 509-513

ZANDSTRA, B.H. et al (1974) Response of purple nutsedge to repeated applications of glyphosate. Weed Sci. 22 : 230-232

ZANDSTRA, B.H. and NISHIMOTO, R.K. (1977) - Movement and activity of glyphosate in purple nutsedge. Weed Sci. 25 : 268-274

APPENDIX 1

ANALYSIS OF VARIANCE OF EXPERIMENT 1

	SOURCE	DF	SS	MS	VR(F)	
1.	REPLICATES	3	0.45	0.15	1.64	NS
2.	CHEMICALS	2	2878.17	1439.08	15762.10	***
3.	RATES	4	2571.85	642.96	7042.28	***
4.	LIGHT/DARK	1	28.16	28.16	308.43	***
5.	CHEMICALS x RATES	8	807.70	100.96	1105.81	***
6.	CHEMICALS x LIGHT/DARK	2	9.22	4.61	50.49	***
7.	RATES x LIGHT/DARK	4	8.23	2.06	22.56	***
8.	CHEMICALS x RATES x LIGHT/DARK	8	4.24	0.53	5.81	***
9.	ERROR (A)	87	7.95	0.0913		
	SUB-TOTAL	119	6315.97			
10.	TIME	4	728.17	182.04	1233.33	***
11.	TIME x CHEMICALS	8	617.43	77.18	522.90	***
12.	TIME x RATES	16	220.92	13.81	93.56	***
13.	TIME x LIGHT/DARK	4	22.54	5.64	38.21	***
14.	TIME x CHEMICAL x RATES	32	201.78	6.31	42.75	***
15.	TIME x CHEMICAL x LIGHT/DARK	8	52.18	6.52	44.17	***
16.	TIME x RATES x LIGHT/DARK	16	17.90	1.12	7.59	***
17.	ERROR (B)	392	57.88	0.1476		
	GRANT TOTAL	599	8234.77			

*** significant at 0.1% level