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An investigation into the life history, methods of control, competition and dispersal of Cyperus esculentus L. (yellow nutgrass) with special reference to the highveld region of South Africa.

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AN INVESTIGATION INTO THE LIFE HISTORY, METHODS OF CONTROL, COMPETITION AND DISPERSAL OF CYPERUS ESCULENTUS L. (YELLOW NUTGRASS) WITH SPECIAL REFERENCE TO THE HIGHVELD REGION OF SOUTH AFRICA.

by

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Being a dissertation submitted in fulfilment of the regulations governing the Degree of Doctor of Philosophy in the Department of Botany, University of the Witwatersrand, Johannesburg.

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CHAPTER I

INTRODUCTION

Two Cyperus species, Cyperus esculentus L. (yellow nutgrass) and Cyperus rotundus L. (purple nutgrass) are recognised as serious weeds in the Republic of South Africa. Yellow nutgrass is generally regarded as the most troublesome weed competing with dryland field crops in the high summer rainfall areas of South Africa. An ubiquitous warm season sedge, adapted to a wide variety of soil types, yellow nutgrass has exhibited a remarkable capacity to invade and proliferate those agricultural soils best suited for the production of grain and fodder crops. Yellow nutgrass is not only difficult to control but, due to a unique subterranean reproductive mechanism, field eradication is almost impossible to achieve. As a result, even when only small, isolated pockets survive in a field, the rapid regenerative and colonising habit of the species ensures a severe infestation within one or two seasons. (Figures 1 and 2).

The phenomenal gains in its invasion of and distribution throughout the high summer rainfall areas of South Africa, especially within the Highveld Region is, indeed, a striking feature of arable production within the Region. The Highveld Region is one of seven agro-ecological regions into which the Republic of South Africa is sub-divided. This Region, formerly known as the "Maize Triangle", is the principal field crop producing area of South Africa, accounting for 77 percent of the Republic's total maize production. The Highveld Region is sub-divided into four principal sub-regions (Baier 1963), namely, the Eastern Highveld, Eastern Free State, Western Transvaal and North-western Free State. Within the Region, yellow nutgrass is almost exclusively confined to the Eastern section of the inland plateau at altitudes below 6,000 feet and receiving an annual rainfall between 650 - 700 mm.

The Author

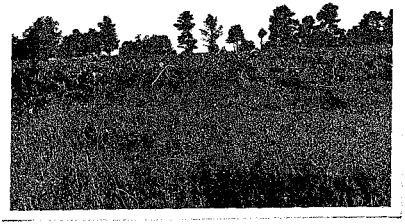


FIGURE 1: Severe infestation of nutgrass adjoining a maize field.



FIGURE 2: Maize field with moderate nutgrass infestation.

Despite the fact that yellow nutgrass is generally regarded as a noxious weed, it is noteworthy that relatively little is known about its ecology and life history in South Africa. Over the past 35 years, 3 scientific papers, Rhoinhold (1942 *a and b*) and Mas (1951), and 2 general papers by Du Preez (1944) and Sellschop and Hattingh (1956), have appeared. The development and introduction of suitable control measures has consequently been greatly hampered by this paucity of basic information. The accent on increased agricultural production and demand for more effective control measures has emphasised the importance of a critical examination of this weed species. Such investigations could assist in establishing a sound basis for an intelligent approach to both cultural and chemical control.

A study was therefore undertaken with a view to investigating the life history, method of competition, dispersal and control of yellow nutgrass. A knowledge of the life history and response of nutgrass to simulated agronomic practices could serve as a basis for the efficient implementation and judicious timing of certain cultural practices. Laboratory and glasshouse investigations could assist in clarifying certain ecological features peculiar to the dispersal and distribution pattern of the weed species. Finally, the continual appearance of new chemical compounds with improved herbicidal efficacy and greater crop selectivity, necessitates periodic field evaluation against this weed problem.

Because of the marked differences between C.esculentus and C.rotundus with regard to growth habit, morphological features, reproduction and distribution, it is important that these distinctions be clearly defined and understood. To obviate the confusion which has often arisen in the past, a comparative description of both species has been presented.

CHAPTER II

ORIGIN AND DISTRIBUTION

Before proceeding with a study of yellow nutgrass, it is necessary to elucidate the exact origin and describe the current distribution of the species.

The earliest authentic records are to be found in the "Flora Capensis" in which Thiselton-Dyer (1900) lists a number of the early botanists who had recorded Cyperus esculentus. Based on information obtained from the Division of Botany, Pretoria, the chronological sequence of these collectors were as follows:-

a) Krauss (1839). Near Umlaas River, Natal.

b) Buchanan (1875). Between Harrismith and Lariba, Orange Free State.

c) Rehmann (1875-1880). Pretoria and Houtbosch, Transvaal.

d) Wood (1880). Kaffir Kraal.

e) Tyson (1882-1886). Marshes near Clydesle (Umzumkulu) and Griqualand East.

It is pertinent to note that in his "Flora of Tropical Africa", Thiselton-Dyer (1902) also mentions that Cyperus esculentus is common to most warm countries in Africa.

Based on the records of the early collectors, there is little doubt that yellow nutgrass is indigenous to South Africa and that the initial source of infestation, unlike most introduced weed species, is of internal origin. There is some room for speculation as to the introduction and migration of yellow nutgrass in South Africa. The tuber, because of its valuable food reserves, served as a famine reserve for most African tribes. For this reason, it is possible that the original introduction of the species may have been associated with the former migratory movements of the Bantu in Southern Africa.

The earliest warnings of the dangers of nutgrass invasions into cultivated sites are attributed to Burtt Davy (1904) who, in his report to the Transvaal Department of Agriculture, mentions that "nut sedge or "einches" (Cyperus esculentus) is establishing itself in orchards, gardens and farm lands, almost throughout the Transvaal, but usually not in great abundance".

In his description of the South African Cyperaceae, Schonland (1922) briefly mentions that Cyperus esculentus L. Schrad. is a troublesome weed in the coastal districts of Natal. For some inexplicable reason, Schonland has not described both C.esculentus L. and C.rotundus L. in his publication.

Listing the plants to be found at Frankenwald, Glover (1937) has grouped these according to their respective habitats. Under disturbed areas (old roads and old ploughed lands), he mentions that the first floral inhabitants are weeds such as Tagetes, Amaranthus, etc., but makes no reference to Cyperus esculentus L. invading such sites. On moist sites, water holes and water courses, Glover states that C.esculentus L. is frequent to abundant, shooting in September, flowering in December to January and setting fruits and seeds in January to February. The moist sites, which are quite familiar at Frankenwald, are caused by the approach of *auklip* (iron sesquioxide or nodular iron) to within a few inches of the surface of the soil. In rainy seasons, the impervious layer acts as a reservoir and keeps the soil very moist, almost throughout the year.

In his subdivision of the early stages of secondary succession (subsere) on the sandy soils of the Transvaal, Davidson (1960 b), states that the Ruderal Stage consists of annual weeds, mainly dicotyledons, but also includes Eleusine indica Gaertn., Panicum laevifolium Hack., Setaria pallide-fusca Stapf and Cyperus esculentus L.

In an attempt to explain the reasons for the restricted confines of nutgrass infestations in the Highveld Region, a number of pertinent climatic and edaphic factors have been investigated. Cyperaceae are generally a hydrophytic group (Holman and Robbins 1947), which have suffered a considerable morphological reduction and specialization in acquiring their present amphibious xerophytic mode of life (Plowman 1906). Schonland (1922), mentions that the South African Cyperaceae are particularly rich in species which grow in localities that are subject to periodic intense drought.

From the anatomical studies of Rheinhold (1942 b), it would appear that *Cyperus esculentus* lacks protection for the stomata in the leaves and the pallisade tissue in the leaves is not differentiated. This indicates that this species is a shade plant adapted to moist regions. The epidermis of the leaf is modified to act as an efficient water jacket, enabling the plant to survive in drier habitats. Rheinhold (1942 b) found that the outer tangential walls of epidermal cells are cuticularised. The radial and inner tangential walls are very thin - a necessary condition where an important function of the epidermis is to act as a water jacket.

Notwithstanding these mesophytic modifications, yellow nutgrass is primarily a hydrophyte (Glover 1937), and a cursory glance at the principal areas of infestation in South Africa reveals a tendency for concentrated distribution in the higher rainfall areas (Figure 35). These include the Eastern Highveld and Eastern Orange Free State, sections of Natal and Griqualand East, as well as the Natal Sugar Belt. This distribution pattern is confirmed by Sallochop and Hattingh (1956).

In his description of the macro-climates of the Highveld Region, Baier (1963) has dealt extensively with the principal climatological variations between the four sub-regions. Baier has established that 39 percent of the Highveld Region lies at an altitude of above 5,000 feet, and that the climate, particularly the distribution of rainfall and temperature, is closely related to the pattern of topography. Lowest maximum and mean air temperatures occur in the south-east and the highest maximum and mean air temperatures in the west. Furthermore, 38.2% of the Highveld receives more than 700 mm annual rainfall. It is, therefore, evident that the climate of the Eastern Free State (altitude 5,000 - 6,000 feet above sea level and average annual rainfall 634 mm), shows a strong similarity to that of the Eastern Highveld (altitude 5,000 - 5,500 feet above sea level and average annual rainfall 696 mm).

The climate of both these sub-regions, however, differs very markedly from that of the remainder of the Highveld Region. The areas of severe nutgrass infestations would therefore appear to be mainly confined to the elevated, cooler, high summer rainfall sub-regions of the Highveld. Whereas climatic factors would appear to be mainly responsible for the adaptation of the species, evidence will also be presented at a later stage (Chapter VIII C) indicating that communities of yellow nutgrass have extended their areas of distribution largely as a result of certain biotic factors (See Figure 35).

From an edaphic point of view, yellow nutgrass reveals remarkable adaptability to soils with divergent texture and structure. This range includes sands (Eastern Free State), loam sands (Frankenwald) sandy loams (Bethel), loams (Bapefontein) and heavy black clays (Standerton).

According to Crafts and Robbins (1962), low winter soil temperatures are responsible for restricting the distribution of yellow nutgrass. These authors state that yellow nutgrass is common throughout the humid tropics, but does not thrive where soils are subject to frost. In contrast, Rahn et al.(1962), working in the north-eastern states of the U.S.A, found that tubers tolerated freezing and drying conditions. Generally, the infested areas of the Highveld Region are subject to particularly severe annual frosts. The distribution of nutgrass within the Highveld Region therefore does not appear to be affected by low winter temperatures.

CHAPTER III

MEDICINAL, NUTRITIONAL AND ECONOMIC USES.

It is not frequently appreciated that, despite its troublesome behaviour in cultivated fields, nutgrass - particularly the tubers - has been, and still is, extensively cultivated by numerous societies and communities. Watt and Breyer-Brandwijk (1962), Killinger and Stokes (1946), Power and Chesnut (1923) and Baughman and Jamieson (1923) have reviewed much of the pertinent literature with regard to medicinal and dietetic value, composition, human food or animal feed, beverage and economic uses. The references, all of which refer to the tuber, are voluminous, and no attempt has been made to reproduce the entire survey. A brief summary of the literature has therefore been compiled and to simplify the presentation, the details have been grouped according to specific end-usage.

A. ARTICLE OF FOOD.

The tubers of nutgrass, with a flavour somewhat like that of almonds, are commonly known under the Spanish name of "chufas" but also as "earth almond" and "rush nut", and in French as "Souchet comestible" or "amande de terre". The edible tubers are said to have been cultivated from the earliest times in Italy and North Africa. In Southern Europe, the tubers are used as a vegetable. Roasted and ground, nutgrass tubers were used as a substitute for coffee and cocoa. Such a preparation was known in Germany towards the middle of the 19th Century as "mandelkaffee" (almond coffee). The nutgrass tubers contain no alkaloids, caffeine or asparagine.

On the Gold Coast markets, the tubers, known as "tiger nuts", are sold for chewing, or in preparing the white, jelly-like tiger nut milk pap, and as a famine food. In West Africa the tuber is cultivated as a sweetmeat. In Northern Nigeria, the fresh nut is eaten raw, if of rich quality, but usually it is roasted on a pan with sand.

B. BEVERAGE

Power and Chesnut (1923) refer to an illustrated article which deals with the development of a sizeable industry in Spain to exploit a summer beverage made from chufas. This industry is alleged to have been of such importance that thousands of persons gained their living thereby in those regions where the material for its manufacture was cultivated and collected. The beverage is made at a chuferia and sold at horchata stands and by many ambulatory salesmen. For the preparation of the beverage, the nutgrass tubers are first washed in cylinders of wire netting by means of a continuous flow of water, then subjected to pressure and the expressed milky liquid, which apparently contains the fatty oil in an emulsified state is finally cooled or frozen. According to the Spanish Commercial Office in South Africa, the popularity of this drink has not waned during present times.

On the Gold Coast, the roasted nuts are ground and served to produce a fine meal, which is added along with sugar to water as a beverage, or even eaten dry.

C. MEDICINAL VALUE

Watt and Breyer-Brandwijk (1962) cite the benefits of utilizating the root. The Zulus chew the root for relief of indigestion, especially when the condition is accompanied by foul breath. The Chinese have used the plant as a stimulant, stomachic, sedative and tonic. The absence of alkaloid and caffeine in the tubers suggests that the value of the tubers is dietetic rather than medicinal.

D. ANIMAL FEED

Power and Chesnut (1923) cits a reference which indicates that the chufa was introduced into the U.S.A towards the last quarter of the 19th Century as a hog feed.

Chufas are used to fatten swine, but produce a soft carcass which must be hardened by feeding corn. During 1941, 172 acres of chufas were dug and 7,072 acres left in the field for hogging off in Florida (Killinger and Stokes, 1945). The chufas are not regarded as a problem as they are easily eradicated by hogging off and then by tillage of the successive crop. Poinar (1964) reports that C.esculentus is regarded as a valuable source of food and shelter for wild life in the U.S.A.

E. COMPOSITION

1) Tubers

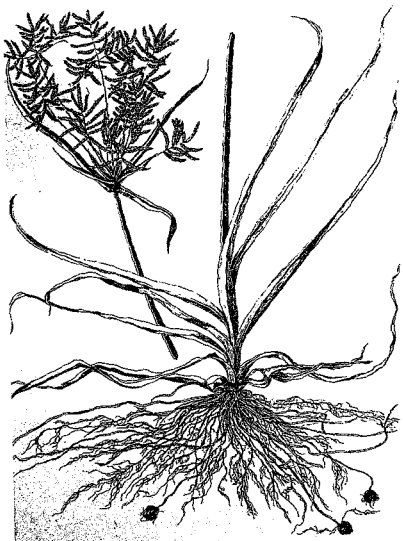
The tubers were analysed by Power and Chesnut (1923) who revealed that the most important constituent of the chufa is unquestionably the fatty oil which, as extracted by light petroleum, was obtained to the extent of 28.9%. Starch and sucrose were also present in considerable amounts. An enzyme, present in only very small quantities capable of slowly hydrolyzing amygdalin, was also reported.

2) Chufa Oil

Baughman and Jamieson (1923) report that the oil contains principally the glyceride of oleic acid 73.3%, followed by the glyceride of palmitic acid 11.8%. The yellow-gold, practically odourless, non-drying oil can be obtained from the tuber by cold expression and resembles olive oil in quality.

F. MISCELLANEOUS USES

From the aforegoing, it is evident that the chufa oil, sometimes known as sedge oil and, in Germany, as earth almond oil (Erdmandelöl) could be used for the same purposes as olive oil, both as food and for the manufacture of soap. In Italy and Egypt, the fatty oil has been employed for this purpose.



FIGU 3: Cyperus esculentus L. - Mature plant with umbel rhizomes and tubers.

nte: Figures 3, 4, 7, 8, 9, drawn by: Mrs. J. Griffiths
19, 20, 21, 22, 23, 29,
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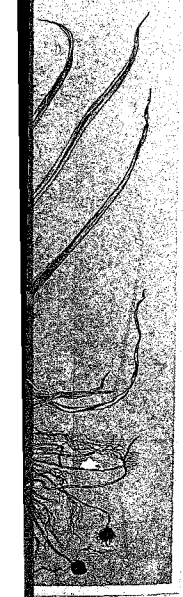


nt with umbel

s. J. Griffiths

CHAPTER IV

COMPARATIVE OUTLINE OF C.ESCULENTUS AND C. ROTUNDUS

Considerable confusion exists regarding the identification of and differentiation between the two most important nutgrass weed species. Because the two Cyperus species are so often mistaken and confused in the field, a comparative guide has been compiled, outlining major differences relative to nomenclature, morphological features, methods of reproduction and distribution zones. The classification is based on local observations and relevant literature. Thiselton-Dyer (1900), Rheinhold (1942 a and b), Du Praez (1944), Bellue (1946) Killinger and Stokes (1946), Day (1953 a), Day and Russell (1955), Wild (1955), Sellschop and Hattingh (1956) and Rahn et al (1962).



FIGURE 4: Cyperus rotundus - Flowering stems with interconnecting rhizomes and tubers.

FAMILY CYPERACEAE

CYPERUS ESCULENTUS	CYPERUS ROTUNDUS
Nomenclature (Vernacular)	1. Purple nutgrass (Para-Uintjie)

ORDER CYPERALES

FAMILY CYPERACEAE

CYPERUS ESCULENTUS	CYPERUS ROTUNDUS
Nomenclature (Vernacular)	
1. Yellow nutgrass (Geel-Uintjie)	1. Purple nutgrass (Pers-Uintjie)
2. Yellow watergrass	2. Purple watergrass
3. Yellow nutsedge, Northern nutgrass	3. Purple nutsedge
4. Chufa, earth almond, rush, tiger and Zulu nuts.	4. Uintjieskweek, steentjieskweek, coco.
Plant (Figure 3)	(Figure 4)
1. Flowering stems 10 - 30" inches tall	1. Flowering stems 5" - 15" inches tall.
2. Leaves as long or longer than flowering stem and yellowish to pale green.	2. Leaves considerably shorter than the flowering stem and dark green.
3. Flowering head - umbel 3" - 12" in diameter subtended by leaf-like rays or bracts 2" - 10" long. As long as umbel or longer. (Figure 5)	3. Flowering head - umbel 1" - 8" in diameter subtended by leaf-like rays or bracts 2" - 4" long, overtopping the umbel.
4. Spikelets - pale yellow to deep brown. (Figure 6)	4. Spikelets - Ferruginous red or chestnut red.
5. Seed - Drab to yellowish brown sometimes slight, *silvery oblong shape.*	5. Seed - Dull, dark greyish to blackish brown - ellipsoid shape.
6. Tubers, round, globular, ½" and upwards in diameter, grey to dark brown with horizontal lines. Tubers with almond-like pleasant taste, attached individually to slender rhizomes. (Figures 7 and 8)	6. Tubers - Oblong, tuberous thickening of the rhizome ½" - 1" long covered with dark reddish brown fibrous coat. Tubers with bitter pungent flavour, occur on chains of inter-connecting rhizomes. (Figure 9)

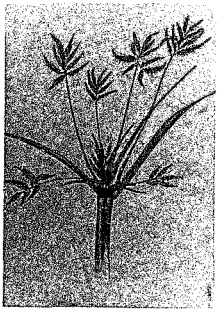


FIGURE 5: Cyperus esculentus umbel subtended by bracts



FIGURE 6: Cyperus esculentus Spikelet
Note: Figures5,6,17 & 18 drawn by: C. Chappell

CYPERUS ESCULENTUS
7. Underground system - Growth habit closely resembles potato.
Rhizomes radiate from central stem

CYPERUS ROTUNDUS
7. Underground system - Deeply ramified underground system.

CYPERUS ESCULENTUS	CYPERUS ROTUNDUS
7. Underground system - Growth habit closely resembles potato. Rhizomes radiate from central stem.	7. Underground system - deeply ramified underground system, strong wiry chains of interconnecting rhizomes.
Reproduction By means of tubers and freely by seeds.	By tubers only. Reproduction by means of seed relatively unimportant.
Distribution Abundant in warm, moist areas . . . Scattered in California, widespread in North-Eastern States, U.S.A. South Africa - Principally high altitude areas with annual summer rainfall exceeding 650 mm per annum and Natal sugar belt.	Cosmopolitan - Australia, India, throughout Africa, South and Central America, widespread in California. In South Africa widespread in low altitude irrigated areas and on dry lands in areas with annual summer rainfall below 600 mm.

NOTE:

1. The word "uintjie" is the most commonly used vernacular term in South Africa, giving rise to tremendous confusion between the two species. According to Patman (1913) the word uintjies is derived from Uyntjes which, in turn, originates from the Dutch "ajuin" meaning onion.
2. Chufa. The word is of Spanish origin but is also used in Shona (Wild 1959).
3. The appendage "kweek" denotes a perennial subterranean system, which C.rotundus shares in common with quick grass (Cynodon dactylon) - Du Preez (1944).

N.B. Throughout this study the word "nutgrass" or "yellow nutgrass" has been used to denote Cyperus esculentus L.



FIGURE 7: Cyperus esculentus - dormant tuber.



FIGURE 8: Cyperus esculentus - Swollen tuber with double vertical rhizomes.

Classification of the Underground Organs of Nutgrass.

The nomenclature used by certain authors in respect of the underground organs of C.esculentus and C.rotundus is confusing. A number of authors refer to nuts, nutlets, corms and bulbs when describing one and the same underground organ. For example, Eames (1948) refers to corms; Du Praez (1944) mentions bulbs, while Killinger and Stokes (1946) describe the organs as nuts. To obtain a correct classification, the descriptions of various underground organs as presented by Holman and Robbins (1947) are given below.

1. Rhizomes. These are elongated, underground, horizontal stems, generally acting as storage organs.

2. Bulbs. A bulb consists of a short, flattened or disc-shaped underground stem upon which are borne fleshy scale leaves filled with stored food. The reserve carbohydrate of most bulbs is not starch, but sugars.

3. Corm. A corm is a short, solid, vertical, enlarged underground stem in which food is stored. Corms are usually flattened from top to bottom and bear a cluster of thick fibrous roots at the lower side and a tuft of leaves on the upper side. They differ from bulbs principally in being almost entirely made up of stem tissue with relatively few scale leaves.

4. Tubers. A tuber is a much-enlarged short, fleshy, underground stem. Tubers differ from rhizomes in their stouter form, their generally shorter internodes and the usual absence of roots. They are commonly produced at the ends of rhizomes.

The swollen underground organs of nutgrass should thus be regarded as tubers, and not as bulbs or corms.

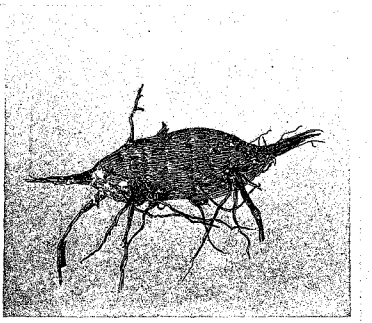


FIGURE 9: Cyperus rotundus tuber with severed, connecting rhizome

CHAPTER V

REVIEW OF LITERATURE *

A. LIFE HISTORIES STUDIES

1. Seed.

a) Viability.

Rheinhold (1942 a) and Mes (1951) stets that the fruit (~~nutlet~~) of nutgrass is covered with an extremely hard, thick outer seedcoat. Dormancy of the seed may be broken artificially by acid treatment of the seeds, a four-minute immersion in concentrated sulphuric acid yielding 90 percent germination. Rheinhold concludes that the poor germination obtained when the seeds are soaked only in water is due to the extreme hardness of the coat and not to any lack of viability in the embryo itself.

Results published by Justice and Whitehead (1946) reveal that nutgrass seed sown in sterilized soil and kept in a greenhouse at 20°C to 30°C failed to emerge within a period of 3 months. Seeds placed between blotters and kept in the greenhouse under similar conditions gave 79 percent germination within 4 months. These workers have also shown that while large numbers of viable yellow nutgrass seeds are produced, reproduction of Cyperus rotundus from seed is relatively unimportant.

A comprehensive study of the germination of yellow nutgrass seed was made by Rahn et al.(1962). Their results show that,

1) There was a highly positive correlation between seed germination and weight.

2) Germination did not take place when temperatures remained constant. Germination of the seed is favoured by alternating daily temperatures of 85 - 95°F for 8 hours and 70°F for ~~5 hours~~ 16 hours.

3) Acid treatment (concentrated sulphuric acid 2 - 10 minutes) increased the germination from 72 - 90 percent.

* N.B. In several cases references in respect of C.rotundus have been cited where corresponding data for C.esculentus, is lacking.

4) Exposure of seed to 0.2% ethylene chlorhydrin and potassium gibberallate increased germination. Germination also took place without special treatment.

5) Seed germinated better on soil than on filter paper.

6) Light or absence of light had little effect on germination when temperature conditions were optimal.

7) Seed exposed to EPTC vapour, germinated well but showed damage shortly thereafter (See Table 7).

8) Late harvested seed gave a higher percentage germination.

9) Dry seeds refrigerated at 36°F for 3 years, germinated as well as a comparable group held at room temperature.

b) Production.

The reproductive potential of yellow nutgrass by seed has been reported by a number of investigators. Hill et al.(1963a)reports that a single seedling developed into a stand of plants that produced 90,000 seeds with a germination of 51%. High seed production appeared to be associated with young, rapidly growing plants and was very low in dense, undisturbed stands. Justice and Whitehead (1946) found that twentyfive inflorescences of yellow nutgrass yielded 50,200 seeds with an average germination of 75.6 percent, or the equivalent of 1521 seedlings per inflorescence.

c) Longevity

Ballu (1946) furnished data as to the longevity of certain weed seeds stored under ordinary laboratory conditions. The longevity of yellow nutgrass is given as 20 years.

2. Tuber

Rahn et al.(1962) have made a systematic study of yellow nutgrass tubers. Their results may be summarised as follows:-

(i) The tubers are confined mainly to the top 6 inches of soil. Shoots mainly emerge from tubers located in the top 2 inch layer.

(ii) Freshly harvested tubers appeared to be dormant and neither constant or daily alterations of temperature induced germination. Storage for 1 month at 50°F increased the germination from 4 to 94 percent.

(iii) Tubers overwintering germinated satisfactorily.

(iv) Potassium thiocyanate and thiourea broke the tuber dormancy, resulting in up to four vegetative sprouts per tuber, but root and shoot growth were retarded after germination. EPTC prevented germination of the tubers without killing them, while atrazine did not stop germination but eventually killed young plants. Herbicidal chemicals did not kill dormant tubers.

(v) Rate and percentage of germination of nutgrass tubers was greatly reduced by heavily compacted soils.

(vi) Exposure of nutgrass on the soil surface to freezing and drying during winter reduced the percentage sprouting but did not kill the tubers.

(vii) Tubers lost their viability between 13 - 22 months. Observations however suggest that some tubers remain viable in the soil for more than two years.

(viii) Tuber production was hastened by a short photoperiod at the expense of topgrowth. Tubers are produced during plant maturation.

(ix) Reduced light intensity reduced plant size, formation of tubers and vegetative shoots.

(x) When light intensity was high, lowering of the soil temperature from 85°F to 65°F reduced tuber formation greatly, but had little effect on vegetative shoots.

(xi) Increased soil moisture levels increased the growth of both tops and tubers.

(xII) Nutgrass produced equally well at pH levels of 5, 6 and 7.

(xiii) Fertilizer applications increased the production of nutgrass.

Mes (1951) reports a case of fully mature tubers which were removed from flowering plants at the end of October and kept on moist filter paper in a petri-dish in the laboratory. The tubers remained dormant till the end of February, after which 85% of the tubers sprouted. Rheinhold (1942 a) found that plants grown in the greenhouse did not produce tubers till five weeks after shooting above the ground whereas tuber production in the field was much more rapid. Investigations by this author revealed that the majority of the tubers lie in the top 6 inch layer of the soil; that the tubers contained food reserves

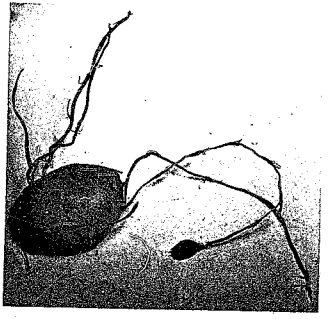


FIGURE 10: Nutgrass rhizomes infesting potatoe tuber.

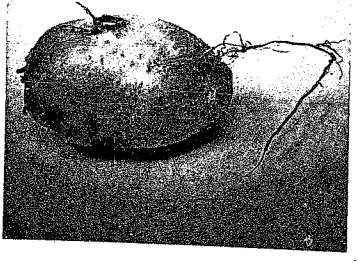


FIGURE 11a) Nutgrass tubers implanted in potatoe tuber.

sufficient for the production of an average of four shoots when subjected to repeated clipping; that exposure of the tubers to laboratory air for 10 days killed the tubers, while direct exposure to the direct sunlight killed the tubers after 5 days; a temperature of 50°C for 8 hours killed the tubers after two hours.

The effect of exposure of C.esculentus and C.rotundus tubers to dry air and dry soil in the laboratory and under field conditions was studied by Day and Russell (1955). C.rotundus tubers were readily killed by drying in the open but yellow nutgrass tubers survived prolonged storage.

Tumbleson and Kommendahl (1960) studied the reproductive potential of nutgrass plants derived from tubers. The population density varied from 13 million plants and 38 million tubers (85% of these tuber in the upper 6 inches of soil) to 800,000 plants per acre. One tuber in one year produced 1,900 plants and 6,900 tubers to a depth of 10 cm in a patch 7 feet in diameter. Tubers harvested in September germinated 12 percent but tubers harvested from the same plots in the next June, germinated 95 percent. Tubers planted in silt loam at depths of 1½ inches produced more tubers per plant than tubers planted in sand or at a depth of 3 inches.

The response of nutgrass to spacement and fertilizer was investigated by Killinger and Stokes (1946). Chufas yielded most when grown in 2 ft rows with 12 inch spacing or in 3 ft rows with a 6 inch spacing. Marked yield increases in both tuber and hay were obtained when certain fertilizer mixtures were applied.

Hall et al.(1948) report that on an unlimed Cynodon dactylon turf plot at Frankenwald, where the continuous use of ammonium sulphate had greatly increased the acidity (in some cases to a pH of 4.0), the grass formed a poor cover and watergrass (Cyperus spp) invaded the stand. Where lime was applied and the pH maintained above 6.0, the Cynodon dactylon was able to keep the weeds in check. Hall et al.(1955) attributes the survival of the nutgrass to the fact that nutgrass is able to grow in an extremely acid soil. Under field conditions nutgrass rhizomes and tubers penetrate potato tubers, rendering them unfit for marketing. The grading of nutgrass infested potatoes in South Africa is described in the Government Gazette (1945).

potatoe tuber.

in potatoe tuber.



FIGURE 11b: Nutgrass tubers and rhizomes imbedded in potatoe tuber - cross section.

B. COMPETITION

1. Influence of Nutgrass in the Field.

A number of field tests have been conducted under Highveld conditions, at Frankenwald and Bapsfontein, to establish the critical period during which weeds exert their most depressing effect on maize. The weed population in these trials consisted of a nutgrass-annual grass complex, and the experiments were conducted under favourable soil moisture conditions. The results of these trials may be briefly summarized as follows:-

Fisher (1957 a) working at Frankenwald, showed that lack of weed control during the first seven weeks after planting, did not reduce grain yield but, as from the 8th week, lack of weed control brought about a steady decline in grain production.

Similar results were obtained in an additional trial (Fisher 1957 b). Results showed that despite the apparent effect of a mixed population of nutgrass and annual grasses on the growth of maize, weeds permitted to compete with maize in the rows for the first 6 weeks after planting and then removed, did not influence the grain yields, cob number, protein composition, etc., In the absence of nitrogen applications, the weed population did have some detrimental effect on grain yield.

The above results were confirmed in subsequent trials conducted at Bapsfontein (Fisher and Stiven 1958). Weeded and unweeded maize competing with a mixed stand of annual grasses and nutgrass produced about the same amount of dry matter up to the sixth week after emergence, after which time the production of dry matter in the unweeded maize dropped sharply. Furthermore, between the fifth and sixth weeks, the weeds began to make their greatest demands on food nutrients. A highly significant correlation was found between the depressed maize dry weights after the sixth week and the amounts of nutrients which the weeds took up after the sixth week. The importance of nitrogen to the maize plant was also demonstrated, for whereas only one pound of phosphate was found in every 500 lbs of dry matter, 5 lbs of nitrogen was found in the same quantity of dry matter.

2. Plant Toxins.

Literature on the role of toxic substances in the competition between higher plants has been reviewed by Bonner (1950), Börner (1960) and Crafts and Robbins (1962). In the case of such mutual effects, for which products of plant metabolism might be held responsible, the term "allelopathy" has been proposed by Martin and Rademacher (1960) and the term "koline" by Grümmer and Beyer (1960) for the substances formed by higher plants which are toxic to other species of higher plants.

The evidence that has accumulated on the ecological significance of these plant toxins, and the role that they play in the distribution of certain species, has been largely circumstantial. Although many observations have been made and hypotheses erected on the nature of "allelopathy", comparatively few well-founded experimental results are available. (Martin and Rademacher 1960).

In the majority of reported cases, it has been shown that the roots and other organs in the soil give off substances which are toxic to other plants. The release of toxic substances above the soil, however, has been reported by Grümmer and Beyer (1960). Their investigations revealed that toxic substances are washed out of Camelina by rain which, in turn, reduce the yield of flax.

The investigations of Le Tourneau et al.(1956) revealed that sterilized, filtered water extracts of 23 species, representing 16 families, were effective in inhibiting wheat germination but usually did not inhibit pea germination. Extracts of crop species (maize and wheat) appeared to be as inhibiting as extracts of weed species. In most cases, increasing the amount of material extracted, resulted in increased inhibition.

Le Tourneau and Heggeness (1957) proved that aqueous extracts of leafy spurge foliage and quackgrass rhizomes contained inhibitors effective on wheat and pea seedlings. Treatment of the aqueous extracts with Norit (activated carbon) removed most of the inhibitors from the solution. Results showed that neither pH nor osmotic pressure was responsible for the inhibition.

pH's of the extracts were all in the range of 4.9 - 6.8 with the majority from 5.1 - 6.0. Furthermore, the amount of inhibitor may depend on the stage of maturity of the collected plants.

The deleterious effects of quackgrass (Agropyron repens) on other plants has been widely studied and the relevant literature is reviewed by Crafts and Robbins (1962) and Ohman and Kommedahl (1964). Considerable evidence has been published on the deleterious effect of quackgrass, or its residues, on the growth of certain plants. However, no one has isolated and identified chemically any substance that can reproduce the effect of quackgrass or illustrate that live quackgrass affects other plants by the production of a phytotoxic substance. Ohman and Kommedahl (1964). The latter state that the early reports were concerned with phytotoxic results obtained from dead material which may have resulted in wrong inferences.

Oswald (1948) was the first to suggest that the deleterious effects of quackgrass were due to toxic exudates from the roots of quackgrass. Kommedahl et al.(1959) concluded that the effect on crop plants may be due to a combination of toxic components produced by the quackgrass and invasion of the crop plants by soil micro-organisms. Results presented by these authors showed that living quackgrass plants and residues from dead ones, severely injured the young seedlings of crop plants. Ohman and Kommedahl (1961) confirmed the presence of toxic substances in the roots, stems and rhizomes which reduced the seedling length of alfalfa.

Welbank (1960), however, could find no evidence of any appreciable growth inhibition when applying leachates of roots and rhizomes of quackgrass to young plants of barley, wheat, kale and tomato, or when growing seedlings of rape and turnip in close contact with living A.repens roots. Sometimes growth was stimulated by the leachates.

Ohman and Kommedahl (1964) were later able to demonstrate that when quackgrass was grown in association with lucerne or oats in a root solution exchange apparatus, which allowed both plants to compete for nutrients, but eliminated competition for light, water and space, chlorosis and stunting of the crop occurred. This was due to the greater ability of quackgrass to withdraw available nutrients, especially nitrogen, and to a less extent phosphorus and potassium from the nutrient solution.

When N was added in combination with Por K, or both, no chlorosis or significant reduction in dry weight of lucerne occurred. Bioassays failed to reveal a phytotoxic substance in the nutrient solution or living rhizomes or roots. Welbank (1956) reported that although there is no secretion of a toxin, inhibitors may arise when root and rhizome residues of A. repens (P. Raw) are incubated with soil. Ohman and Kommedahl (1964) explain this phenomenon in terms of a high C : N ratio, with consequent temporary deficiency of available nitrogen.

The influence of root exudates of Cyperus rotundus L. on the growth and chemical composition of certain plants was investigated by Boshoff (1965). He reports that when cultivating the plant in the same growth medium as C. rotundus L. or by culturing the plant in a cultural medium containing root exudates from C. rotundus L., strong evidence was gained that the root exudates of C. rotundus L. most probably contained a substance or substances toxic for the growth of Zea mays L. and Vigna sinensis Endl. The C. rotundus L. plants were replaced every 14 days and the cultures fed with Hoagland's solution.

Furthermore, it was found that C. rotundus L. had a retarding effect on the absorption of phosphorus and magnesium by Zea mays L. in water culture, and on the absorption of nitrogen, potassium and magnesium by Zea mays L. in sand culture. The growth and chemical composition of Solanum lycopersicum was only slightly influenced by C. rotundus L.

Boshoff also found that when Vigna sinensis Endl. and Zea mays L. were cultured together in the same medium, the growth of the Zea mays L. was retarded. If cultured together in sand culture, Vigna sinensis Endl. stimulated the growth of Zea mays L.

The only available record of growth inhibition studies with yellow nutgrass were reported by Tumblesson (1960), who found that washing of fall harvested tubers in cold water, increased the sprouting percentage of the tubers from 10. to 75%. The water extracts inhibited the germination of nutgrass tubers and seeds of alfalfa, red clover, peas, soybeans, barley and oats.

C. TILLAGE AND CULTIVATION.

1. Tillage

The influence of field tillage practices on the survival of C.rotundus has been investigated by numerous workers (Andrews 1940, Smith and Mayton 1938, 1942 and Day and Russell 1955). Weed control was achieved by severing the tubers, ensuring that the latter remain in the dry soil for at least one month (Andrew 1940). Ploughing at intervals of three weeks during two successive growing seasons eradicated C.rotundus (Smith and Mayton 1942). Day and Russell (1955), established that discing at intervals of three to four weeks under dry conditions was highly effective in killing the tubers, whereas moist tillage did not give control. This tillage programme aimed at control by drying out the tubers, would not appear to be applicable to C.esculentus in view of the resistance of the latter to prolonged storage under air-dry conditions (Day and *Russell*, 1955).

In South Africa, both Du Preez (1944) and Sellschop and Hattingh (1955) approached the nutgrass control programme from the tuber desiccating and exposure point of view. Du Preez (1944) is of the opinion that the critical stage of C.esculentus is reached when the young tubers are *immature and tender, and the old tuber has* lost its sprouting capacity. This period, which lasts from December until late in January, is regarded as the weak link in the life cycle of yellow nutgrass. According to Du Preez, uprooting and exposure to the sun would result in a high mortality. Disturbance at flowering is also recommended in Swaziland (*Anon.* 1963) and by Sellschop and Hattingh (1955)

Sellschop and Hattingh (1955) however, see the solution in terms of dry winter ploughing and the exposure of the tubers to the cold and drought. Rheinhold (1942) however, found that winter fallowing (ploughing at monthly intervals) did not prove benaficial. In the successive summer following on the winter treatments, there were no appreciable differences in the nutgrass population between strips ploughed twice in winter (May and September), once a month throughout the winter and unploughed.

Rheinhold found that these winter practices increased the incidence of the nutgrass when compared with the density of the previous season. She postulates that this trend is due to a scattering of tubers through the field and the stimulation of more tubers to shoot. The same results were obtained by hand digging of infested plots during winter, in which case, plots which were dug over monthly throughout the winter were more heavily infested than the control plots.

Early, shallow and relatively frequent cultivation - at intervals of about three weeks - preferably when the soil is dry, by means of superficial cultivators, is advocated by Mes (1951). This programme is based on severing the vertical rhizome below the soil surface.

The significance of tuber formation with short photoperiods and its influence on tillage control in nutgrass, is emphasised by Rahn et al.(1962). In a programme of tillage eradication, it is important to prevent growth of nutgrass plants during the fall months. Rahn et al. report that tubers which germinated late in the season produced 1 to 3 new tubers within three weeks.

2. Cultivation Practices.

a) Cover and smother crops.

In the selection of field crops which can compete with nutgrass it is advisable to choose crops which are planted in rows and yet afford the soil ample shade (Sellschop and Hattingh 1955). Accordingly, they recommend an increased planting population of maize, soybeans, babala, sunflowers and the erect growing cowpea types. A 3 ft row spacement has a detrimental shading effect on the nutgrass, whereas a 7 ft row spacement does not. The latter, however, lends itself more suitably to speedy and timely mechanical cultivation. Furthermore, they state that unless measures are successfully applied to eradicate nutgrass before seeding, broadcast methods of sowing cannot be regarded as suitable control measures. Buckwheat, lucerne and perennial ley crops grow with the nutgrass with the result that when the grass is ploughed up and followed up with a cash crop, a severe infestation of nutgrass may be expected.

Rheinhold (1942 a) reports encouraging results with lucerne, whereas buckwheat and sunhemp did not afford suitable control of nutgrass. Rheinhold suggest "that the low level of nitrates which lucerne is stated to maintain in the soil is a more effective weapon against nutgrass than the cutting down of light achieved by smother crops".

Preller and Van Wyk (1958) describe an experiment in which fertilizer treatments were applied pre-planting to a ley grass, (Eragrostis curvula). This site was ploughed and planted to maize four years later. They conclude that it is possible to control nutgrass (species unspecified, but presumably C.rotundus) in arable fields by utilising crops which are well managed and fertilized.

b) Smothering.

The use of straw, manure, sawdust and paper mulch as a means of eradicating yellow and purple nutgrass on a small scale have been investigated by Rheinhold (1942 a) and Pollock (1925). Rheinhold describes an experiment with double layer sacking between rows of *Paspalum*. *After heavy rains*, the sedges sprouted through the sacking with which they were covered.

c) Grazing.

Pollock (1925) and Wild (1955) suggest that pigs be used for the control of nutgrass. The influence of poultry on purple nutgrass has been investigated by Mayton et al (1945).

D. CHEMICAL CONTROL

Prior to the advent of selective herbicides, the use of chemicals for the control of nutgrass was confined to a small range of compounds with restricted use. Due to low activity, short residual or soil sterlising action, these chemicals were never widely used. Pollock (1925) recommended the application of salt or arsenic, both of which render the soil unfit for crop production. Sodium chlorate 10 - 15% proved effective for the control of nutgrass, but phytotoxic to subsequently seeded maize and Rhodes grass. (Rheinhold 1942 a).

Coal tar derivatives were ineffective (Rheinhold 1942 a). Tillage, and a simultaneous application of a 2 N Thiocyanate solution (Ca salt) gave control of nutgrass (unspecified) - (Fromm 1942).

1. Soil fumigation.

For the complete eradication of purple nutgrass, a number of soil fumigants provide an effective means of spot treatment of small infestations; chloropicrin (Godfrey 1947), methyl bromide (Leonard and Harris 1950) and 1,chloro-3,bromopropane (CBP) (Day 1953b). The application of brominated and chlorinated hydrocarbons, DD, chlorobromopropane, ethylene dibromide and methyl bromide as used in the tobacco nematode control programmes in Southern Rhodesia, are regarded as being the best method of controlling C.esculentus (Wild 1955). Rahn et al.(1962), however, report that methyl bromide did not kill dormant nutgrass tubers.

2. Phenoxyaliphatic Acid Derivatives.

Numerous reports are available which indicate that nutgrass can be killed by 2,4-D or MCPA applications. It could seem, however, that the doses recommended are too high to give economic control (Wild 1955). 2,4-D, in combination with aromatic oils fortified with PCP, has been recommended as a post-emergence control measure for nutgrass in sugar cane (Stewart 1955). Stewart recommends that for maximum benefit from one application a full flush of aerial nutgrass shoots should have developed above the soil surface. This treatment gives complete kill of the succulent yellow nutgrass bulb. Altona and Muntz (1953) state that a pre-emergence application of 2,4-D or MCPA will control nutgrass for approximately one month. After this period, one or two cultivations appear to be necessary to produce a good crop yield. Post emergence applications of the weedkillers had no effect on an established crop of nutgrass (Altona 1950).

Both 2,4-D and MCPA may be successfully used to check nutgrass if applied at rates of 2 to 3 lbs of acid equivalent per morgen 5 days after maize, soyabeans or cowpeas have been planted. (Sallschup and Hattingh 1955). This treatment destroys a large percentage of the seedlings and retards the formation of secondary tubers, rhizomes and roots. The first applications may be followed by a second after

six weeks, using 1½ lb acid equivalent per morgen (1 morgen = 2,116 acres), and spraying by means of drop arms to prevent injury to the maize.

In Natal, however, Birch (1964) found that 2,4-D did not affect nutgrass, except in the second season of treatment when it increased the population density.

The effect of 2,4-D applications on the anatomical modifications of Cyperus rotundus L. is described by Eames (1949). He found that leaves are stimulated to mature at once in abnormal form, and stems become abnormally meristemic under the stimulus, forming abnormal tissues continuously for some time or as long as the organ or plant lives.

Applications of 0 - 3.6 lbs acid equivalent per acre of 2,4-D (Cosnell 1964 a) to yellow nutgrass growing in trays, resulted in a slight reduction of both foliage and tuber production but did not significantly reduce the weight of foliage or number of tubers.

3. Contact Herbicides.

The effect of herbicidal oils on purple nutgrass has been reported by Dey (1953 a) and Rhem (1956), and that of activated oil emulsions containing PCP or dinoseb in diesel oil, by Robinson (1959) and Cosnell (1964 b). Paraquat has been successfully introduced into the Natal Sugar Belt, Thompson and Cosnell (1963), and Cosnell and (1965 a). Rates of 2/3rds to 1 pint per acre, applied as a row treatment, give a complete scorch of the well developed nutgrass. The subsequent regrowth of nutgrass is comparable with that occurring after more expensive hand weeding. The period of effective control has been increased in irrigated cane by adding DCMU and/or bromacil depending on the soil type (Cosnell 1965 a). A paraquat/TCA mixture has also proved effective (Cosnell 1964 b).

4. Substituted Ureas.

Early tests with CMU (Dotzenko 1952 and Whitworth 1952) revealed CMU at 16 lbs p/acre, lbs/acre highly effective for controlling established stands of nutgrass.



FIGURE 12: Influence of TC4 on nutgrass. Initial effect.

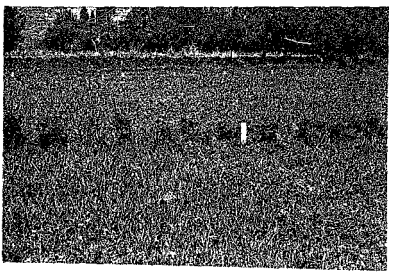


FIGURE 13: Influence of TC4 on nutgrass. Residual effect.

Evaluating two new substituted ureas in maize, Fisher 1955) found a differential behaviour on two sites using similar concentrations. At Delmas (33 percent soil clay content) the weed population showed no pattern of susceptibility to increased herbicidal concentration, whereas at Frankenwald the increased dosages increased weed control but proved phytotoxic to the maize at the high levels. Sheets (1958) however, showed a positive correlation between herbicidal toxicity of substituted ureas and organic matter of the soil, cation exchange capacity and percent clay, with organic matter contributing more to toxicity reduction. The reduction in phytotoxicity is explained in terms of adsorption of the chemical onto the colloidal complex (Harris and Warren, 1964). Linuron, a substituted urea with a short persistance, was reported to be active against the foliage of yellow nutgrass plants 20 - 24 inches tall, giving a full season's kill of the tops, but the effectiveness of the chemical was nullified by as little as 1/3rd inch of water being applied to the foliage immediately after spraying (Hargan et al. 1962).

5. Chlorinated Aliphatic Acids

TCA and dalapon are both well known and effective grass killers with a more limited action on Cyperaceae (Thompson and Cosnell 1963). Both compounds have been in use for some years with rather variable results. When soil moisture is adequate, TCA effectively controls grass weeds and to a certain extent nutgrass (Cosnell 1964 b). Figures 12 and 13.

6. Propylthiol Carbamates.

One of the most effective compounds against nutgrass, to have been developed during the past decade, is undoubtedly EPTC (EPTAM). This compound is most effective if incorporated into the soil, decomposing after incorporation to release a volatile toxic vapour (Crafts and Robbins 1962). In pot experiments, EPTC incorporated into the soil at rates of 6 and 9 lbs per acre, prevented the sprouting of yellow nutgrass tubers for 6 weeks after which half of the tubers were removed and washed.

These tubers sprouted readily (Rahn et al 1962).

The selective action of EPTC has been extensively investigated in South Africa. Visser (1960) demonstrated that a blanket application of 3 lbs active ingredient EPTC applied at the last discing of seed bed preparation, will prevent the sprouting of the tubers for the whole season. When maize is to be planted on an EPTC-treated field, a delay of one week between EPTC applications and planting appears to be sufficient to reduce to a minimum, any possible deleterious effect on the germination and growth of the maize. EPTC applied in a 12 inch band along the rows at planting resulted in delayed damage to the young plants. Up to 6% damage was recorded but most of the plants recovered completely and grain yields were not reduced when as much as 9 lbs active ingredient per morgen was applied. This problem of toxicity to maize is alleged to have been overcome (Anon, 1965 a) by fitting specially modified shoes to the cultivators.

Birch (1964), also reported excellent control of nutgrass with pre-planting soil incorporation of 3 - 12 lbs EPTC per acre, with no noticeable detrimental effect to the crop.

The safe use of EPTC in potatoes at planting has been demonstrated by Visser (1960). Rates of 12 lbs active ingredient per morgen, which is more than double the recommended rate, did not reduce yields (Visser 1961). Nel and Ventar (1964) have reported excellent control of *C.rotundus* when applying 6 lbs of EPTC per morgen to potatoes two weeks before planting.

7. Symmetrical Triazines.

Atrazine was readily translocated through nutgrass plants following soil applications to plants, measuring 2 - 12 inches, but did not enter ungerminated tubers (Donnelly and Rahn 1961).

Under favourable moisture conditions, 2 lbs of atrazine per acre provided practical nutgrass control on a sandy loam (Vengris 1963). The recommended rate for nutgrass control, however, is 3 - 4 lbs per acre, preferably incorporated to a depth of 3 - 5 inches at planting if dry weather or dry soil conditions are anticipated.

Kitchin et al.(1962) found that on a fine, sandy loam, good control of nutgrass could be achieved with 4 lbs of atrazine per acre, applied pre- or post-emergence. Two lbs, followed by 2 lbs post-emergence 18 days later also gave excellent nutgrass control. Hargan et al.(1962) reported that pre-planting applications of atrazine to a bare soil were ineffective but post-emergence foliage applications, coupled with discing were most effective. Fertig (1963) reported poor control of nutgrass with post-emergence applications of 3 lbs per acre.

Bell and Gardner (1962) found that on a silt loam, nutgrass exhibited remarkable tolerance towards atrazine, growing luxuriantly in areas which one year before had received 12.5 lbs per acre of this material, while red clover and timothy were completely eliminated. At 21 lbs per acre, nutgrass still survived. Ample moisture supply seemed necessary for the activation of atrazine. When moisture conditions are ideal, atrazine complements the depressing effect of corn on nutgrass yield and therefore contributes to the control of the weed. Use of 5 or more lbs of atrazine per acre could influence the establishment of forage crops.

In order to obtain satisfactory nutgrass control with atrazine, a rate of 4 lbs per acre pre-emergence or post-emergence is necessary (Santelman and Meade 1962). Atrazine at rates above 2 lbs however, precludes the growing of anything but corn the following year.

Fink and FlotoHill (1963) provide data on the residual effects of atrazine and simazine. Four forage grasses and five forage legumes showed adverse effects when planted in April on soil treated with simazine or atrazine in May of the preceding year. Significant yield reductions occurred with all crops following treatment of 2 and 4 lbs per acre of both chemicals.

The influence of simazine on nutgrass was investigated by Birch (1954) in Natal on soils with a clay content of 28.8%. He found that the nutsedge was not controlled by normal application rates of simazine used in maize.

Applications of simazine actually increased the nutsedge percentage. Simazine applications are considered to have prevented the establishment of nutsedge from seed and to have adversely affected the establishment of nutsedge from tubers located in the zone of high simazine content.

In Natal, Gosnell (1964b)states that atrazine and simazine under moist conditions or irrigation, have not given adequate control of nutgrass when applied pre-emergence.

8. Amino triazole (Amitrole).

This compound has proved very effective as a translocated herbicide on a great variety of weeds.

Donnelly and Rahn (1961) demonstrated that amitrole was translocated acropetally and basipetally in nutgrass when applied to plants bearing tubers, the labeled compound accumulating in the tubers. Similarly, Hill et al.(1963b)were able to demonstrate that amitrole was readily translocated from the point of application to the seed and that seed germination was significantly reduced following amitrole applications. The physiological maturity of the plant did not influence the direction of translocation to any extent. The most effective point of application appeared to be just below the umbel.

Of the herbicides screened by Rahn et al.(1962) amitrole was the outstanding chemical tested. The viability of small and large tubers from plants sprayed with amitrole 6 lbs per acre was markedly reduced.

9. Surfactants.

The addition of a surfactant to a herbicide may either increase, decrease or have no effect on the phytotoxic properties of that herbicide. The addition of ethoxylated, nonionic surfactants in aqueous spray mixtures of DCMU, greatly increased its toxicity to Digitaria sanguinalis Scop. (McWhorter 1963). Bayer and Drever (1965) found that enhancement of DCMU toxicity, applied as a foliar spray to oat plants, was not dependant on type of surfactant - anionic, cationic or nonionic - but that the specific surfactant and the concentration of the surfactant were important.

Temple and Hilton (1963) state that the apparent solubility in water of atrazine and diuron was increased when a surfactant was added to the water.

Hill et al. (1964) studied the ability of surfactants to enhance the herbicidal effect of diuron, linuron and bromacil. Temperature, humidity, drought stress and concentration of surfactant influenced the foliar activity of the spray mixtures containing a dodecyl ether of polyethylene glycol (Surfactant W.K./nonionic) and diuron or linuron.

The efficacy of soil acting herbicides such as diuron, linuron, atrazine, simazine and bromacil are dependant on prevailing soil moisture conditions. Applied as a foliar spray in conjunction with surfactants, diuron proved more useful as a post-emergence than as a pre-emergence spray and was effective at lower rates than when used post-emergence (Gosnell 1965 a).

Control of yellow nutgrass in corn with linuron 2 lbs per acre, plus surfactant, has been reported by Shear (1965), Gosnell (1965 b) and Hasblethwaite (1965).

E. BIOLOGICAL CONTROL.

Insects attacking nutgrass.

Because chemical control measures against C.rotundus are limited in effectiveness or expensive, several attempts have been made towards biological control. Poinar (1964) reports that of the insects discovered attacking C.esculentus and C.rotundus in Southern California, Bactra venosana var. chryses appears to be the most likely agent for the biological control of both Cyperus species. It attacks and destroys both yellow and purple nutgrass and seems to be specific to nutgrass, at least in Southern California.

Other attempts towards biological control of nutgrass have not resulted in satisfactory control. Of these, the Hawaiian introduction in 1925 of Bactra truculenta and Athesapeuta cyperi, gave a fair measure of success (Poinar (1964).

Satterthwait (1932, 1942a and 1942b) describes a large number of curculionids of the genus Calondra which feed on yellow nutgrass but also tend to oviposit and feed on forage or grain crops.

A coccid Antonina australis was first recorded attacking Cyperus rotundus in New South Wales and later introduced into Queensland (Summerville 1933). The insect appeared to work efficiently only under dry soil conditions. Faure (1956) has reported a thrips species collected on Cyperus spp., while Poinar (1964) cites the discovery of an aphid, Carolinaia cyperi, on yellow nutgrass by Ainslie.

Attempts to eradicate C.rotundus with hens and geese have been described by Mayton et al.(1945). The former were effective in eradicating purple nutgrass from small areas. Because of their grazing habits, hens were ineffective in eradicing C.rotundus when placed in large pens. Geese however were only effective in ½ acre pens cropped to cotton.

CHAPTER VI

METHODS AND MATERIALS

A. EXPERIMENTAL SITES

The experiments described in this study were conducted at three locations, situated on the Highveld, during the period October 1959 to April 1965. The field experiments were concentrated on heavily infested nutgrass sites at Frankenwald, Bapsfontein and Bethal. The field trials at Frankenwald and Bapsfontein were conducted on arable sites well suited for field cropping. The site at Bethal was unsuitable for crop production, being poorly drained and becoming waterlogged after heavy rains. The texture and composition of representative soil samples taken from each experimental site are given in Table 1.

TABLE 1 : COMPOSITION AND TEXTURE OF SOILS OF THE EXPERIMENTAL SITES.

SOIL ANALYSIS	FRANKENWALD	BAPSFONTEIN	BETHAL
Available phosphate (p.p.m P_2O_5)	5	1	65
Available potash (% K_2O)	0.010	0.004	0.017
Available calcium (% CaO)	0.042	0.031	0.108
Total nitrogen (% N)	0.046	0.066	0.104
Organic carbon (% C)	0.90	0.90	-
pH in water	5.1	4.8	5.6
Clay (%)	7	15	13
Silt (%)	6	10	16
Coarse and fine sand (%)	87	75	71

The two extremely positioned sites, Frankenwald and Bethal, are approximately 100 miles distant, with Bapsfontein some 20 miles from Frankenwald. The three sites lie at altitudes ranging between 5,000 - 5 300 feet above sea level. The winters are dry and cold with severe frosts occurring periodically during the months May to August. Not infrequently the spring rains fail, so that winter is followed by periods of drought, coupled with rising temperatures. During the summer months, the mean monthly maximum temperatures range between 25 - 28°C and the mean monthly minima between 12 - 14°C.

Laboratory, glasshouse and open air pot experiments were carried out at Frankenwald. Seed germination studies were conducted at the Seed Testing Station laboratories of the Department of Agriculture, Pretoria.

B. METEOROLOGICAL DATA

Maximum and minimum glasshouse temperatures were recorded daily for the period mid-December until the end of April during 1964 and 1965. The maximum temperature varied from 30°C to 37°C and the minimum from 12°C to 18°C. During April, 1964, however, minimum temperatures of 5 and 6°C were recorded for short spells. Humidity in the glasshouse was not controlled. Meteorological data for the summer months, October to April at Frankenwald recorded over the period 1961 - 1965 are given in Table 2 where R refers to rainfall in millimetre points, HS, daily hours of sunshine and MA and MI to maximum and minimum air temperatures in centigrades respectively.

TABLE 2. METEOROLOGICAL RECORDS FOR FRANKENWALD FOR THE SUMMER PERIOD: OCTOBER-APRIL, 1961 - 1965 (MONTHLY MEANS)

PERIOD	1961/62				1962/63				1963/64				1964/65			
	R	H.S	MA	MI	R	H.S	MA	MI	R	H.S	MA	MI	R	H.S	MA	MI
OCTOBER	440	9.1	28.4	3.6	262	9.5	28.9	11.6	452	8.3	27.2	11.3	1606	7.7	24.7	8.8
NOVEMBER	757	7.7	25.7	-	1554	6.7	25.2	12.8	1214	7.5	26.0	12.8	277	8.8	26.5	10.8
DECEMBER	873	7.6	26.4	-	368	9.4	28.3	13.2	1050	9.9	27.6	12.6	1473	7.6	25.8	12.1
JANUARY	226	8.2	[illegible]	-	765	6.3	25.7	13.7	1099	9.0	27.8	12.6	1361	8.9	27.1	12.9
FEBRUARY	454	8.5	28.3	-	232	9.9	28.1	12.4	365	9.0	28.4	13.2	1167	10.0	28.7	13.1
MARCH	1019	8.3	27.5	-	296	8.9	26.6	10.5	566	9.3	29.2	12.3	120	9.3	28.4	9.4
APRIL	630	8.0	22.5	-	630	7.0	22.2	7.8	535	8.3	24.0	7.6	400	8.1	22.9	6.7

The mean monthly temperatures recorded at 10 cm depth at Frankenwald over the period 1957 - 1964 are shown in Table 3.

TABLE 3 : MEAN MONTHLY SOIL TEMPERATURE AT FRANKENWALD AT 10 CM DEPTH (3.9") PERIOD 1957 - 1964.

MONTH	TEMPERATURE °C
JANUARY	20.3
FEBRUARY	20.3
MARCH	18.2
APRIL	14.7
MAY	9.0
JUNE	5.4
JULY	5.3
AUGUST	7.7
SEPTEMBER	13.0
OCTOBER	16.9
NOVEMBER	19.4
DECEMBER	20.2

Rainfall records in millimetres at Bapfontein for the period 1959 till June 1961, are given in Table 4. Rainfall records for Bethal are not available.

TABLE 4 : RAINFALL RECORDS BAPSFONTEIN RESEARCH STATION (MRS)

MONTH	YEAR	
	1959/60	1960/61
JULY	10.1	0
AUGUST	0	7.1
SEPTEMBER	1.9	3.5
OCTOBER	34.6	56.2
NOVEMBER	135.0	114.3
DECEMBER	151.9	109.5
JANUARY	61.2	87.3
FEBRUARY	55.4	64.4
MARCH	75.1	90.1
APRIL	62.9	68.2
MAY	2.5	19.6
JUNE	3.7	19.3
SEASONAL TOTAL	594.3	638.8

C. EXPERIMENTAL DESIGNS AND STATISTICAL PROCEDURES.

The experimental designs employed in this study were as follows:-

1) Completely random designs. Laboratory, glasshouse and open air experiments.

2) Randomised blocks. Field experiments.

3) Factorials - Laboratory, pot and field experiments.

Most of the statistical analyses were conducted on an IBM 1620 computer according to standard statistical methods.

The statistical tests and computations employed in this study were as follows:-

1) Correlations - Fertilizer experiments.

2) Regression - Fertilizer experiments.

3) t-Test - Inhibition studies - Variable squared method (Paterson 1939)

4) Transformations (Steel and Torrie, 1960).

a) Angular Transformations. Applied to binomial data expressed as decimal fractions or percentages, e.g. percentage germination of seed or percentage of sprouted tubers, ratings of herbicidal efficacy. The method of converting data to a percentage of maximum and then transforming the percentages to degrees of an angle has also been used.

b) Square root transformation. This method of transformation was engaged where the data consisted of small, whole numbers or showed limited variation, e.g. weed counts, plant numbers.

c) Log transformation. This transformation was applied to the data where treatments differed very markedly from one another, e.g. weed counts. Where zero numbers occurred, the value Log $(x + 1)$ was used.

F-Values.

The analysis of variance tables with respective F significance values, have been inserted together with the original data in the relevant Appendix Tables. The calculated F values have not been inserted. Siginificance has been indicated by means of single or double asterisks where treatment variance is greater than error variance and the calculated F value exceeds the theoretical values of F for probabilities of 0.05 and 0.01 respectively. N.S in main tables denotes "not significant".

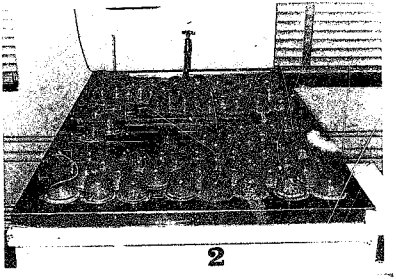


FIGURE 14: Seed germination. Jacobsen apparatus with bell-shaped plastic covers.

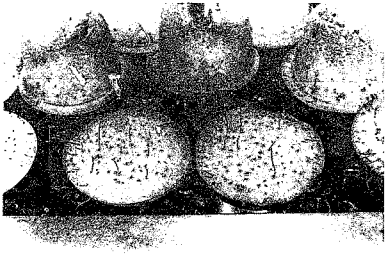


FIGURE 15: Seed germination. Dutgrass seedlings on filter paper.

The L.S.D has not always been calculated where significance was indicated by the F test.

Transformed data:

Where the analysis of variance has been carried out on the transformed data, the transformed means have been tabulated and the calculated L.S.D's for the transformed data given, if applicable. The latter means and L.S.D's have not been detransformed, but are presented together with the original actual data.

Experimental design.

Simple field experimental designs have been preferred in this study because of possible errors of execution involved with complex experiments. Certain experiments which were dependent on the co-operation of growers were purposely modified and replication excluded to permit the maintenance and supervision of such trials without upsetting normal farming practical routine. Because of the standard field designs employed, the actual layout of the plots has been omitted from all experiments reported in this study.

Repetition.

To ascertain whether environmental conditions such as soil type or climatic conditions could influence the validity of experimental conclusions from a single experiment, certain experiments were repeated over a number of years and on several soil types.

D. EXPERIMENTAL MATERIAL.

1. Nutgrass Seed.

Seed was collected in the field at Bethel and stored in air-tight containers at room temperature. Seeds were planted 100 to a dish on filter paper moistened with tap water in standard 10 cm petri dishes. For the Jacobsen apparatus tests, the seeds were placed on filter paper discs and fitted with bell-shaped transparent plastic covers. (See Figures 14 and 15).

2. Nutgrass tubers. (See Figure 16).

Pot experiments were planted with sprouted tubers at equidistant intervals unless specified otherwise. Tubers were selected for uniformity in size and planted from $\frac{1}{2}$ to $\frac{3}{4}$ inch below the surface. Replacements were inserted, when necessary, to ensure a uniform plant population per pot.



paratus with



seedlings on filter

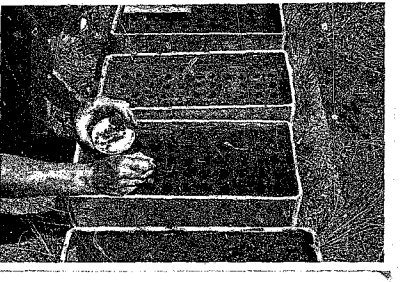


FIGURE 16: Planting trays with sprouted nutgrass tubers.

3. Pot Studies.

Pots were filled with equal amounts of unsterilised Frankenveld loam sand, removed from an arable site which had been subjected to continuous cultivation. (For the respective composition see Table 1). The soil was screened to remove the larger aggregates and foreign material. Where fertilizers were applied prior to planting, these were lightly forked into the top 2" layer. All pots were fully randomized in the glasshouse and open. Aerial growth of all pots was clipped at ground level.

4. Pot and Tray Sizes.

1. Polyethylene pots - a) Small - 13 cms diameter
   b) Medium - 16 " "
   c) Large buckets 24 " " x 28 cm high.
2. Clay pots - 15 cm diameter
3. Deep fibre asbestos trays - 21 cm x 45 cm (18 cms deep)
4. Germinating trays - 22 mm x 28 mm.

5. Fertilizers.

Standard grade fertilizers were used. Complesal Supra was applied as a standard fertilizer treatment in most pot experiments as indicated and used in solution as a drip feed. The composition of Complesal Supra is as follows:-

12% N Equal parts of NO_3^- and NH_4^+

12% P_2O_5 1/3rd water soluble and 2/rds citric acid soluble.

17% K_2O Equal parts of KCl and K_2SO_4

2% MgO

Furthermore, 100 kg of Complesal Supra contains 900 gm borax, 280 gm manganese sulphate, 160 gm copper sulphate, 90 gm zinc sulphate and 2.5 gm cobalt sulphate.

6. Crops.

Crop varieties which were used in this study were obtained from the Seed Testing Station of the Department of Agriculture. The crop varieties were as follows:- Sorghum (Hertin); Sunflower (Jupiter); Radish (Sparkler and Japanese); Hairy Vetch (Code 238); Cowpeas (Witzenberg,; Teff (Unie Bruin); Beetroot ; Lupine (Bitter); Beans (Contender); Lucerne; Cucumbers (Longmarket); Peas (Black Eye Susan;

E. ANALYSIS OF PLANT MATERIAL AND SOILS.

1. Plant Material.

Chemical analyses were based on air-dried basis and were conducted according to the following methods:

(i) Protein: Modified Kjeldahl Gunning method with HgO (red) and $Na_2S_2O_3$ excessed directly as protein and not as N.

(ii) Calcium: Standard ammonium oxalate + $KMnO_4$ method.

(iii) Phosphorus: Colorimetric Molybdenum Blue.

(iv) Ash: Charring and ashing at 600°C to constant weight.

(v) Fat: Standard Soxlet Method with Petroleum ether.

(vi) Fibre: Standard S.A. Maize Board method.

(vii) Moisture: Drying at 100°C to constant weight.

(viii) N free extract: By difference.

(ix) Carbohydrate: N free extract plus fibre.

2. Soils.

Soil analyses were conducted as follows:-

(i) Nitrogen: Micro-Kjeldahl.

(ii) Phosphate: Brays Extract - Eel Portable Colorimeter.

(iii) Potash: Flame photometer.

(iv) Calcium: Extraction with NH_4 acetate - evaporate to dryness, dissolve extract in dilute Hcl and titrate with EDTA.

(v) Magnesium: By means of an atomic absorption spectrophotometer.

(vi) pH: Soil suspension, allowing slurry to stand for 1 hour.

(vii) Texture: Hydrometer - Sodium oxalate

F. HERBICIDAL TRIALS.

1. Common Names and Abbreviations used for Herbicides:

Herbicide terminology used in this study is based on that approved by the British Standards Institution (BSI and the Weed Society of America (WSA). Details of herbicides are given in Table 5.

TABLE 5 : LIST OF COMMON NAMES, CHEMICAL COMPOSITION AND CONCENTRATION OF HERBICIDE USED IN HERBICIDAL TRIALS.

Common Name	Chemical Composition	Concentration & Formulation
1. Amitrole	3,amino-1,2,4-triazole + NH_4SCN	2.4 lbs per Imp.gal. E.C.
2. Atrazine	2-chloro-4-ethylamino-6-isopropylamino 1,3,5-triazine	80% W.P
3. Bromacil	5-bromo-6-methyl-3-(1-methylpropyl) uracil	80% W.P
4. 2,4-D	*2,4-dichlorophenoxyacetic acid-isopropyl ester*	4 lbs a.e per Imp.gal.
5. Dinoseb (Dinosam)	4,6,dinitro-o-sec-butylphenol	50% w/w E.C
6. Diuron (DCMU)	N'-(3,4-dichlorophenyl)NN-dimethylurea	80% W.P
7. EPTC	S-ethyl NN-dipropylthiocarbamate	5% Granular
8. Dalapon	2,2-dichloropropionic acid - Na salt	85% W.Sol.Crystals
9. Linuron	N'-(3,4-dichlorophenyl)-N-methoxy-N-methylurea	50% & 80% W.P
10. MCPA	4-chloro-2-methylphenoxy acetic acid K salt	48% w/w
11. Monolinuron	N'-(4-chlorophenyl)-N-methoxy-N-methylurea	50% & 80% W.P
12. Monuron (CMU)	N'-(4-chlorophenyl)-NN-dimethylurea	80% W.P
13. Paraquat	1,1'-dimethyl-4,4'-bipyridilium salt	2 lb a.i per Imp gal.W.Sol salt
14. PCP	Pentachlorophenol	5% w/w E.C
15. TCA	Trichloro acetic acid - Na salt	94% a.i W.Sol.Granules
16. Triuron	Trichloro acetic acid - Na salt + 2 parachlorophenol 3-(p-chlorophenol)-1,1-dimethylurea	90% + 8% Wettable Powder.

E.C. = Emulsifiable Concentrate
W.P. = Wettable Powder
w/w = Weight/weight
a.i = Active ingredient
W.Sol.= Water soluble
a.e = Acid equivalent

2. Weed Flora.

Except where stated to the contrary, field experiments were conducted on arable sites, specifically selected for their uniform and dominant nutgrass populations. Generally speaking, annual grasses were of secondary or tertiary importance. In order of ~~weight~~ dominance, the annual grasses consisted of Eleusine indica (L.) Gaertn., Panicum laevifolium Hack., Digitaria sanguinalis (L.) Scop. and Setaria verticillata (L.) P. Beauv. Dicotyledonous weeds (broadleaf weeds) were very sporadic and scattered as isolated, or clusters of plants over the sites. The broadleaf species, in order of ~~weight~~ dominance, consisted of Tagetes minuta L., Amaranthus spp. L., Bidens spp. L.

3. Spray Apparatus and Method of Herbicidal Application.

Herbicides were applied by means of a Holder, manually operated knapsack sprayer, fitted with a hand lance and a modified extended length of delivery tubing. By attaching this tubing to the lance, spraying could be carried out by two operators, thus ensuring a fairly constant rate of delivery and, simultaneously, a favourable distribution spray pattern. The lance was equipped with a pressure gauge and a 3' spray boom containing 3 nozzles arranged at 18" intervals. The nozzles were fitted with ceramic tipped orifices, producing a fan spray pattern. Swath width was controlled by adjusting the height of the boom.

Numerous herbicide wettable powders and, particularly mixtures of the powders, as well as mixtures of wettable powder and miscible formulations, caused considerable blockage on the filter screens, or in the nozzle orifices. To overcome this problem, single nozzles fitted with jets, delivering a cone spray pattern were employed. This single nozzle was also employed for administering directed row spray patterns.

Spray pressure in these trials, varied from 30 - 40 lbs p.s.i and the volume of spray mixture from 40 - 50 gallons per acre. Calibration exercises and constant speed of walking ensured uniform spread and delivery of the spray mixture. In spite of the limitations and criticisms levelled against the use of knapsack sprayers in field plot work, the relatively high volume rate permitted satisfactory coverage of the experimental plots.

4. Evaluation of Results.

Various criteria have been employed to evaluate the efficacy of the herbicidal treatments. These included,

a) Weeds

(i) Ratings:

The degree of weed control was determined by assessing the experimental plots periodically during the active growing period and awarding subjective scores to each plot. (Willard 1958; and Ries and Jacobs, 1954). The scoring system was based on the following scale.

0 = No control of, or effect on, nutgrass growth (Weed coverage as in controls).

10 = Complete kill of aerial nutgrass growth (no weed coverage, bare ground).

Intermediate gradations refer to very slight, slight, few, moderate, severe etc.,

(ii) Plant population density.

Weed counts of treated plots were made at certain post-treatment intervals in quadrat frames measuring 20" x 20". Frames were placed at equidistant intervals along the plot centre or diagonal. Total numbers of living or surviving nutgrass stems were recorded. The dimensions of other quadrat frames employed in various trials are given in the text. The first and last quadrats were always taken approximately 3 ft from the plot border. Results are given as the number of nutgrass stems per quadrat.

(iii) Weights.

The results of clip quadrats are recorded as the weight of green herbage in grams per quadrat. Stems were cut as near as possible to ground level.

b) Crops

(i) Population

The influence of herbicidal treatment on the emergence or survival of the crop was established by recording the number of plants per given number of rows within each plot.

(ii) Rating

The influence of herbicidal treatment on crop growth was established by awarding subjective scores to each plot. The scoring system was based on the following scale:-

0 = No effect on or damage to the crop (growth as that in untreated controls).

10 = Complete kill of aerial growth.

In some trials consecutive ratings for the duration of the trial were made, thus obtaining a record of both initial and residual phytocidal effects.

(iii) Crop heights and yields were taken from the central plot rows.

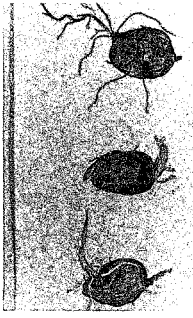


FIGURE 17: Sprouted nutgrass tubers showing various stages of growth.

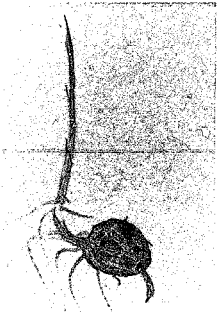


FIGURE 18: Sprouted nutgrass tuber with vertical rhizome.

CHAPTER VII

REPRODUCTION, GROWTH AND RESPONSE TO FERTILISER.

A. GROWTH AND REPRODUCTION

Life history studies of nutgrass have been made by Rheinhold (1942 a), (1942 b) and Sas (1951). Rheinhold has also given a detailed description of the morphology of the plant. The following is a brief summary of studies reported by the above workers, together with observations made during the present laboratory, glasshouse and field investigations. This description is given in detail to facilitate the interpretation of subsequent experimental data.

Nutgrass reproduces both by means of seed and tubers.

Development from tubers:

In the early spring, most plants found in the field develop from tubers which have overwintered in the soil. At the apex of the tuber, 4 - 5 buds are clustered. These can successively, or occasionally two or more simultaneously, grow out to form a vertical rhizome to the soil surface (Figure 8). The young shoot which emerges from the distal end of the tuber is white, very robust and appears to be almost swollen at its base. The roots which are fibrous, develop at the juncture of the tuber and the new vertical rhizome. The length of the vertical rhizome is determined by the depth of the tuber below the soil surface. After emergence, the rhizome thickens slightly to form a tuberous enlargement termed the basal bulb from which leaves, roots and other rhizome later develop. (Figures 17 and 18).

The first roots of the plant are formed at the base of the vertical rhizome where it is embedded in the tuber tissues, and very often on the vertical rhizome itself, especially if the tuber is lying at a considerable depth below the soil. Rudimentary non-functional roots are frequently found on the surface of the tuber.

The rhizomes arising from the basal bulb may appear from several days to several weeks after the leaves and roots have developed. Young rhizomes are pale and succulent, becoming thin and dark with maturity. The lateral rhizomes may also develop on the vertical rhizome. Normally, most tubers are formed at the terminals of the thin lateral rhizomes radiating from the basal bulb. (See figures 19 - 23).

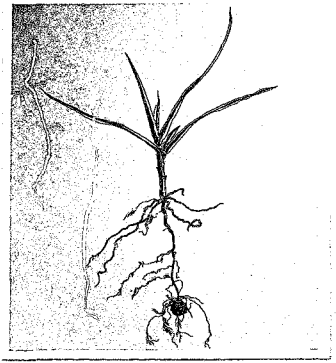


FIGURE 19: Nutgrass. 6th leaf stage

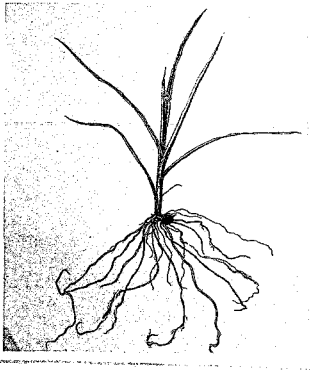


FIGURE 20: Nutgrass. 7th leaf stage.

Under optimum growing conditions or where low density populations are present in mid-summer, the formation of thicker, faster growing, lateral rhizomes ending in new daughter plants at the surface of the soil, predominate over the formation of the thinner rhizomes ending in new tubers. From an approximate horizontal position in the soil, the rhizomes turn upwards, grow vertically through the soil and produce new basal bulbs from which leaves, roots and rhizomes emerge. The lateral rhizomes vary in length and in some cases may reach a length of 2 feet. In this way a chain of plants is formed linked together by interconnecting rhizomes and presenting an overall growth habit not unlike that of Cyperus rotundus. (See Figures 26, 27 and 28).

In severely infested fields, where the plants are growing under competitive conditions, lateral rhizomes ending in daughter plants are not common, but short, tuber-bearing rhizomes predominate.

Leaves developing from tubers planted 2 inches or deeper below the soil surface often developed lateral alternating yellow and green bands. This striping effect was particularly evident when the tubers were planted during the cooler or cold months, but gradually disappeared as the plant developed.

Development of tubers.

Generally, adverse conditions such as drought, low temperatures, low soil nutrient supply and high population levels, which slow down the growth of the aerial part of the plant, favour the development of tubers (Rohn et al.1962). Under such conditions, tubers may develop on plants no higher than 2" ~~sunlight~~. In the field, tubers may be formed about 21 days after emergence of the parent plant above ground. Under Highveld conditions, tuber formation does not appear to be affected by seasonal influences. Tubers are formed from early spring to late summer, long after flowering has been completed.

Viability of tuber.

Young tubers are yellowish-white, darkening in colour. They become very hard and develop an outer protective layer of cork or a sclerenchyma. Small, immature tubers which are not more than 2 mm in diameter at the end of a rhizome are capable of producing new plants when detached from the mother plant.

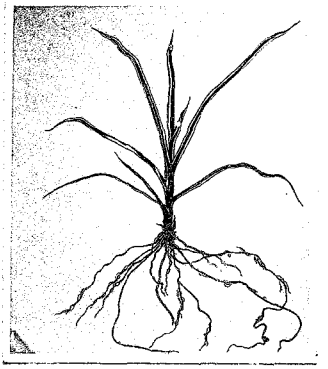


FIGURE 21: Nutgrass. 8th leaf stage.



FIGURE 22: Nutgrass with lateral rhizome terminating in daughter plant.

Tubers planted in clean river sand and watered daily, apart from being chlorotic, grew normally and developed normal umbels and daughter tubers. Food reserve in the tubers appeared to be adequate for reproduction, despite the absence of nutrient supply.

Development of inflorescence.

In general, plants produce umbels one month after emergence.

Growth of seedling.

The plumule and not the radicle is the first to emerge. The plumule is enclosed in the coleoptile. Approximately 4 days after the start of germination, adventitious roots make their appearance. The first leaf makes its appearance 12 - 14 days after sowing. Seedling ± 1" high, containing three leaves, reaches a height of 2.5 - 3.5 inches one month after sowing. Two months after sowing (4 leaf stage) the seedling reaches a height of 4 - 5 inches. Tubers are formed only late in the season. Seedling growth is depicted in Figures 29, 30 and 31.

B. FERTILIZER RESPONSE

Field observations have indicated that nutgrass responds to fertilizer dressings. Such responses are particularly evident when nutgrass is competing with row crops which have received fertilizer treatment, either at planting or as a side dressing. From the available literature, it would appear that no critical work has been undertaken previously in regard to the response of nutgrass to fertilizer treatment. To establish which plant nutrients influence nutgrass growth, a series of fertilizer experiments were conducted both in the glasshouse and in the field. The results from such experiments could assist in explaining certain problems relative to the ecology of the species and clarify the factors responsible for competition between nutgrass and field crops. Furthermore, the data obtained from such investigations would permit certain fertilizer recommendations which might obviate severe competition during the critical stages of crop growth.

The initial trials consisted of a field and pot experiment in which identical treatments were used. Two levels of N, P and K were applied to nutgrass in 2^3 factorially designed experiments.

hizome terminating

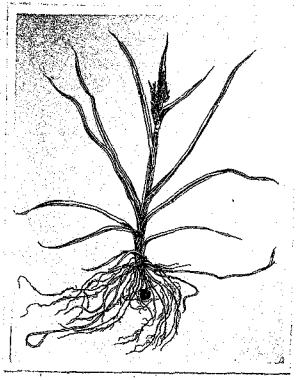


FIGURE 23: Nutgrass inflorescence emerging.

1/ N.P.K Pot Experiment.

Clay pots were filled with soil, removed from the site selected for the corresponding field trial. The top 6" soil layer was sampled and sieved. Fertilizers were uniformly distributed over the soil surface and lightly forked into the top 2" layer. Treatments, details of which are given in Table 6 below, were replicated three times. Fifteen tubers were planted in each pot. The aerial growth was clipped 51 days after planting.

TABLE 6 : FERTILIZER TREATMENTS AND RATES OF APPLICATION.

TREATMENTS	FERTILIZER	RATE PER ACRE IN LBS	COMPOSITION	NUTRIENTS PER ACRE.
1. Po Ko No - O				
2. Po Ko Ni - N	UREA	250	46% N	115 lbs N
3. Po Ki No - K	MURIATE OF POTASH	200	60% K_2O	120 " K_2O
4. Po Ki Ni -NK				
5. Pi Ko No - P	SUPERPHOSPHATE	600	19% K_2O Soluble P_2O_5	114 " P_2O_5
6. Pi No Ni -NP				
7. Pi Ki No -PK				
8. Pi Ki Ni-NPK				
9. 12:12:17:2	COMPLESAL SUPRA	900	12% N	108 lbs N
			12% P_2O_5	108 " P_2O_5
			17 K_2O	153 " K_2O
			2% MgO	18 " MgO

The Complesal Supra (12 : 12 : 17 : 2) treatment was included to test the response of nutgrass to a N.P.K mixture containing a trace element mixture (See Methods and Materials, Page 39 for relevant composition). Total macro-elements applied with the Complesal treatment were approximately of the same order as that of the NPK factorial treatment, with the exception of potash.

RESULTS

Green and air-dry herbage yields are recorded in Appendix Table 1.

The mean herbage weights are given in Table 7.

TABLE 7: MEAN GREEN AND AIR-DRY WEIGHTS OF NUTGRASS HERBAGE GRAMS PER POT

TREATMENT	GREEN WEIGHT	AIR-DRY WEIGHT
0	10.61	3.00
N	20.10	5.29
P	14.43	3.79
K	14.00	3.77
NP	48.81	13.21
NK	24.56	16.34
PK	13.10	3.49
NPK	44.66	11.74
COMPLESAL	51.07	13.35

INTERACTIONS

GREEN WEIGHT					AIR-DRY WEIGHT				
		No	vs	Ni			No	vs	Ni
N		13.03		34.53	N		3.51		9.14
		Po	vs	Pi			Po	vs	Pi
P		17.31		30.25	P		4.60		8.05
NxP		No	vs	Ni	NxP		No	vs	Ni
	Po	12.30		22.33		Po	3.38		5.81
	Pi	18.76		46.73		Pi	3.63		12.47
		Ko	vs	Ki			Ko	vs	Ki
K		23.49		24.07	K		6.32		6.33
NxK		No	vs	Ni	NxK		No	vs	Ni
	Ko	12.52		34.45		Ko	3.39		9.25
	Ki	13.54		34.60		Ki	3.63		9.04
PxK		Po	vs	Pi	PxK		Po	vs	Pi
	Ko	15.35		31.62		Ko	4.14		8.49
	Ki	19.28		28.87		Ki	5.05		7.61
NxPxK		No	vs	Ni	NxPxK		No	vs	Ni
	PoKo	10.61		20.10		PoKo	3.00		5.29
	PiKo	14.44		48.81		PiKo	3.78		13.21
	PoKi	14.00		24.56		PoKi	3.77		6.34
	PiKi	13.09		44.65		PiKi	3.49		11.73

[1]Treatment 9, (Complesal) gave similar yields as Treatment 5(NP)and 5(NPK), and was therefore excluded from the analysis, the remaining 8 treatments being analysed as a 2^3 factorial.

The two varieties, viz. green weights and air-dry weights gave very similar results. The main effects of N and P were positive and highly significant. There was, however, also a significant interaction between N and P. The NxP table shows the effect of N to be 10.03 and 32.97 gms per pot green weight in the absence and presence of P application respectively; the effect of P in the absence and presence of N was 1.46 and 24.40 gms per pot respectively. Whereas N had some affect in the absence of P, P had no effect on weights of herbage when no N was applied. K had no effect on yields. There was no apparent response to the micro-elements when applied as a Complesal treatment.

2. N.P.K Field Experiment.

Treatments were identical to those employed in the fertilizer pot experiment (Table 5), and were arranged in randomized blocks with 3 replications. The trial was designed to furnish complementary data to the pot experiment.

The site consisted of a uniform infestation of nutgrass which had invaded a disturbed site at the Frankenwald Turf Research Station. Fertilizer treatments were applied by hand to plots measuring 11' x 4'. The soil, deficient in organic matter and low in base exchange capacity, is representative of disturbed sites at Frankenwald, the composition of which has been described (See Page 33).

Fertilizer treatments were applied to nutgrass measuring 3 - 4" high and in the 5 -6 leaf stage. Rainfall, during the growing period, was augmented when necessary by additional overhead irrigation. The plots were mown by means of a manually operated cylinder-type of lawn mower fitted with a catchment bin.

RESULTS

a) Green herbage weights - Clip quadrat yields.

In order to assess the rapidity of response to fertilizer treatment, a probe analysis was carried out one week after application of the fertilizers.

One clip quadrat ($\frac{1}{4}$ square metre) was removed from the centre of each plot. The green herbage weights per $\frac{1}{4}$ square metre quadrat are given in Appendix Table 2 and the means in Table 8.

TABLE 8 : GREEN WEIGHTS OF NUTGRASS HERBAGE IN GRAMS PER $\frac{1}{4}$ SQUARE METRE QUADRAT.

TREATMENT	YIELD
0	40.3
N	46.6
P	32.7
K	34.2
NP	67.4
NK	46.8
PK	34.5
NPK	61.9
COMPLESAL	63.4

INTERACTIONS

N		35.41	vs	55.69
P		41.97	vs	49.13
NxP	Po	37.25	vs	46.70
	P1	33.58	vs	64.68
K		46.75	vs	44.35
NxK	Ko	36.48	vs	57.01
	K1	34.35	vs	54.36
PxK	Ko	43.45	vs	50.25
	K1	40.50	vs	49.21
NxPxK	PoKo	49.30	vs.	46.60
	P1Ko	32.66	vs.	67.43
	PoK1	34.20	vs	46.80
	P1K1	34.50	vs	61.93

The effect of nitrogen was highly significant. Application of N on the average increased the green weight of nutgrass by approximately 57% one week after application. The N x P interaction was not significant, though the indications of an interaction at this stage was very strong.

b) Green herbage weights - Plot yields.

The yields of the cuttings made on 18, 42 and 77 days after fertilizer application, were combined for the analyses.

Results of the respective cuttings are given in Appendix Table 3.

The mean seasonal green herbage weights are shown in Table 9.

TABLE 9 : MEAN SEASONAL GREEN WEIGHTS OF NUTGRASS HERBAGE IN GRAMS PER PLOT

TREATMENT	YIELD
0	1038.2
N	1912.9
P	1389.6
K	1114.9
NP	2777.0
NK	2222.1
PK	1346.8
NPK	2842.0
COMPLESAL	2728.4

INTERACTIONS

N		1222.36	vs	2438.49
P		1572.00	vs	2088.85
NxP	Po	1076.52	vs	2057.48
	Pi	1368.20	vs	2809.50
K		1779.40	vs	1881.45
NxK	Ko	1213.86	vs	2344.95
	Ki	1230.86	vs	2532.03
PxK	Ko	1475.51	vs	2083.30
	Ki	1668.50	vs	2094.40
NxPxK	PnKo	1038.16	vs	1912.86
	PiKo	1389.56	vs	2777.03
	PoKi	1114.90	vs	2222.10
	PiKi	1346.83	vs	2841.96

Both N and P significantly increased weights. The action of N just about doubled the yield while the phosphate dressing increased the herbage weights by approximately 35%. Despite strong indications of an N x P interaction, the significance of this treatment was not substantiated by the analyses of variance.

3. Correlation between Green and Air-dry Herbage Weights.

Two correlations were made, one on the green and air-dry weights of individual pots (27 observations) and one on the treatment totals (9 observations). The correlations were 0.9954 and 0.9994 respectively, showing a nearly perfect linear relationship between the two.

A regression line y = 0.14 + 0.26x was calculated from the data.

The calculations above were based on data collated from a pot experiment which might be easier to handle than in the field where the relationship between green and air-dry herbage weights might not be so close. The high correlations suggest that the fertilizer did not significantly influence the moisture content of the herbage.

4. Correlation between Results obtained from Field and Pot Experiments.

Several calculations were made, all based on treatment totals (9 observations). The correlation between total green weights in the field experiment and total green weight and total air-dry weight in the pot experiment were 0.9503 and 0.9449 respectively, both significant at $p < (0.001)$. A regression line, y = 731 + 46.23x was calculated from the data.

The high correlations indicate that the pot experiment has represented fairly accurately the results obtained under field conditions. It should however be remembered that the pot experiment showed a highly significant NP interaction, which was not significant in the corresponding field experiment. The relationship between the results obtained from the pot and field experiment is confirmed in Figure 24 , suggesting that pot experiments offer an effective means of predicting field behaviour of nutgrass.

5. Nitrogen Carriers.

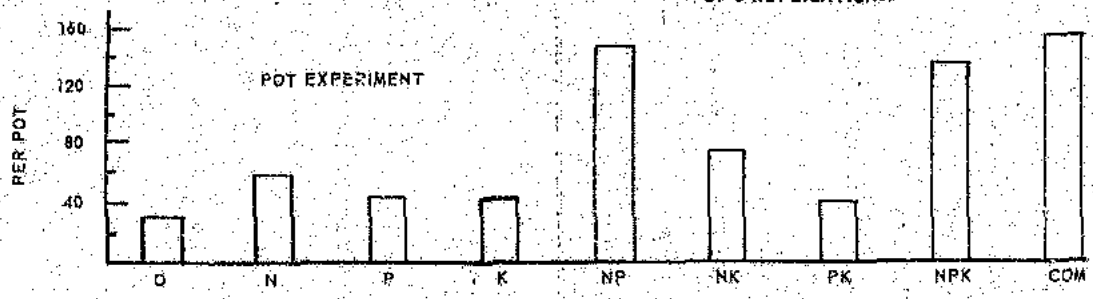
It was evident that nitrogen was the principal plant nutrient responsible for marked increases in the aerial growth of nutgrass, particularly when applied in the presence of phosphate. Two further pot studies were thus initiated to establish, (a) the nitrogen carrier which would yield maximum increases in aerial and underground growth, and (b) the optimum level of response to nutgrass dressings.

To evaluate the relative efficacy of a number of nitrogenous carriers, six ~~forms of~~ nitrogen were applied at the equivalent rate of 100 lbs N per acre, and combined with a standard dressing of KH_2PO_4 which was applied to all pots at the equivalent rate of 600 lbs per acre. The pots were kept in the glasshouse.

Eight tubers were planted in each pot.

FIGURE 24.

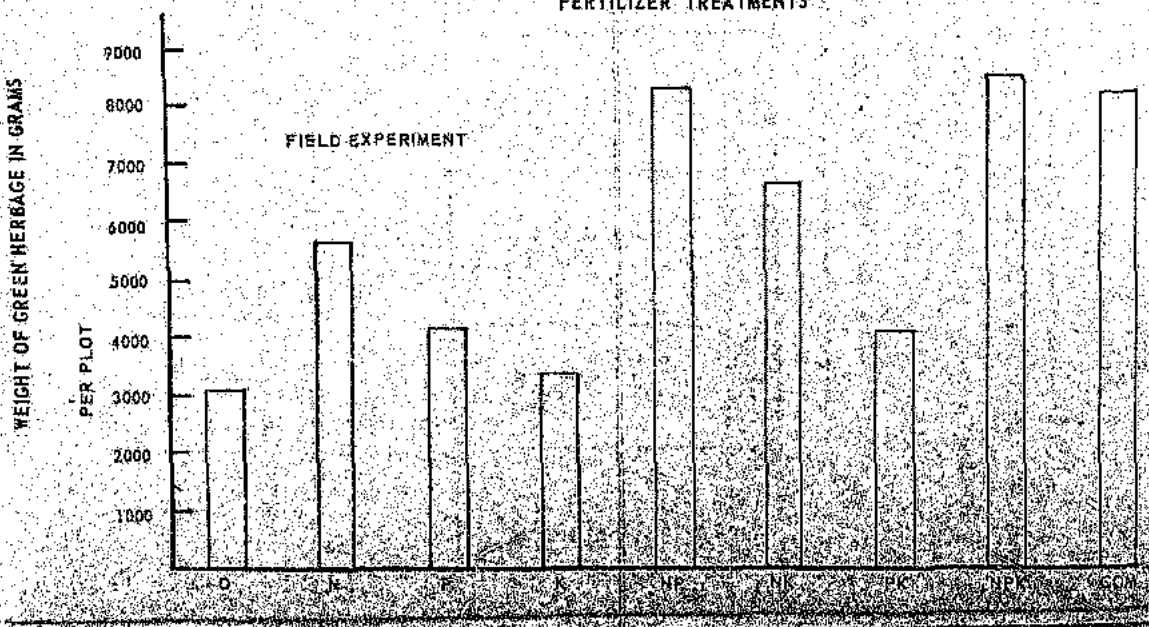
COMPARITIVE RESPONSE OF NUTGRASS TO FERTILIZER TREATMENT WHEN GROWN UNDER POT AND FIELD CONDITIONS. GREEN HERBAGE YIELDS OF 3 REPLICATIONS.



LEGEND. (per acre)

O – NO Fertilizer
N – 115 lbs N
P – 114 lbs P_2O_5
K – 120 lbs K_2O
COM – 108 lbs N, 108 lbs P_2O_5, 152 lbs K_2O

FERTILIZER TREATMENTS



Aerial herbage was clipped twice, the first clipping on 39 days and regrowth 68 days after planting. The underground fractions were washed, separated and weighed. Treatments were replicated 4 times as shown in Table 10.

TABLE 10 : NITROGEN CARRIERS AND PERCENTAGE NITROGEN CONTENT.

N CARRIER	% NITROGEN
1. Calcium nitrate	15.5
2. Potassium nitrate	14.0
3. Ammonium sulphate	21.0
4. Limestone ammonium nitrate	21.0
5. Urea	46.0
6. Ammonium nitrate	35.0
7. Control	

Green aerial weights of nutgrass for the individual and combined clippings and tuber numbers and respective weights are given in Appendix Table 8. Mean values for the results are given in Table 11.

TABLE 11 : WEIGHTS OF GREEN NUTGRASS HERBAGE AND TUBERS IN GRAMS.

TREATMENT	1ST CUTTING	2ND CUTTING	COMBINED CLIPPING	TUBER	
				NUMBER	WEIGHT
1.Calcium nitrate	14.22	11.25	25.47	28.7	2.97
2.Potassium nitrate	20.22	17.72	37.75	41.2	3.82
3. Ammonium sulphate	15.75	11.32	27.07	44.7	4.20
4. Limestone ammonium nitrate	18.90	13.97	32.87	47.7	6.25
5. Urea	23.20	15.77	38.97	49.0	4.95
6. Ammonium nitrate	18.25	14.32	32.57	41.7	4.90
7. Control	3.60	6.02	9.62	26.2	2.65
L.S.D p = 0.05	5.35	3.92	7.94	13.0	1.48

Green weights of nutgrass herbage.

All the nitrogen carriers increased green weights. Urea and Potassium nitrate produced higher increases than Calcium nitrate and Ammonium sulphate, with Limestone ammonium nitrate and Ammonium nitrate intermediate.

Number of tubers.

All carriers except Calcium nitrate increased the number of tubers significantly above the control.

Weight of tubers.

Calcium nitrate and potassium nitrate did not affect the weight of tubers significantly. All other treatments did.

6. Levels of Nitrogen

From the preceding data, it appeared that urea produced the most significant increases in the aerial growth of nutgrass. To establish the optimum levels of response to urea, nutgrass, increasing rates of urea equivalent to 0, 50, 100, 200 400 and 800 lbs urea per acre were applied to nutgrass tubers planted in small polythylene pots. A basal dressing of KH_2PO_4, equivalent to 800 lbs per acre was applied to all pots. Eight nutgrass tubers were planted in each pot. Treatments were replicated 4 times. The aerial growth was cut after 42 days.

RESULTS

The results of the green aerial weights are given in Appendix Table 5 and the mean values in Table 12.

TABLE 12 : MEAN GREEN WEIGHTS OF NUTGRASS HERBAGE IN GRAMS, PER POT.

TREATMENT PER ACRE	YIELD
0 lbs	6.07
50 "	13.50
100 "	18.80
200 "	23.25
400 "	23.85
800 "	25.47
L.S.D p = 0.05	3.15

The effect of nitrogen on the green weight of stems was highly significant. The weights increased rapidly with increasing applications of N up to 200 lbs urea per acre, and thereafter remained fairly constant. Based on the aforegoing, nutgrass appears to tolerate high nitrogen dressings in the form of urea.

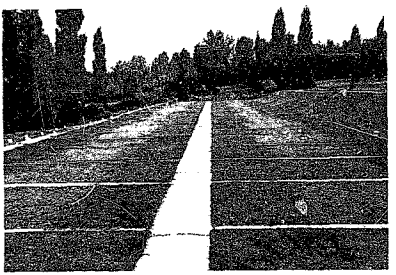


FIGURE 25: Response of turf to fertilizer treatment. NK and NZ strips on left and right of concrete pathway respectively. Note O and P plots in centre.

Results of N.P.K Experiments.

The results obtained in these investigations showed clearly that nutgrass responded favourably to nitrogen, especially when applied with phosphate. Of the N carriers used, urea gave the best response. Furthermore, it was evident that nutgrass responded to increasing levels of nitrogen and that growth was not depressed by heavy dressings, e.g. 800 lbs N per acre. The results obtained in pot studies showed a positive correlation to identical field experiments.

7. Response of Nutgrass to Fertilizer Application in Turf.

During the past five seasons, field inspections of a long term turf experiment at the *Frankenwald Turf Station*, revealed that the plots receiving annual nitrogen dressings for the past 32 years, were heavily infested with nutgrass. Turf plots receiving no fertilizer or only phosphate, supported poor turf growth and were not infested with nutgrass. In view of the response to nitrogen which had been established in the earlier tests, attempts were made to record the influence of fertilizer treatment on the spread of nutgrass. (Figure 25).

According to Meredith (1948) this turf grass experiment was begun in the 1933/34 season at Frankenwald on a level terrace with two rows of twenty-eight plots each. Numerous turf grasses were planted in these plots, most of them being types or strains of Cynodon dactylon. Each plot was divided into four 5 ft strips, and on the strips N.P.K, O, P, and N.P fertilizer treatments were applied annually.

Three of the grass plots, namely, Uclora Mouth, Halls Selection and Royal Cape have remained undisturbed since inception of the trial. The remaining plots were replanted in 1955. Details of fertilizer treatments and management have been decribed by Meredith (1948). At the end of January 1965, the number of nutgrass shoots per 3, circular frames, measuring 7.5 inches in diameter was recorded. The frame was placed at random at equidistant intervals along the plot centres. Counts were made in 15 turf plots. Composite soil samples were taken from each of the 15 plots and analysed. Results are given in Appendix Table 6. Nutgrass counts are given in Appendix Table 7. The soil reaction P,K,Ca and Mg status of the four fertilizer plots ; with

respective number of nutgrass shoots per frame, are given in Table 13. The data has not been statistically analysed.

TABLE 13 : MEAN NUMBER OF NUTGRASS SHOOTS AND SOIL ANALYSIS OF TURF PLOTS. SHOOTS PER 7.5 INCH CIRCULAR FRAME.

FERTILIZER TREATMENT	NUTGRASS SHOOTS	SOIL ANALYSIS IN P.P.M.				
		pH	P	K	Ca	Mg
0	1.6	6.3	35.5	93.3	610.0	71.3
P	2.2	6.2	59.5	89.3	643.3	62.6
NP	25.3	4.5	63.1	47.3	363.3	46.6
NPK	36.9	4.5	90.3	79.3	480.0	46.6

The results show clearly that annual nitrogen dressings in the form of ammonium sulphate over the past thirty years markedly depressed the soil pH and decreased the calcium and magnesium contents of the soil. Phosphate soil levels were increased by all the fertilizer treatments, especially in the case of the N.P.K treatment. Additions of potash did not increase the K status of the soil.

The results reveal that the population density of nutgrass per frame was directly related to fertilizer treatment. The increased density of nutgrass on the N.P.K plots could perhaps be ascribed to a long term potash effect, a response which could not be measured in the short term fertilizer pot and field studies described earlier. Nutgrass was almost entirely absent - and grass growth - on the control and P sub-plots.

The results from the above experiment confirmed that nutgrass is able to invade and survive in turf which has received annual dressings of nitrogen. Despite the fact that the pH of the soil had declined, nutgrass and the 15 turf varieties grew more vigorously on the N.P.K and N.P plots than on the P or control plots. The response of nutgrass to long term applications of nitrogen in the presence of phosphate or phosphate and potash, was mainly in agreement with the short term fertilizer trials which were conducted in pots or in the field.

In the early fertilizer experiments on turf, Hall et al.(1955) had drawn attention to the nutgrass invasion of the turf plots which had received heavy dressings of ammonium sulphate over a long term period.

According to the authors, the turf cover became "thin and unhealthy", and the poor growth of the turf was attributed to a marked change in the soil reaction. On these acid soils, however, nutgrass was seen to thrive. A popular opinion held by many growers is that nutgrass prefers acid sites, its habitat being mainly associated with low lying, poorly drained areas. Consequently, it has often been postulated that an increased soil pH could have a deleterious influence on the growth and survival of the species and might offer a suitable method of control.

To test the validity of this hypothesis, several experiments were conducted in which attempts were made to alter the soil pH and measure the response of nutgrass to these changes. The trials consisted of two field trials which were conducted at two different sites, (a) Bepfontein and (b) Bethal, and during different seasons. A more critical pot experiment was also conducted in the glasshouse. Attempts were made to increase the soil pH by means of calcium hydroxide or calcium carbonate, while for soil acidification, ammonium sulphate was used.

B. Response of Nutgrass to increased dressings of Lime and Ammonium Sulphate - Field Experiments.

Increasing levels of ammonium sulphate and agricultural lime were applied to nutgrass in the 4 - 5 leaf stage. The following treatments were applied during mid-December, 1959. (Rates per acre).

(a) Bepfontein:

1.	Ammonium sulphate	A1	- 800 lbs
2.	" "	A2	- 1600 "
3.	" "	A3	- 2800 "
4.	" "	A4	- 4000 "
5.	Hydrated lime ($Ca(OH)_2$)	C1	- 800 "
6.	"	C2	- 1600 "
7.	"	C3	- 2300 "
8.	"	C4	- 3000 "
9.	"	C5	- 3800 "
10.	"	C6	- 4500
11.	Control		
12.	Control		
13.	Control		

Treatments were arranged in randomized block designs with 3 replications and three untreated controls per block. Plot size was 1/200th of an acre.

Prevailing soil moisture conditions at the time of and subsequent to the application of the treatments were favourable. Where heavy dressings of lime were applied, residues on the soil were evident even twelve months after application. The following data was recorded.

(i) Soil pH.

Eleven months after applying the treatments, the top 6" soil layer from each plot was sampled along a transect diagonal line at equidistant intervals. Four soil cores were removed, bulked and the pH determined. Results are given in Appendix Table 8 and the means in Table 14.

(ii) Weight of nutgrass herbage

The green weight of nutgrass herbage was clipped from 4, (20" x 20") quadrats equidistantly spread within each plot, eleven months after application of the treatments. The weights were bulked and the results are given in Appendix Table 9 and the means in Table 14

(iii) Number and green aerial weights of nutgrass herbage.

The experimental site was disc ploughed and disced 3 times one year after application of the treatments. The site was then replogged and the number of nutgrass plants and the respective aerial weight per 2, (3' x 3') quadrats within each plot was recorded. Results are given in Appendix Table 10 and the means in Table 14.

RESULTS:

TABLE 14 : SOIL pH AND NUTGRASS COUNTS AND GREEN HERBAGE WEIGHTS. MEAN NUMBER AND WEIGHT PER QUADRAT.

TREATMENTS	pH 21/11/60	HERBAGE WEIGHTS 30/11/60	HERBAGE WEIGHTS 23/1/61	NUTGRASS COUNTS 23/1/61	
				ACTUAL	SQ.RT TRANS
1. A1	4.63	356.2	241.0	171	12.8
2. A2	4.53	335.1	329.6	250	15.6
3. A3	4.60	400.1	426.3	271	16.3
4. A4	4.70	365.1	401.6	305	17.0
5. L1	5.23	192.3	265.3	133	11.5
6. L2	5.43	169.9	227.3	134	11.6
7. L3	5.80	149.0	372.0	105	15.4
8. L4	5.36	158.6	321.3	226	14.7
9. L5	5.90	191.2	360.3	253	15.4
10. L6	5.56	160.2	433.6	302	16.7
11. Control M	5.40	206.5	237.3	252	15.7
12. Control	5.03	139.8	255.3	211	14.3
13. Control	5.06	195.2	265.3	210	13.9
L.S.D p = 0.05	0.42	138.5	N.S	N.S	N.S

OVERALL FERTILIZER MEANS

1. Am.Sulph.	4.62	364.1	349.6	174	15.4
2. Lime	5.55	170.2	329.9	192	14.2
3. Control	5.16	180.5	259.3	224	14.6

M NOTE: The controls were excluded from analyses of variance.

Soil pH.

The nitrogen treatments decreased and the liming treatments increased the pH of the soil significantly in comparison with the control. The effects of the different levels of liming tended to be rather erratic.

Green aerial weights of nutgrass after 11 months.

The four ammonium sulphate treatments did not differ significantly among themselves, neither did the six liming treatments. The mean of nitrogen was about twice as high as those of the lime and control treatments. Liming had no effect on yield.

Nutgrass counts and green aerial weights after 12 months.

There were no significant differences between treatments with regard to both nutgrass counts and aerial weights.

(b) Bethal.

This trial differed principally from the previous trial at Bapsfontein in that heavier dressings of lime were employed and the influence of soil incorporation (discing) of the fertilizer treatments was examined. The following treatments were applied to nutgrass in the 10 - 12 leaf stage during November, 1963. (Rates per acre).

1.	Ammonium sulphate	0 lbs	A0
2.	" "	100 "	A1
3.	" "	200 "	A2
4.	" "	400 "	A3
5.	" "	800 "	A4
6.	" "	1600 "	A5
7.	Hydrated Lime (86% $Ca_mOH)_2$)	0 "	C0
8.	"	500 "	C1
9.	"	1000 "	C2
10.	"	2000 "	C3
11.	"	4000 "	C4
12.	"	8000 "	C5

Treatments were arranged in randomized blocks with 4 replications. Plot size was 1/200th acre. Each block was split for discing and no discing. The fertilizers were incorporated into the soil immediately after application by means of an offset disc which traversed the disced sub-plots 6 times.

Soil samples, within the undisced strip from the top 4" layer of each plot, were removed two months after application of the treatments. Three soil cores per plot were taken across the plot diagonal and bulked. Results are shown in Appendix Table 11 and the means in Table 15.

Clip quadrats: Two clip quadrats from the plot centres of both undisced and disced sub-plots were taken 8 weeks and 9 weeks after application of the treatments, respectively. The green aerial growth was air-dried and weighed. The results are given in Appendix Table 12 and the means in Table 16.

(b) Bethal.

This trial differed principally from the previous trial at Bapsfontein in that heavier dressings of lime were employed and the influence of soil incorporation (discing) of the fertilizer treatments was examined. The following treatments were applied to nutgrass in the 10 - 12 leaf stage during November, 1963. (Rates per acre).

1.	Ammonium sulphate	0 lbs	A0
2.	" "	100 "	A1
3.	" "	200 "	A2
4.	" "	400 "	A3
5.	" "	800 "	A4
6.	" "	1600 "	A5
7.	Hydrated Lime (80% Ca_2OH)	0 "	C0
8.	"	500 "	C1
9.	"	1000 "	C2
10.	"	2000 "	C3
11.	"	4000 "	C4
12.	"	8000 "	C5

Treatments were arranged in randomized blocks with 4 replications. Plot size was 1/200th acre. Each block was split for discing and no discing. The fertilizers were incorporated into the soil immediately after application by means of an offset disc which traversed the disced sub-plots 6 times.

Soil samples, within the undisced strip from the top 4" layer of each plot, were removed two months after application of the treatments. Three soil cores per plot were taken across the plot diagonal and bulked. Results are shown in Appendix Table 11 and the means in Table 5.

Clip quadrats: Two clip quadrats from the plot centres of both undisced and disced sub-plots were taken 8 weeks and 9 weeks after application of the treatments, respectively. The green aerial growth was air-dried and weighed. The results are given in Appendix Table 12 and the means in Table 16.

TABLE 16 : SOIL ANALYSIS

TREATMENT	MAGNESIUM CONTENT ppm	CALCIUM CONTENT %	TOTAL NITROGEN%	pH
1. A0	165.0	0.100	0.104	5.77
2. A1	169.0	0.098	0.111	5.72
3. A2	181.7	0.091	0.102	5.75
4. A3	186.5	0.091	0.108	5.62
5. A4	111.5	0.088	0.113	4.97
6. A5	86.2	0.071	0.119	4.92
7. C0	179.0	0.108	0.104	5.70
8. C1	185.7	0.128	0.081	6.00
9. C2	196.0	0.164	0.103	6.27
10. C3	198.0	0.120	0.106	6.05
11. C4	209.2	0.155	0.105	6.40
12. C5	246.0	0.338	0.103	7.27
L.S.D p=. 0.05	56.0	0.052	N.S	0.35

OVERALL FERTILIZER MEANS

Ammonium sulphate	147	0.088	0.111	5.40
Lime	207	0.183	0.098	6.40
Control	172	0.104	0.104	5.74

1) Magnesium Content of the Soil.

The high nitrogen applications viz. 800 lbs and 1600 lbs ammonium sulphate per acre, decreased magnesium content significantly, whereas the lower levels had no effect. Liming on the average increased the Mg content significantly. Liming gradually increased the magnesium content of the soil with increasing levels of application.

2) Calcium Content of the Soil.

Ammonium sulphate decreased the Ca-content significantly, the negative effect increasing sharply with the very high applications of ammonium sulphate. Liming increased the calcium content, a very high value being obtained with the highest dressing (8000 lbs hydrated lime per acre).

3) pH of the Soil.

Ammonium sulphate applications up to 400 lbs per acre, had no measurable effect on pH, applications of 800 lbs and 1600 lbs per acre decreased the pH by about 0.8 units compared to the control.

Liming increased the pH as expected, 8000 lbs of hydrated lime per acre increasing the pH by approximately 1.5 units.

4) Total Nitrogen Content.

Treatments did not affect the total N content of the soil significantly. This might be partly due to the response of the nutgrass to nitrogen applications, the additional nitrogen being used by the nutgrass for increased growth.

TABLE 16 : AIR-DRY WEIGHT OF AERIAL NUTGRASS HERBAGE. GRAMS PER 1' x 1' CLIP QUADRAT.

TREATMENT	DISCED	NON-DISCED	DISCED + NON-DISCED
1. A0	0.74	1.47	2.21
2. A1	1.44	3.17	4.61
3. A2	2.22	3.32	5.54
4. A3	2.66	4.31	6.97
5. A4	3.76	4.55	8.31
6. A5	2.83	4.19	7.02
7. C0	0.78	2.19	2.97
8 C1	1.16	1.88	3.04
9. C2	0.90	2.39	3.29
10. C3	1.12	1.93	3.05
11. C4	1.81	2.57	4.38
12. C5	1.25	1.54	2.79
L.S.D p=0.05	0.92	1.01	1.49

OVERALL FERTILIZER MEANS

Ammonium sulphate	2.58	3.91	6.49
Lime	1.23	2.06	3.31
Control	0.76	1.83	2.59

Air-dry weights of aerial nutgrass growth.

a) Disced sub-plots.

All nitrogen levels except the lowest (100 lbs ammonium sulphate per acre) increased weights significantly above the control. The weights increased with increasing amounts of nitrogen up to 800 lbs ammonium sulphate per acre and then apparently showed a downward trend.



FIGURE 24: Spread of nutgrass. Initial stage.

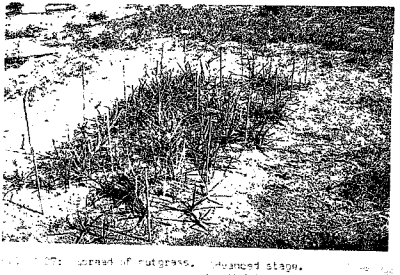


FIGURE 25: Spread of nutgrass. Advanced stage.



FIGURE 26: Spread of nutgrass. Colonization.



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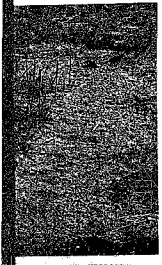
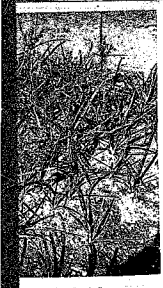


ed stage.



sation.

TABLE 17 : WEIGHTS OF GREEN HERBAGE AND UNDERGROUND NUTGRASS GROWTH IN GRAMS PER POT.

TREATMENT	1ST CLIPPING	2ND CLIPPING	COMBINED CLIPPING	UNDERGROUND WEIGHT
1	5.56	6.13	11.70	2.80
2	5.36	5.66	11.03	3.60
3	6.50	8.53	15.03	4.50
4	9.23	8.66	17.90	7.43
5	5.90	6.06	11.96	4.86
6	4.56	7.20	11.76	3.83
7	4.10	5.63	9.20	4.46
8	4.10	5.10	9.20	5.83
9	5.06	6.36	11.43	3.80

Increasing levels of agricultural lime had no significant effect on the green weights of nutgrass herbage or on the root weights.

Results of lime and ammonium sulphate experiments.

Attempts to change the soil reaction by means of heavy dressings of lime did not reduce the growth of the nutgrass. Ammonium sulphate decreased the soil pH, but these nitrogen dressings caused marked increases in herbage yields. The results from the investigation confirmed the response of nutgrass to nitrogen and a tolerance to a range of soil pH (4.6 - 7.3) and divergent soil nutrient levels. The results obtained from the field experiments at two different sites and during two different seasons, were similar. Where the heavily limed nutgrass infestation was ploughed over and seeded to a row crop, there was no evidence of a decreased nutgrass population density.

C. GROWTH AND SPREAD OF NUTGRASS.

In order to investigate the control and possible eradication of nutgrass, it was important to study the growth rate and spread of the weed. An experiment was accordingly carried out in which sprouted tubers were planted in plots (3' x 2') on a disturbed site at Frankenwald. (See Figure 26).

The site was forked over several times, sieved and raked and the weed growth removed.

Ten micro plots each measuring 3' x 2', arranged as 5 randomised blocks were laid out, half of the plots receiving a fertilizer dressing of Complesal Supra at the equivalent rate of 800 lbs per acre. Fertilizer treatments were fully randomized, applied and forked in. Two sprouted tubers were planted in each of the plot centres, thinning out to one single nutgrass plant per plot. The plots were watered twice daily during the first week after planting. The plots received additional irrigation whenever necessary. Volunteer weeds were removed immediately after emergence. Records in respect of growth and development were made at regular intervals. The data is given in Appendix Table 14 and summarized in Table 18. The plots were harvested after 5 months, after the first frost. Aerial and underground fractions were removed, separated, weighed and counted. The results are given in Appendix Table 14 and the means in Table 19.

RESULTS:

The sprouted tubers emerged 6 days after planting. The mother plants commenced to produce daughter plants within 2 weeks after emergence. Thereafter the micro plots were rapidly colonised. Daughter plants and inflorescences emerged, refer to numbers derived from the original mother plant. Leaf counts per mother plant were discontinued after the emergence of the inflorescence. (See Figure 27 and 20)

TABLE 18 : LEAF NUMBER, DAUGHTER PLANTS AND UMBELS EMERGING FROM A SINGLE MOTHER PLANT.

TREATMENT	DAYS AFTER EMERGENCE											
	3	7	10	14	17	20	31	38	45	52	49	70
Leaf No.* 0	4.8	6.0	7.2	9.4	11.2	11.8	15.2	-	-	-	-	-
N.P.K	4.0	6.2	7.8	10.0	10.4	11.4	15.2	-	-	-	-	-
Daughter Plants 0				0.8	0.8	1.0	3.8	5.0	10.4	18.0	25.8	33.4
N.P.K				0.8	1.75	2.2	5.2	10	16.4	27.4	36.8	45.2
Inflorescence 0								1.0	1.4	1.6	2.6	3.0
N.P.K								0.8	0.8	1.8	3.8	3.8

* Based on growth of original mother plants.

Growth and spread of nutgrass.

In the absence of alien weed competition, this trial furnished valuable information on the growth behaviour of nutgrass grown under two levels of fertility. The plants produced 15 leaves prior to the emergence of the inflorescence, the latter being first observed 38 days after the vertical rhizome had emerged. Daughter plants were produced within 14 days after emergence of the vertical rhizome.

With the exception of numbers of daughter plants produced, fertilizer treatment appeared to exert little influence on the number of leaves and inflorescence produced per plant. The rate of leaf emergence was also not apparently influenced by the fertilizer treatment.

The number of daughter plants produced 70 days after emergence was statistically analysed. Treatment differences, though large, were not significant. Inadequate replications (5) may have been a contributory factor. It should be noted that at the termination of the trial, the daughter plants had practically completely overrun the total area of each plot.

TABLE 19 : MEAN AIR-DRY WEIGHT AND NUMBER OF AERIAL AND UNDERGROUND NUTGRASS FRACTIONS. WEIGHT IN GRAMS PER PLOT

PLANT FRACTION	0	N.P.K
Stem weight	20.8	26.0
Number of tubers	79	161.0
Weight of tubers	10.80	23.20
Weight of roots	13.40	14.75

The data in respect of the above were analysed and the following conclusions may be made.

Fertilizer had no significant effect on the weight of the nutgrass stems or roots.

Fertilizer application increased the number of tubers as well as their corresponding weights.

The spread and growth of an invading sprouted nutgrass tuber growing in the absence of competition was examined during the second half of the summer season. Despite the restricted growing period, the results showed clearly that the rate of proliferation of this species is quite remarkable. Given favourable nutrient and soil moisture conditions, the plant will colonise and produce a crop of underground tubers which, in turn, are capable of invading and infesting new areas if mechanically disturbed. Since each individual daughter plant is capable of generating its own crop of tubers, it is necessary to apply control measures at the critical stage. Eradication of the mother plant within the first two weeks after emergence is thus of the utmost importance. From the results in Table 19, it will be noted that a well fertilized tuber produces 151 tubers within a period of 3 months or possibly 320 tubers over a full summer season. Furthermore, each tuber could give rise to a system of daughter plants which are capable of colonising an area 3' x 2' square feet within the 3 month period. Assuming that each tuber is capable of producing a colony which will cover 9 square feet over an entire summer season, it is possible to theoretically calculate the period required by nutgrass to achieve pest status in an arable field.

After the primary introduction of the tuber and completion of the first season, we have 320 tubers. The latter are then distributed and each gives rise to 320 square yards of colonised nutgrass pockets. During the second season, these colonies would again be distributed, coalescing to form unbroken stands of nutgrass during the third or fourth season. Control during the primary stages of colonisation is therefore essential.

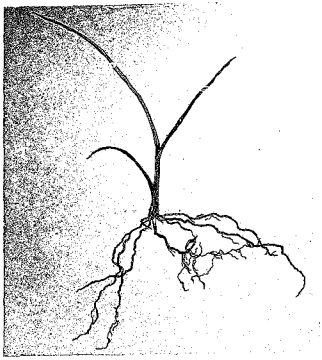


FIGURE 29: Nutgrass seedlings. 3rd leaf stage.

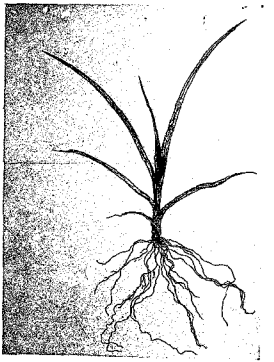


FIGURE 30: Nutgrass seedling. 5th leaf stage.

CHAPTER VIII

SEED AND SEEDLING STUDIES

A. SEED

Both Rheinheld (1942 a) and Moe (1951) have reported that nutgrass seed possesses an extremely hard seedcoat and that germination is stimulated by subjecting the seed to sulphuric acid treatment. In preliminary trials at Frankenwald, it was found that nutgrass seed placed in an oven, kept constantly at 28°C, failed to germinate. Seeds kept moist in petri dishes at room temperature and placed on a north-facing window sill during the winter months, gave approximately a 60 percent germination. Under these conditions, the seed was subject to considerable diurnal temperature fluctuations and exposed to direct light. These results suggested that certain factors were responsible for promoting/ the influence of light, substrate and sulphuric acid treatment on the condition of nutgrass seed, was therefore investigated in a number of experiments.

seed germination.

1. Substrate, Acid and Environment.

Freshly harvested seed was sown on a number of substrates and subjected to acid treatment and different temperature exposures. Single replicates of 100 seeds each were placed on soil, sand and filter paper after exposure to 0, 5 and 10 minute concentrated sulphuric acid treatment. The seed was then washed under tap water to remove acid residues and subjected to a series of temperature and light conditions, designated as A, B, C, D and E, where

A = Jacobson apparatus - 16 hours at 20°C and 8 hours at 30°C. Light supplied for 8 hours at 30°C.

B = Germination chamber - Constant temperature of 20°C, Constant darkness.

C = Lautenschlager Apparatus - Constant temperature of 30°C. Constant darkness.

D = Germination Chamber - 16 hours at 20°C and 8 hours at 30°C.

E = Germination Chamber - 16 hours at 15°C and 8 hours at 30°C.

Regular germination counts were made over a period of 1 weeks. The percentage germination at various intervals after sowing is given in Table 20.

leaf stage.

leaf stage.

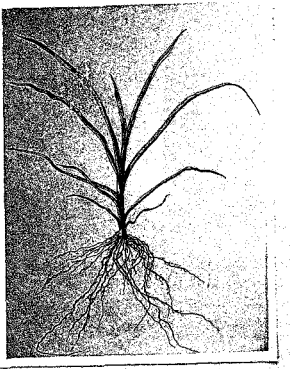


FIGURE 31: Nutgrass seedling. Advanced stage.

TABLE 20 : INFLUENCE OF SUBSTRATE AND EXPOSURE ON THE GERMINATION OF NUTGRASS SEED (% GERMINATION).

SUBSTRATE	DAYS AFTER SOWING	ACID TREATMENT											
		UNTREATED				5 MIN H_2SO_4				10 MIN. H_2SO_4			
		A	B	C	D	A	B	C	D	A	B	C	D
SOIL	10	8	0	0	0	26	0	0	2	3	0	0	3
	14	11	0	0	0	34	0	0	2	5	0	0	3
	27	21	0	0	1	39	0	0	3	18	0	1	5
	36	21	0	0	1	41	0	0	3	23	0	1	5
	54	23	0	1	1	41	0	0	4	24	0	1	7
	71	25	0	1	1	41	0	0	4	26	0	1	9
SAND	10	12	0	0	4	30	0	0	8	13	0	0	6
	14	14	0	0	7	50	0	0	12	26	0	0	10
	27	21	0	0	8	57	0	1	12	31	0	1	13
	36	28	0	0	8	59	0	1	12	34	0	1	14
	54	30	0	0	8	63	0	1	12	35	0	1	14
	71	32	0	0	8	64	0	1	12	36	0	1	15
FILTER PAPER	10	10	0	0	2	29	0	0	5	16	0	0	5
	14	16	0	1	5	57	0	4	6	24	0	2	8
	27	24	0	1	7	71	0	4	7	36	0	3	13
	36	29	0	1	7	75	0	4	7	42	0	3	13
	54	40	0	1	9	79	1	4	7	43	0	4	14
	71	48	0	1	9	79	1	4	7	43	0	4	14

TABLE 20 : (CON'T)

SUBSTRATE	DAYS AFTER SOWING	TREATMENT E UNTREATED
		E
FILTER PAPER	10	1.5
	14	6.0
	27	11.5
	36	21.0
	54	31
	71	36.5

Substrate:

Nutgrass seed gave constantly higher germination percentages on filter paper. This was valid for untreated and acid treated seed.

Acid treatment:

A brief acid treatment (5 minutes) generally doubled the germination for every substrate employed in the test. The 10-minute treatment, however, proved to be too drastic, reducing the germination irrespective of the substrate used.

Temperature-Light:

The best results were obtained when germinating the seed, irrespective of the acid treatment or substrate, on the Jacobsen apparatus (A), or in the germinating chamber (E). Alternating temperatures under dark conditions gave poor seed germination. It was therefore quite evident that nutgrass seed was very sensitive to light. Because nutgrass germinated best on filter paper on the Jacobsen apparatus, the subsequent germination studies were carried out by means of this method.

2. Substrate and Acid

To test the influence of room storage on the viability of nutgrass seed, a replicated test was conducted on seed which had been harvested during the late autumn of 1961 (April) and stored at room temperature for approximately 5 months. Each treatment consisted of 4 replications of 100 seeds.

Acid-treated and untreated seeds were sown on 3 substrates. Germination was recorded on three dates. The final percentage germination was analysed after the data had been converted to an angular transformation. The results are given in Appendix Table 15 and the mean (Angular transformation) in Table 21.

TABLE 21 : INFLUENCE OF ACID TREATMENT AND SUBSTRATE ON THE GERMINATION OF NUTGRASS SEED. MEAN PERCENTAGE GERMINATION.

SUBSTRATE	ACID-TREATED		UNTREATED	
	TRANSFORMED	ACTUAL	TRANSFORMED	ACTUAL
SOIL	53.28	64.1	21.08	13.1
SAND	50.40	59.1	19.97	12.0
FILTER PAPER	53.73	65.0	34.55	32.1
L.S.D for transformed data = 4.23				

Mean percent germination (Angular transformation) of

1) Substrates :- SOIL 37.18
SAND 35.19
FILTER 44.14

2) Acid treatment:-
TREATED 52.47
UNTREATED 25.20

A higher average germination was obtained on filter paper than on soil and sand with no difference between soil and sand substrates. Acid treatment doubled the average percent germination. The interaction between acid treatments and *substrates* was significant. The acid treated seed was not affected by the substrate, whereas untreated seed germinated much better on filter paper than in soil and sand.

The germination test lasted for 5 weeks only. These results indicate that the viability of the seed did not deteriorate with storage.

3. *Low Temperature Exposure.*

To establish the susceptibility of nutgrass seed to low temperature exposure, nutgrass seed harvested in the late autumn was inserted in a refrigerator which was maintained constantly at 5°C. *Samples consisting* of 100 seeds, were drawn and sown at fortnighly intervals as shown in Table 22 .

TABLE 22 : INFLUENCE OF LOW TEMPERATURE STORAGE ON THE GERMINATION OF NUTGRASS SEED. (PERCENTAGE GERMINATION).

TREATMENT EXPOSURE PERIOD	GERMINATION ON						
	15/8/64	24/8/64	11/9/64	28/9/64	12/10/64	31/10/64	21/11
A.2 weeks*	7	14	26	36	42	42	43
B.4 weeks		5	25	35	40	41	43
C.6 weeks			15	41	51	54	56
D. 8 weeks				21	30	49	54
E.10 weeks					23	48	54
F. 12 weeks						33	59

* Sown 1/8/64

The date in Table 22 illustrate the resistance of nutgrass seed to prolonged low temperature storage. In fact the results suggest that prolonged chilling periods (3 months) tend to improve the germination of the nutgrass seed.

4. Seed Maturation.

Nutgrass seed was harvested in the field at different stages. The harvesting dates and corresponding commencement date of the germination test are given in Table 23 . The first sample of seed was harvested as soon as seed was available. Each sample consisted of 4 x 100 seeds, acid-treated and untreated. The angular transformation was applied to the results before analysis. Percent germination of the seed is given in Appendix Table 16 and the means (angular transformation) after 40 days in Table 23.

TABLE 23 : INFLUENCE OF SEED ~~MATURITY~~ AGE ON THE GERMINATION OF NUTGRASS SEED. MEAN PERCENT GERMINATION AFTER 40 DAYS.

TREATMENT		UNTREATED		ACID TREATED	
SEED HARVESTED	SOWN	TRANSFORMED	ACTUAL	TRANSFORMED	ACTIAL
30/12/63 a	4/1/64	43.55	48	54.83	66.8
18/1/64 b	30/1/64	25.49	19	34.28	31.8
24/1/64 c	30/1/64	51.20	61	46.25	56.0
31/1/64 d	12/2/64	34.71	33	48.28	56.0
14/2/64 e	4/3/64	42.84	46	50.66	60
27/2/64 f	4/3/64	23.17	16	27.49	22

Mean Percent Germination (Angular Transformation)

1) Harvesting Dates: a) 30/12/63 - 49.19
b) 18/1/64 - 29.88
c) 24/1/64 - 49.72
d) 31/1/64 - 41.50
e) 14/2/64 - 46.75
f) 27/2/64 - 25.33
L.S.D Harvesting dates - 4.39

2) Acid treatment
a) Untreated - 36.82
b) Treated - 43.96

Acid treatment significantly increased germination from 36.8 to 44.0 (angular transformation). Harvesting dates had an irregular effect on germination, harvesting dates, a),c) and e) being highest and d) significantly lower than these three, and harvesting dates b) and f) again much lower. The interaction was significent, but this might not be of much use in view of the irregular effect of harvesting dates. This analysis was a somewhat approximate one on account of the unequal numbers of seed used in the different treatments. Samples harvested on 18/1/64 were immature, while seeds harvested on 27/2/64 were light and poorly developed.

Reduced viability of the late harvested seed was due, in part, to the sampling technique employed, and the growth habit of the plant. The same plant population was used for seed collection. Seed harvested after the 31/1/64 was obtained from umbels : with : collapsed floral bases, causing the umbel to invert and shed its seed. The remaining seed was generally of inferior quality and weight, thus giving reduced germination for the late harvested treatments.

5. Seed Storage

The viability of nutgrass seed which had been stored under laboratory conditions for periods ranging from 3 to 18 months was investigated. 4 x 100 seeds of each harvesting date were planted 29/6/65. The seed samples were harvested according to the schedule given below.

1. 30/12/63
2. 18/1/64
3. 24/1/64
4. 31/1/64
5. 14/2/64
6. 27/2/64
7. 13/3/64
8. 12/3/65

Sample 8 germinated poorly and was excluded from the analysis of variance. Percent germination for each date are given in Appendix Table 17. The final percent germination has been converted to an angular transformation. The means of the percent germination actual and angular transformation are given in Table 24. 4 x 100 seeds were planted 29/6/65.

TABLE 24 : INFLUENCE OF SEED MATURITY ON THE GERMINATION OF NUTGRASS SEED MEAN PERCENT GERMINATION AFTER 91 DAYS.

TREATMENT (HARVEST DATE)	PERCENT GERMINATION	
	TRANSFORMED	ACTUAL
1. 30/12/63	34.72	33
2. 18/1/64	55.70	68
3. 24/1/64	55.94	68
4. 31/1/64	56.30	69
5. 14/2/64	62.17	78
6. 27/2/64	49.78	58
7. 13/3/64	35.01	33
L.S.D. p = 0.05	5.41	

There were significant differences among treatments. Compared with the percent germination data in Table 23 the overall germination of laboratory stored seed was of a higher order than that of the original harvested material.

The results from the various germination studies confirmed the findings of Justice and Whitehead (1946). The viability of untreated nutgrass seed generally varied between 50 - 60 percent if kept under alternating temperatures 20° - 30°C, and given light at 30°C for a period of 8 hours. Contrary to the findings of Rahn et al. (1962) light was a critical factor.

In a normal season, viable nutgrass seed was available by the beginning of January at Bethal. Naturally, the production of viable seed would be dependent on the rainfall distribution pattern for any particular season. From a dispersal point of view it was, however, important to know that viable seed was freely available approximately 2½ months after emergence of the nutgrass. The dangers of drawing incorrect conclusions from a faulty sampling technique were also highlighted.

The fact that stored nutgrass seed did not appear to deteriorate with storage and that low temperature exposure had no detrimental effect on the seed, indicates that the seed of nutgrass could survive under adverse conditions.

For these reasons it was apparent that two additional investigations be undertaken. Firstly, to establish the seed producing potential of nutgrass and secondly the presence of seedlings under dryland conditions.

6. Seed production

To determine the seed production per plant, a number of examinations of fully mature nutgrass plants sampled at Bethal and Frankenwald were made several weeks after flowering.

Test (a).

Ten plants examined. Average number of spikes per umbel and the number of spikelets per spike were recorded 15/1/62. Seed production is based on an average number of 12 seeds per spikelet. Results are shown in Appendix Table 19 and the means in Table 25.

TABLE 25 : MEAN NUMBER OF SPIKES, SPIKELETS AND CALCULATED SEEDS PER NUTGRASS UMBEL , 10 PLANTS EXAMINED.

NUMBER OF SPIKES PER UMBEL	NUMBER OF SPIKELETS PER SPIKE	TOTAL SEEDS PER UMBEL
7.1	17.5	1495.2

Test (b)

Plant height at flowering, number of spikes and total number of spikelets per umbel were recorded for 20 plants on 26/1/65. Seed production is based on an average number of 12 seeds per spike. Results are shown in Appendix Table 19 and the means in Table 26.

TABLE 26 : MEAN HEIGHT, NUMBER OF SPIKES AND SPIKELETS AND CALCULATED SEEDS PER NUTGRASS UMBEL - 20 PLANTS EXAMINED.

HEIGHT OF PLANT IN CMS	NUMBER OF SPIKES PER UMBEL	NUMBER OF SPIKELETS PER UMBEL	TOTAL SEEDS PER UMBEL.
43	7.35	171.9	2062.2

Test (c)

Total number of seeds on one spike was counted. This amounted to 102. The Number of spikes per umbel from 25 nutgrass flowers were counted 30/12/63. Calculated seeds per umbel are given in Table 27.

TABLE 27 : MEAN NUMBER OF SPIKES AND CALCULATED SEEDS PER NUTGRASS UMBEL - 25 PLANTS EXAMINED.

NUMBER OF SPIKES PER UMBEL	TOTAL SEED PER UMBEL
7.6	775.2

Seed production per plant thus varied between 700 to 2,000 per umbel. Allowing for a 50 percent germination of the seed, 1 inflorescence could thus yield between 33F to 1,000 seedlings. These figures are in agreement with results obtained by Justice and Whitehead (1946) and Hill et al (1963 a).

B. SEEDLINGS.

Nutgrass seedlings are not commonly found in infested fields on the Highveld. Throughout the course of this study, attempts were made to locate nutgrass seedlings. Despite the liberal dissemination of seed from mid-January onwards by mature plants, and the high seed density deposit on the soil surface, inspections failed to reveal seedlings on the shaded soil surface. Seedlings were, however, found, but this proved to be more of an exception than the rule. The appearance of nutgrass seedlings was confined to the first half of the summer season. Seedlings were seldom found within a dense nutgrass colony, but mainly adjacent to the infested sites. The nutgrass seedling colonies were usually small and could be found growing in isolated local artificial depressions. Seedlings were located at Bethal, Gogies, Frankenwald and Bapefontein in severely infested fields. Nutgrass seedlings in the 4 - 5 leaf stage with small attached tubers, were found on the Turf Station at Frankenwald during February.

A fallow site at Frankenwald was disturbed during the later summer of 1964, ploughed during the 1964/65 summer and disced prior to planting of maize in mid-December. Nutgrass seedlings were observed 3 weeks after planting, (2 - 3 leaf stage), and the population density of the nutgrass seedling colony was established. The number of nutgrass seedlings per 7.5 inches diameter circular frame was 40.3.

From the germination studies it is clear that under favourable conditions, nutgrass seed is viable by the third week in January, and shatters readily by the end of January. Under a dense canopy of mature nutgrass (400 - 600 stems per 20" x 20" quadrat), soil moisture conditions are suitable for germination. Failure on the part of seeds to germinate under such conditions must be attributed to one or other factor, namely, either the exclusion of adequate light, or a possible inhibitory toxin excreted in the rhizosphere.

C. DISPERSAL AND DISSEMINATION

Having now demonstrated the viability of nutgrass seed in the laboratory and established the presence of seedlings in the field, it was logical to seek an efficient dispersal mechanism other than natural agents, which could be held responsible for the widespread nutgrass invasion of the Highveld. It is well-known that teff seed (Eragrostis tef Trott) has, ever since the promulgation of the seed purity laws in South Africa, been contaminated with nutgrass seed (Sallachop and Hattingh 1955). The present seed regulations (Government Gazette, Regulation Gazette 215, 26th July, 1963 (No.563)) states that "Seed shall not be sold if it contains weed seed in excess of 50 per ounce of teff seed". In the absence of supporting evidence regarding seed viability and seedling emergence, the Department of Agriculture has, in recent years, granted extraordinary concessions to teff seed producers, and permitted the sale of teff seed with contamination levels of up to 500 weed seeds per 1 oz of teff seed.

In an effort to elucidate the problem of seed dispersal, three aspects of the problem were investigated.

1. Pollution of Teff Seed.

A total of 207 teff seed samples which had been submitted to the Department of Agriculture's Seed Testing Station at Pretoria, for purity and viability tests, during the years 1963, 1964 and 1965, were examined. Teff seed impurities were converted to a uniform basis and classified into various groups in respect of the number of nutgrass seeds per 28.3 gms of teff seed. The classes selected were 0, 0-10, 10-20, 20-30 nutgrass seeds, etc., The results for each year over the three-year period appear in Appendix Table 20. The data has been summarised in Table 28 . The analysis is only concerned with nutgrass contamination. The total number of foreign weeds per teff seed sample has been excluded. Also refer to Figure 32.

TABLE 28 : NUMBER OF TEFF SEED SAMPLES CONTAINING NUTGRASS SEEDS.

CONTAMINATED WITH	YEAR			TOTAL	
	1963	1964	1965	NUMBER	PERCENT
1. Less than 50 nutgrass seeds per 28.3 grams teff	37	25	58	120	58%
2. More than 50 nutgrass seeds per 28.3 grams of teff	26	10	51	87	42%

Referring to the data presented in Figure 32 and Table 28 it will be noted that over the past three years, 42% of the teff samples which have been submitted to the Department of Agriculture for approval, contained more than the prescribed 50 nutgrass seeds per 28.3 grams of teff sample. There also appears to be an inter-seasonal variation; the percentage of heavily contaminated seed being particularly high during the 1965 season. Another salient feature of the analysis which is not reflected in the above two tables, was the fact that most of the heavily infested teff seed samples originated mainly from specific areas. The latter included Standerton, Platrand, Holmedene, Val, Perdekop, Endicott, Bethal, Reitz, Fickeburg Vrede, and Pietermaritzburg.

2. Areas of Teff Production in South Africa.

From the aforegoing analysis, it was evident that teff seed production was mainly concentrated in specific areas. From the latest agricultural statistics supplied by the Department of Agriculture (Agricultural Census No.34 1959-60 for the Republic of South Africa) it was possible to extract the principal teff growing and teff seed producing magisterial districts. The latter have been arranged in descending order according to area sown annually to teff (Table 29). The data for the entire Republic is summerized in Table 30 .

FIGURE 32. NUMBER OF TEST SEED SAMPLES CONTAMINATED WITH NUTGRASS SEED.
BASED ON 207 TEST SEED SAMPLES SUBMITTED FOR ANALYSIS DURING THE PERIOD 1963 – 65.

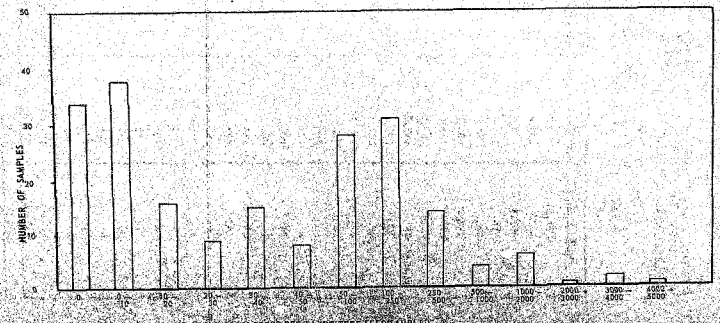


TABLE 29 : AREA SOWN AND THE NUMBER OF BAGS OF TEFF SEED PRODUCED IN THE MAJOR TEFF SEED GROWING DISTRICTS IN THE REPUBLIC OF SOUTH AFRICA.

Area = Fodder and seed in morgen;
Bags in 200 lb nett weight;
Based on Agricultural Census - 1959/60.

TRANSVAAL	AREA SOWN a)	NUMBER OF BAGS b)
1. STANDERTON	15,529	13,488
2. BETHAL	6,656	756
3. HEIDELBERG	5,829	1,087
4. VOLKSRUST	3,513	714
5. ERMELO	3,346	468
6. MIDDELBURG	3,244	197
7. NIGEL	3,141	508
8. DELMAS	2,217	27
9. WITBANK	1,525	49
10. VEREENIGING	1,740	88
11. BRONKHORSTSPRUIT	1,455	5
12. AMERSFOORT	1,402	259
13. CAROLINA	650	11
14. KEMPTON PARK	635	2
15. GERMISTON	579	4
16. BRAKPAN	529	31
17. POTCHEFSTROOM	500	2
18. VAN DER BIJL PARK	411	18
19. BELFAST	405	106
20. BENONI	396	-
21. WAKKERSTROOM	310	8
22. PRETORIA	299	-
23. RANDFONTEIN	293	-
24. SPRINGS	292	-
25. ROODEPOORT	234	34
26. VENTERSDORP	232	6
27. KRUGERSDORP	228	-
28. RUSTENBURG	228	6
TOTAL FOR 28 DISTRICTS	56,121	17,897
TOTAL FOR TRANSVAAL	57,122	17,908
% of SOUTH AFRICA	46.4%	60.84%

a)= 12.8% of S.A b)= 45.9% of S.A.

TABLE 29 . (CON'T).

CAPE PROVINCE	AREA SOWN	NUMBER OF BAGS
1. MOUNT CURRIE	4,529	76
2. MATATIELE	1,797	132
3. ELLIOT	863	27
4. VAN RHYNSDORP	810	-
5. HUMANSDORP	417	2
6. MACLEAR	395	-
TOTAL FOR 6 DISTRICTS	8,811	237
TOTAL FOR CAPE PROVINCE	9,383	237

ORANGE FREE STATE	AREA SOWN	NUMBER OF BAGS
1. VREDE	c) 10,963	d) 2,270
2. HARRISMITH	10,915	e) 3,523
3. BETHLEHEM	6,366	1,953
4. FRANKFORT	4,359	135
5. REITZ	3,764	343
6. LINDLEY	2,821	225
7. HEILBRON	1,847	114
8. SENEKAL	1,591	510
9. THABA NCHU	1,224	151
10. FICKSBURG	980	667
11. LADYBRAND	924	360
12. FOURIESBURG	836	657
13. CLOCOLAN	702	95
14. KROOMSTAD	584	-
15. WINBURG	477	90
16. MARQUARD	357	25
17. BLOEMFONTEIN	268	-
18. SASOLBURG	203	8
TOTAL FOR 18 DISTRICTS	49,181	11,126
TOTAL FOR O.F.S	50,376	11,165
% of O.F.S	97.6%	99.6%
% of SOUTH AFRICA	40.6%	38%

c) = 9.86% of S.A d) = 17.7% of S.A

e) = 9.02% of S.A f) = 11.98% of S.A.

TABLE 29 : (CON'T)

NATAL	AREA SOWN	NUMBER OF BAGS
1. UNDERBERG	868	1
2. ESTCOURT	611	3
3. KLIPRIVER	581	-
4. BERGVILLE	523	-
5. NEWCASTLE	390	-
6. UTRECHT	374	72
7. LIONS RIVER	206	-
TOTAL FOR 7 DISTRICTS	3553	76
TOTAL FOR NATAL	4189	103

TABLE 30 :
PRODUCTION OF TEFF IN THE REPUBLIC OF SOUTH AFRICA 1959/60.

PRODUCTION	S.A	CAPE	NATAL	TRANSVAAL	O.F.S
		(7.76%)	(3.46%)	(47.2%)	(41.6%)
Area sown - morgen	121,070	9,383	4,189	57,122	50,376
Hay reaped - tons	245,389	23,839	11,083	126,213	84,254
Hay marketed- tons	19,142	105	108	14,210	4,721
Seed production, 200 lbs	29,413	237	103	17,908	11,165
		(0.81%)	(0.36%)	(60.88%)	(37.96%)

The analysis is concerned solely with those magisterial districts in which more than 200 bags (200 lbs) of teff seed is produced or more than 200 morgen of teff is sown annually.

The Transvaal and Orange Free State rank as the principal teff producing areas of South Africa, the area sown being 47.2% and 41.6% respectively. Of interest is the fact that of the total area sown in South Africa to teff, 41% of the plantings are confined to 5 magisterial districts within the Highveld Region, namely, Standerton, Vrede, Harrismith, Bethel and Bethlehem. Within each Province over 90% of the area sown to teff is restricted to the districts listed in Table 29 , most of which fall within the limits of the Highveld Region. In the Transvaal, teff assumes a minor role in the western sections of the province, suggesting a relationship between teff production and rainfall pattern . In fact the production of teff throughout South Africa appears to be closely allied to total rainfall and distribution.

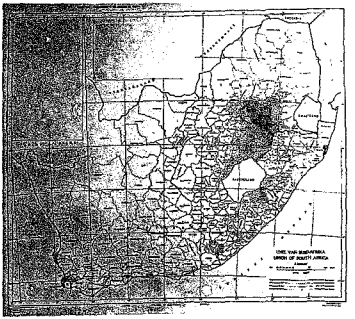


FIGURE 33: Teff producing areas in the Republic of South Africa. Each unit represents 100 morgen of teff.

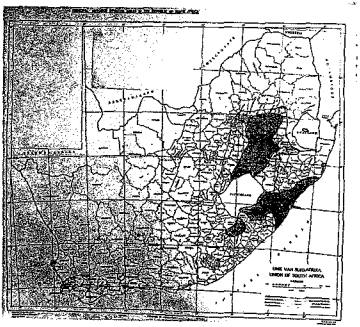
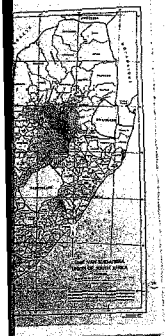


FIGURE 34: Principal nutgrass infested areas in the Republic of South Africa. Dark and light shaded areas represent heavily and moderately infested areas respectively.



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With regard to teff seed, the area of production is far more restricted, the Transvaal and Orange Free State accounting for 96% of the total seed produced. Standerton features as the primary producer (46%) followed by Wrede (17.7%) and Harrismith (12.0%), with Bethlehem and Middelburg showing some prominence. All the five magisterial districts fall within the Highveld Region.

3. Distribution of Nutgrass-infested and Teff-producing Areas in South Africa.

From the above analysis, it was possible to compile two distribution maps illustrating areas sown to teff, and areas producing teff seed, comparing these maps with the nutgrass-infested areas of South Africa (Figures 33, 34 and 35 respectively). By superimposing the nutgrass-infested areas over those of the respective teff growing areas, it is possible to draw sound conclusions relative to the dispersal mechanism of nutgrass.

While the accompanying map shows nutgrass as generally scattered throughout the area, the records on which this distribution map is based, are confined primarily to cultivated dryland arable fields. The map is not intended to convey the impression that all crops in this area are generally infested, but rather that C. esculentus can and does occur as a principal weed problem. With the exception of the sugar cane producing areas in Natal (Anon.1965 b), the infestations reported for the various field cropping areas in South Africa are based on observations of the author and information obtained from various technical officers attached to Government Departments.

4. Pathways of Introduction and Dispersal.

From the abovementioned statistics, experimental evidence and field observations, it was also possible to compile a suggested pathway for the introduction and dispersal of nutgrass into non-infested and infested arable fields (Figure 36). The scheme is based on the assumption that the seed of nutgrass passes through the digestive tract of the animal without having its viability impaired.

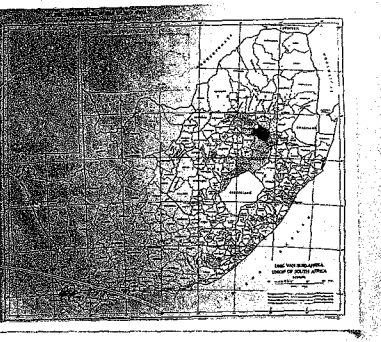


FIGURE 35: Teff seed producing areas in the Republic of South Africa. Each unit represents 50 bags of teff seed.

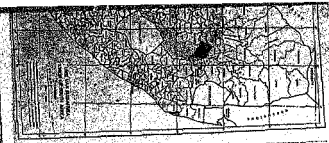
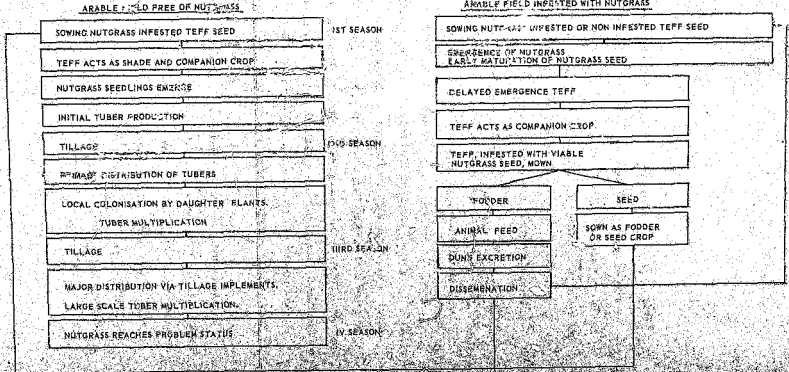


FIGURE 36. SUGGESTED PATHWAYS FOR THE INTRODUCTION AND DISPERSAL OF CYPERUS ESCULENTUS IN ARABLE FIELDS



CHAPTER IX
TUBER AND PLANT STUDIES

A. TUBER STUDIES

The principal method of nutgrass dispersal in an arable field is by means of tubers. It is essential that every effort be made to prevent the development of these organs. Experiments were carried out to obtain information regarding the distribution of tubers in the soil, factors influencing the sprouting of the tubers and the effect of different treatments on the viability and survival of the tubers.

1. Distribution of Tubers in the Soil Profile.

From a control point of view, particularly where tillage methods are employed, it is essential to establish the infestation level of nutgrass tubers in the soil profile.

The nutgrass population in each soil layer was therefore established by screening out and counting the firm and depleted tubers from 20" x 20" quadrats. Sample blocks were excavated to a depth of 9" from two locations, both of which are representative of heavily infested, poorly drained sites. The samples were removed and washed through a 2 mm screen. The tubers were then classified as firm or depleted of reserves. Tubers which could be crushed with moderate pressure were classified as depleted.

In the first experiment (Sapsfontain), the soil samples were removed during the winter months following a heavy rainfall. The tubers per soil layer were recorded. The second series of tubers were removed during mid-January (Bethel). In this case the entire soil block was excavated and no attempt was made to establish positional distribution. Results of tuber numbers are given in Appendix Table 2I and the means in Tables 31 and 32.

TABLE 31 : DISTRIBUTION OF NUTGRASS TUBERS IN THE SOIL PROFILE AT BAPSFONTEIN. MEANS OF 6 FRAMES 20"x20".

SOIL DEPTH IN INCHES	FIRM TUBERS	DEPLETED TUBERS	PERCENTAGE DISTRIBUTION
0 - 3"	815	128	61,84%
3 - 6"	316	70	25,31%
6 - 9"	138	57	12,85%
Total 0 - 9"	1269	255	

TABLE 32 : DISTRIBUTION OF NUTGRASS TUBERS IN THE TOP 9" SOIL LAYER AT BETHAL. MEANS OF 3 FRAMES 20"x20"

Number of nutgrass plants	- 534
Number of firm tubers	- 643

The results in Tables 31 and 32 reflect the distribution and concentration of nutgrass tubers on two heavily infested sites. Approximately 87% of the tubers are concentrated in the top 6" layer. The ratio of nutgrass tubers to nutgrass plants on heavily infested sites was almost of the order 1 : 1. The number of firm tubers found below the 9" layer was negligible and it may therefore be assumed that the principal infestation is confined to the 0 - 9" horizon. From the results it would appear that where tillage control measures are applied, disturbance below the 9" layer would not enhance the efficacy of these treatments.

2. Tuber Population per Plant.

To gain further information with regard to the tuber population density in the soil, the number of nutgrass tubers per plant was established.

a) A total of 27 individual plants were removed at random from a moderately infested arable field towards the termination of the growing season. The plants were carefully removed and the tuber population per plant recorded. Results are given in Table 33 .

TABLE 33 : NUMBER OF TUBERS PER NUTGRASS PLANT (27 PLANTS)

NUMBER OF TUBERS PER PLANT	NUMBER OF PLANTS
2	3
3	6
4	5
5	4
6	1
7	4
8	1
15	1
16	1
19	1

The average number of tubers per plant appears to fall principally in the class of 2 - 7 with the norm around 3 - 4.

b) Twenty plants were removed at the end of summer from a moderately infested site at Frankenwald and the number of tubers per plant recorded. No distinction was made between firm and depleted tubers. There were approximately 4.5 tubers per nutgrass plant.

Tuber number per plant was was apparently dependant on intra specise competition. In the earlier plant dispersal studies, one sprouted tuber could produce 101 tubers within 3 months resulting in the formation of a new nutgrass colony. Where nutgrass infestation levels were very high, i.e. 500 - 600 plants per 20" x 20" frame the number of tubers per plant dropped very sharply.

A population level of 500 tubers per 20" x 20" frame is equivalent to a population of 7,840,800 tubers per acre. By comparison, Tumbleson and Kommedahl (1960), recorded from 13 million plants and 38 million tubers per acre in various soils. The tuber populations given in Table 31 however, are equivalent to a population of 20 million firm tubers and a total of 23.5 million firm and depleted tubers.

3. Influence of placement on Tuber Emergence.

The depth from which tubers sprout is of importance in a control programme. Since the tubers are mainly confined to the top 9" layers, experiments were conducted to ascertain whether the tubers emerge throughout this depth.

Author Fisher Jonah
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