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A morphological study of the subterranean part of the plant was made. I Diagrammatic drawings (Figs. I-V) II General III Competition experiments

found, to those reported elsewhere in the tropics, but it was decided to refer to the swelling at the junction of the leaves and stem as a stipe rather than use the misleading term 'basal bulb'. A life history from a single tuber was studied and the importance of local spread by means of subterranean rhizomes and tubers is stressed. The most encouraging methods of controlling underground spread by cultural and herbicidal methods are summarized as well as the difficulties involved in attempting such control. Tuber distribution in the soil at the College compared favourably with that found elsewhere in the tropics, the majority occurring in the top six inches, and only rarely below nine inches.

Under favourable growing conditions flowering took place in one month from a previously dormant tuber. The rate of seed production was low, being approximately one seed per inflorescence. Freshly collected seed could not be induced to germinate but viability of 50-60% was demonstrated by use of the Tetrazolium salt test. Efforts to gain an assessment of pollen viability were unsuccessful and such work must be repeated.

The competitive effect of the weed was tested against rice and millet plants in a pot experiment. The radish appeared to withstand the competition better, but for both crops considerable reduction in plant yield resulted with increasing nut-grass population. More fertile soil resulted in more rapid production of tubers though tuber weight and size were always relatively constant.

Possible associations of nut-grass with other plants (*Utricularia* spp. and *Utricularia* spp.) are reported, but such associations will require further study. Other observations made for future work are also given.

SYNOPSIS

The purpose in making a detailed study of Cyperus rotundus, nut-grass, was to ascertain its habit under Trinidad conditions, and to compare such findings with those already reported from other parts of the Tropics. Such work, it was hoped, would further clarify the problem which nut-grass presents as a pan-tropical weed.

A morphological study of the weed is reported with details of the subterranean parts and also of the inflorescence. No real differences were found, to those reported elsewhere in the tropics, but it was decided to refer to the swelling at the junction of the leaves and rhizome as cormlike rather than use the misleading term 'basal bulb'. A life history from a single tuber was studied and the importance of local spread by means of underground rhizomes and tubers is stressed. The most encouraging methods of controlling underground spread by cultural and herbicidal methods are summarised as well as the difficulties involved in attempting such control. Tuber distribution in the soil at the College compared favourably with that found elsewhere in the tropics, the majority occurring in the top six inches, and only rarely below nine inches.

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Possible associations of nut-grass with other plants (Cynodon dactylon and Cleome spp.) are reported, but such ecological work needs further study. Other recommendations for future work are also given.

Section I

INTRODUCTION

In temperate regions much investigation has been carried out on crop weeds and their control. Equivalent studies in the tropics have tended to lag behind and only during comparatively recent years, particularly since the advent of hormonal herbicides, has a considerable volume of literature appeared concerning tropical weed control. Although weed problems appear basically the same in the tropics to those elsewhere in the world, there are the specific cases which resist the usual control measures. In making a detailed study of a plant it was decided to take such a weed, and by making detailed observations in association with the published literature, to build up a better understanding of the weed under Trinidad conditions.

Cyperus rotundus L., commonly known as Nut-Grass, a pan-tropical weed, was selected for study. It was realised that with the restricted amount of time available there would be a limit to the amount of detailed investigation that could be made. However, the principal objective was to gain as thorough knowledge of the plant as possible so as to make recommendations for further study.

Initially it was decided to make a more intense study of the flowering and seeding habit of the plant, but factors of general morphology and habit were later included. It was also found possible to make some simple observations into the competitive properties of the plant without detracting from the main studies.

REVIEW OF LITERATURE

To give a concise review of literature published concerning the control of nut-grass is beyond the scope of this report. A.J. Boyd (1921) states: "To find a method of eradication of nut-grass has been the theme of hundreds of articles and as many papers—but all in vain." Since his time advances in agricultural practices, and particularly the use of the different types of weedkiller, have led to a considerable volume of literature being

published on the subject of nut-grass control. Very little of this, however, presents economic methods of eradication, the majority reporting failure and the difficulty of exterminating the weed from arable land. Sparrow (1958) gives an up-to-date account of the recommended methods of control and also a list of the relevant literature on the subject.

The first really comprehensive study of Cyperus rotundus, or nut-grass as it will now be referred to, was carried out by Ranade and Burns (1925) in India. Their aim was to fully understand the weed's life cycle, to find its weakest point, and then to attack it at that point to gain control. They fully appreciated that such a method of attack was slow, but felt at the conclusion of their work that it was justified. Their very full study of the plant's life history and its general morphology has served as a basis for much subsequent work.

Andrews (1940, 1945, 1946) studied the nut-grass weed over several years under the conditions found in the Sudan Gezira. Climatic conditions were obviously different to those found by the Indian workers; nevertheless the problem presented by the weed was basically the same. Andrews agreed in the majority of his findings with Ranade and Burns and recommended similar cultural practices of deep ploughing in the dry season to kill the weed. Following the work done by Andrews, herbicides became more generally used and rapid development resulted as to their mode of action, potency and selectivity. The resistance of nut-grass to these more advanced chemicals caused a group of workers (Muzik, Cruzado and Loustalot, 1948-51) in Puerto Rico to make a detailed morphological and physiological examination of the plant. They were particularly concerned with the plant's ability to survive applications of hormonal weedkillers and concluded (Muzik and Cruzado, 1950) that such herbicides, at the time of their work, were translocated too slowly throughout the plant system producing no more than a check to growth.

The consideration of the above three sets of work has largely governed the course of observations in this report. A brief mention needs to be made of other workers who have interested themselves in particular aspects of the nut-grass problem.

Smith and Fick (1937), in America, worked on the underground habit of nut-grass and, in particular, the factors associated with apical dominance.

Their work concerning the effects of extremes of temperature and drying on tuber viability encouraged Smith and Mayton (1938) to try a scheduled system of tillage on arable land to exhaust the nut-grass weed. This they found could command a fair degree of control, especially if summer fallowing was associated with the use of winter cover crops. Recent work (U.S.D.A., 1958) has further substantiated the importance of cover crops in suppressing nut-grass growth when aiming at control by tillage methods.

The response of nut-grass to moisture as an important factor of field eradication has been studied by several workers. Davies (1942) aimed at determining levels at which the plant showed differential response to soil moisture under greenhouse conditions. Du Preez (1944), in a general study, considers the degree of desiccation that nut-grass tubers can withstand before death and gives a figure of 15% moisture as the average, below which shooting capacity is lost.

That the nut-grass problem still exists is borne out by Cox (1959) in an article on "Weed Control in West Indian Sugar Cane". The publication of studies made concerning the metabolism of nut-grass by Palmer and Porter (1959) shows a new departure into the study of the plant. They worked on details of enzyme activity within the plant and also the effect of different levels of carbon dioxide and oxygen on metabolic reactions and shoot production. It can be hoped that such work may suggest new methods of attack. Until then the continual appearance of numerous reports concerning trials of new ideas, new techniques and new herbicides aimed at solving the nut-grass problem can be expected.

by one or more involucreal bracts. Perianth reduced to scales, bristles or hairs, often absent. Stamens usually three, hypogynous. Anthers basifixed. Ovary superior, unilocular with a solitary ovule. Style two-, three-branched. Fruit an achene, indehiscent. Seed erect, small embryo, abundant oily endosperm.

Characters such as the unjointed, triangular and solid stem, leaves in three ranks having closed sheaths and no ligule, and the fruit being an achene, which clearly distinguish members of the Cyperaceae (Sedges) from the Poaceae (Grasses) are all clearly exhibited by nut-grass (*Cyperus rotundus*). The plant also conforms to being a perennial, consisting of an underground system of rhizomes which produce tubers at intervals. These

Section II

tubers produce an extensive rhizome system and also give rise to the aerial part of the plant. For the sake of clarity in reporting the morphology of the plant division will.

DESCRIPTION OF THE PLANT components.

(a) Systematic position

Cyperus rotundus L., occurs in a genus composed of about 400 spp. The genus is one of seventy five that make up the family Cyperaceae in the Monocotyledons.

The detailed systematic position of the family varies according to the major systematists. That set out by Engler and Prantl, where the family Cyperaceae along with the Gramineae form the natural order Glumiflorae, is used by most workers. Hutchinson, whose system of classification is becoming widely used, places the family under its own order Cyperales which with the Graminales and Juncales form the division Glumiflorae of the sub-phyllum Monocotyledons. His splitting of the family into seven tribes, of which the tribe Cyperaceae contains the genus Cyperus, is simpler than that proposed by earlier taxonomists.

(b) General morphology

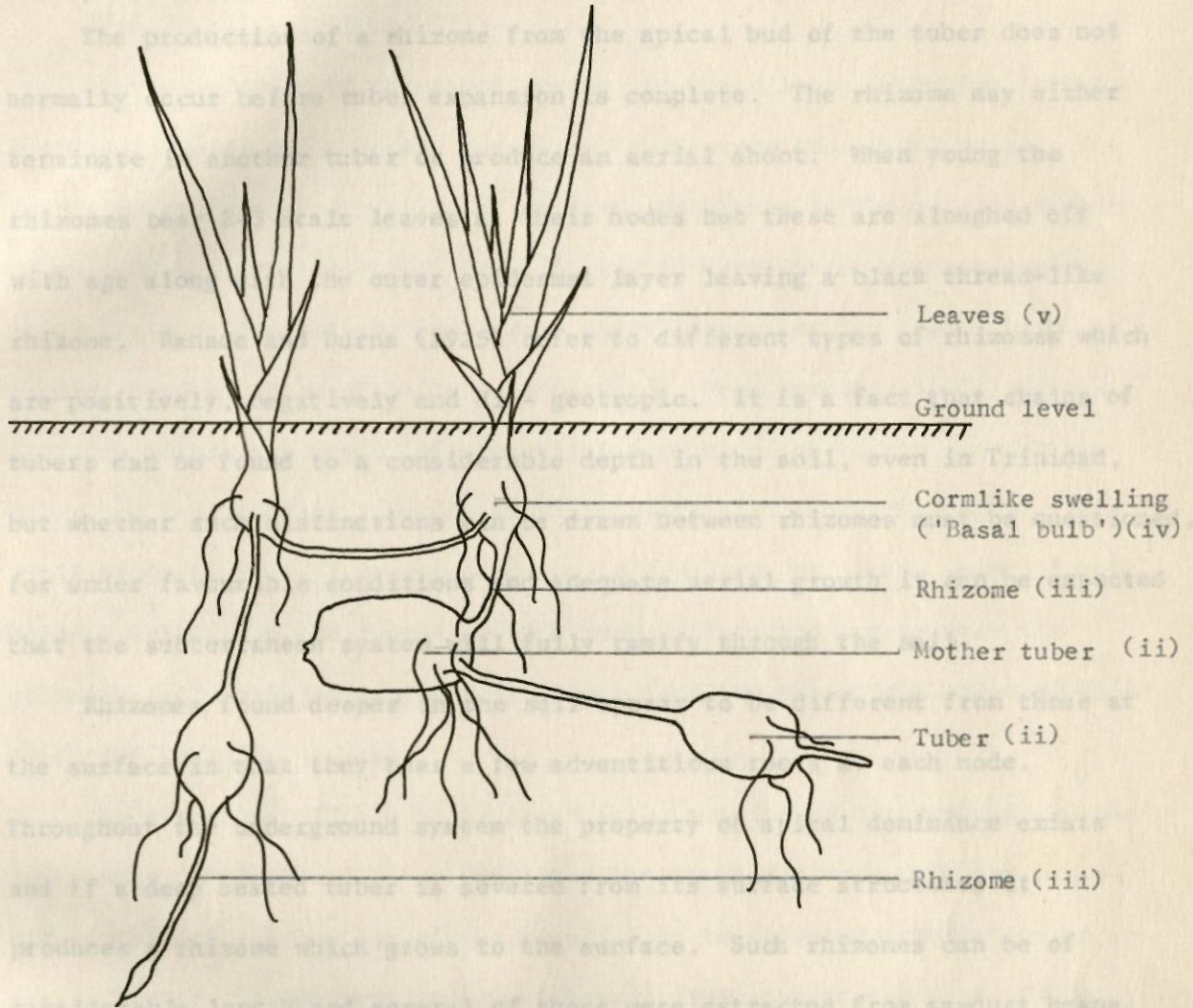
(i) Main family characters

Usually perennial grasslike herbs. Stems solid, not jointed, frequently triangular in cross section. Leaves with a grasslike blade, three ranked and with a closed sheath. Flowers small, bisexual or unisexual, generally monoecious, arranged in spikelets. The flowers are solitary within a glume and are either arranged in two ranks or spirally. Inflorescence subtended by one or more involucre bracts. Perianth reduced to scales, bristles or hairs, often absent. Stamens usually three, hypogynous. Anthers basifixed. Ovary superior, unilocular with a solitary ovule. Style two-, three-branched. Fruit an achene, indehiscent. Seed erect, small embryo, abundant mealy endosperm.

Characters such as the unjointed, triangular and solid stem, leaves in three ranks having closed sheaths and no ligule, and the fruit being an achene, which clearly distinguish members of the Cyperaceae (Sedges) from the Gramineae (Grasses) are all clearly exhibited by nut-grass (Cyperus rotundus). The plant also conforms to being a perennial, consisting of an underground system of rhizomes which produce tubers at intervals. These

tubers produce an extensive root system and also give rise to the aerial vegetative shoot, and from these buds rhizomes are produced. There is a part of the plant. For the sake of clarity in reporting the morphology of the plant division will be made into its various components.

(iii) Rhizomes



Components of the nut-grass plant

(ii) Tubers (see Figs. I & II)

When mature tubers vary from about $\frac{1}{2}$ -1" in length and $\frac{1}{4}$ - $\frac{1}{2}$ " in diameter. Initially they are almost spherical, white-skinned and succulent. With age they become almost black-surfaced and hard, a result of the tissues being packed with starch. Papery brown scale leaves persist on the tubers until a considerable age and if they are lost leave characteristic leaf scars on the tuber skin. Buds on the tuber are mainly concentrated at the

morphological apex, and from these buds rhizomes are produced. There is a close resemblance in structure between rhizome and tuber (Muzik, 1950), the latter containing more parenchyma cells and a more complex network of vascular tissues. The tubers are essentially food storage organs.

(iii) Rhizomes

The production of a rhizome from the apical bud of the tuber does not normally occur before tuber expansion is complete. The rhizome may either terminate in another tuber or produce an aerial shoot. When young the rhizomes bear 2-3 scale leaves at their nodes but these are sloughed off with age along with the outer epidermal layer leaving a black thread-like rhizome. Ranade and Burns (1925) refer to different types of rhizomes which are positively, negatively and dia-geotropic. It is a fact that chains of tubers can be found to a considerable depth in the soil, even in Trinidad, but whether such distinctions can be drawn between rhizomes must be questioned, for under favourable conditions and adequate aerial growth it can be expected that the subterranean system will fully ramify through the soil.

Rhizomes found deeper in the soil appear to be different from those at the surface in that they bear a few adventitious roots at each node. Throughout the underground system the property of apical dominance exists and if a deep seated tuber is severed from its surface structures it produces a rhizome which grows to the surface. Such rhizomes can be of considerable length and several of these were extracted from sawdust heaps. The sawdust had been dumped onto nut-grass infested land thereby artificially producing the conditions of deep-seated tubers unattached to aerial growth. On examination it was found that besides bearing the occasional root at the nodes, several bud swellings were also produced which were usually internodal (see Fig.IIID). Such buds appeared to remain inactive unless the apical bud of the growing rhizome died before reaching the soil surface whereupon they would develop and continue upward growth. When such a bud did develop, besides the production of a new rhizome, a flush of adventitious roots also appeared. This form of development resulted in the surface-seeking rhizomes becoming considerably branched. No equivalent bud formation has been found on rhizomes connecting tubers. Ranade and Burns (1925)

mention the formation of intercalary tubers on rhizomes from deeply buried tubers but none were found when the observations described above were made.

The rhizome being an underground stem has an equivalent structure (Muzik, 1950) and is mainly an organ for the spread and translocation of food material.

(iv) 'Basal bulb' (Fig. III)

At the junction of the shoot leaves and the rhizome producing them a swelling results which Ranada and Burns (1925) term the 'basal bulb'. The formation of this structure is of extreme importance to the success of the plant because it is essential for full aerial development and subsequent tuber and root production. Du Preeze (1944) describes the 'basal bulb' as forming between 2" to 4" below soil surface. More commonly in Trinidad it is found within the top 2" of the soil and quite often occurs immediately below the soil surface. Muzik (1950) suggests that the formation of the swelling prior to full leaf production is dependent on light, which if not present results in the formation of a tuber. It would appear that the stimulus for formation of the organ comes from the tip of the rhizome behind which the swelling occurs.

The structure of this basal organ forms a point of disagreement in the literature. Ranade and Burns (1925), although they give a detailed description of the anatomy of the plant, fail to give any information as to its structure. Subsequent workers (Andrews, 1940; Smith and Fick, 1937; etc.) describe it as a tuberous enlargement, whilst Muzik (1950) regards it as a bulb comparing it to the structure of an onion. Under careful study it appears to be a definite enlargement of the rhizome, the lower region producing scale leaves and roots, and the upper region giving rise to leaves. It also seems that the swelling can develop into a more mature type of tuber. Besides aerial growth this basal structure also produces rhizomes which subsequently produce strings of tubers. The naming of this swollen rhizome tip as a 'basal bulb' is distinctly misleading as it is in no way a bulb structure (Fig. III A & B) but much resembles a corm and it will further be referred to as a corm-like structure pending further study to decide its actual naming.

(v) Leaves

It is the surface layer of tubers that normally give rise to the aerial growth. The leaves conform to those of the family having grasslike blades about 1/16-1/4" wide and varying in length according to habit. Normally under field conditions in full sunlight this varies between 2-8" when mature. Each leaf carries a distinct midrib and is very dark green in colour.

(vi) Inflorescence (Fig. IV)

From the basal tuft of leaves arises the flowering scape. This flower stalk is leafless, solid and triangular in cross section. The inflorescence is essentially a compound spike, resembling an umbel, with 4-6 spikes, all except the terminal one being subtended by an involucre bract. The lower bracts tend to remain green and leaflike until well after flowering. Most of the spikes are longer than the bracts which subtend them (the outer ones not always so) and on a broadly winged rachilla bear from 2 to 9 spikelets which are linear or slightly curved. Spikelets are 6 to 18(24)-flowered, the flowers being typical of the Cyperaceae. The basal glumes on the spikelet are commonly sterile and of a more delicate nature than the fertile glumes which are boat-shaped and brown in colour with a prominent green keel. This produces a brown compressed spikelet with a green lateral stripe useful in identification. The solitary flower of 3 stamens, a single ovary bearing a style with 3 branches, and no perianth, is carried within the glume. The trigonous achene that is produced is dark brown, very thick coated and about half the length of the glume.

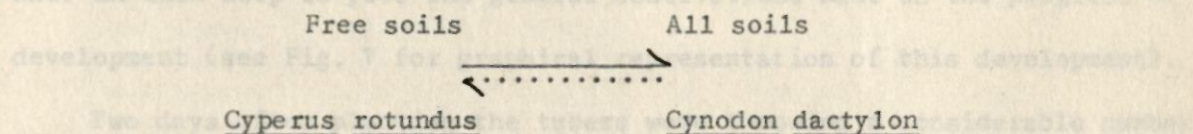
(c) Ecology

Cyperus rotundus is a widespread weed of the tropics and subtropics. In dry areas such as the Sudan Gezira (Andrews, 1945) it is mainly a weed of irrigation channels and irrigated fields. When there is a less intense dry season the plant is more widespread and this is the case in Trinidad. It is solely a weed of cultivated land, being unable to stand up to competition from other vegetation, and grows best in full sun, failing to thrive under shady conditions. Although its water requirements are high it will not grow in inundated land. Because of its subterranean tubers its drought resisting

powers are high, though the growth rate of the aerial parts of the plant is reduced to a minimum during dry periods. The ability of the plant to grow in seemingly unsuitable places, such as cracks in pavements, demonstrates its audacious and persistent character.

Roche Couste (1958) presents an ecological classification of the major weeds in Mauritius. Using Thornwaite's classification of climate zones he discusses weeds in relation to: (a) subhumid zone, (b) humid zone, (c) superhumid zone, (d) weeds common to all zones. He suggests that Cyperus rotundus only attains full development on free soils in the humid zone though he also notes it under weeds common to all zones, its abundance varying according to the annual precipitation. Roche Couste also presents a weed succession of Cyperus rotundus with Cynodon dactylon as follows:

(Cultivated land indicated by dotted line, abandoned land by plain line)



Although the climatic conditions in Trinidad are not identical with those in Mauritius, it would be interesting to know whether any such associations occur in Trinidad. In data made available from a weed succession study (Haggarty, 1960) on cultivated land with a high percentage cover of Cyperus rotundus, when abandoned, Cynodon dactylon did increase in importance whilst Cyperus rotundus decreased. However it did not become the most important weed in respect of ground cover, over the limited recording period of five months, half of which occurred in the dry season. In the same succession a positive association was found between Cyperus rotundus and Cleome spp. (C. spinosus and C. cristatus) (Grime, 1960). Both were reported as being underdispersed, the underdispersal being coincident.

Other species of the Cyperaceae which have occurred on nut-grass infested land, and which might possibly be confused with Cyperus rotundus in the vegetative phase, are:

Kyllinga odorata (Vahl)
Kyllinga brevifolia (Rottb.)
Kyllinga monocephala (Rottb.)
Torulinium ferax (L.C. Rich.)
Cyperus sphacelatus (Rottb.)

The latter may be particularly confusing, even in the flowering stage, but can be distinguished by having green spikelets, producing abundant seed, the glumes being shed when ripe, and having an adventitious root system. None of the above species produce underground tubers.

(d) Life history

At the commencement of the investigations it was hoped to follow the life history from seed to flowering. From about 1,000 seed collected and put to germinate no seedlings were produced even after prolonged attempts (see Section IIIb). However the life history from a tuber was examined. Dormant tubers obtained by breaking up several tuber systems were sown about half an inch deep in pots and general observations made on the progress of development (see Fig. V for graphical representation of this development).

Two days after planting the tubers were throwing a considerable number of new roots and a further two days later the first shoots broke the surface. After one week all the tubers that had been planted had aerial shoots. In the majority of tubers disturbed whilst making observations the rhizome giving rise to the first aerial shoot was very short. The cormlike swelling was first noticed on some shoots on the 6th day after planting and at the 10th day all shoots carried this basal swelling. It was estimated that this cormlike formation occurs during the production of the third and fifth leaf—though swelling continues whilst subsequent leaves are produced. New rhizomes produced from the tubers were seen after ten days and these resulted in the formation of new tubers by the third to fourth week. This compares favourably with Smith and Fick's (1937) figure of 21 days from planting. Subsequent tuber formation occurred at about fortnightly intervals and this is supported by figures of tuber production in the two competition experiments (Section IV). No assessment of rhizome production from the cormlike swelling was made, long-term observations would determine this.

In an effort to follow the overground development of the plant, four

quadrat counts were made on a piece of rotovated land which had a high nut-grass population. A square quadrat (50 cm. x 50 cm.) was used divided into twenty-five 10 cm. squares. This was laid over the nut-grass at four fixed positions and plant counts made. In assessing the development it was decided to record the number of leaves per plant. Whilst the nut-grass sward remained thin this was easy, but in the third count the number of plants were divided into those with 0-3 leaves and those with more than 3 leaves. Counts were made at weekly intervals following an initial period of eleven days after rotovating. In the fourth week due to the density of the sward only two out of the four quadrats could be counted and then only a distinction between vegetative and flowering shoots was made.

Table I: Development of nut-grass shoots on rotovated land

	11 days	18 days	25 days	33 days
Total	413(145)	788(339)	1,260(533)	(550)
0-3 leaves	313(113)	263(121)	246(101)	} (410)
4-5 leaves	97(31)	308(137)	} 890(394)	
6-8 leaves	3(1)	208(77)		
9 leaves +		9		
Flowering		1	124(38)	314(140)

(Figures in brackets denote counts on only 2 quadrats.)

Unfortunately no counts after 33 days were made, though it appears, from the trend of figures obtained, that the overground shoot population was beginning to balance itself and from general observations little extra flowering resulted. The above studies demonstrate the speed with which the overground life cycle is completed under favourable conditions of growth.

	Fertilized Soil			Unfertilized Soil		
	7	14	21	7	14	21
<u>Experiment I</u>						
at 5 weeks	3.7	2.5	1.3	2.0	2.3	2.0
at 8 weeks	4.0	4.0	4.0	4.0	4.0	4.0
<u>Experiment II</u>						
at 7 weeks	5.0	4.0	3.0	3.0	3.0	3.0
at 12 weeks	7.0	6.0	5.0	5.0	5.0	5.0

Section III

DISPERSAL

Methods of dispersal of the nut-grass weed can be considered under the two headings: (a) Vegetative, and (b) Seeding.

(a) Vegetative

This is the most striking method of spread by the plant and is dependent on the formation of rhizomes from a tuber or cormlike structure which ramify through the soil forming new tubers at intervals. The formation of a tuber from a rhizome was simplified into four stages by Muzik (1950).

1. Development of a rhizome from a bud,
2. Cessation of growth of the rhizome,
3. Expansion of the region just behind the rhizome apex resulting in a tuber,
4. New growth of rhizome and repetition of the process giving a string of tubers.

(i) Tuber formation

The rate at which new tubers are formed from the mother tuber can be considerable. Smith and Fick (1937) report that they obtained a system of 146 tubers in 3½ months from a single tuber. If this was the case, growth must have been under very artificial conditions. In two pot experiments where a constant number of crop plants were grown with a varying number of nut-grass tubers (Section IV) perhaps a more natural increase of tubers resulted. In Table 2 is indicated tuber numbers obtained for each experiment at different dates from planting. (For full experimental data see Appendix III).

Table 2: Numbers of tubers per tuber planted (nearest 0.5)

No. of tubers planted	Fertilised Soil			Unfertilised Soil		
	7	14	28	7	14	28
<u>Experiment I</u>						
at 5 weeks	3.5	2.5	2.5	2.0	2.5	2.0
at 8 weeks	6.0	4.0	4.5	5.0	4.0	4.0
<u>Experiment II</u>						
at 7 weeks	5.0	3.5	3.0	3.5	3.0	2.5
at 12 weeks	7.0	6.0	5.0	6.0	5.5	4.5

It must be remembered that these figures were obtained with the nut-grass growing in competition with another plant. They however indicate the rate of tuber production over a relatively short period, and show that this is accelerated under more fertile conditions. Competition resulting from high populations of tubers tends to retard the formation of new tubers.

In harvesting plants of Experiment II at 12 weeks, counts were made of the tubers produced from the originals. In general the numbers of tubers per chain closely agreed with the figures shown in Table 2 (i.e. pot of 28 tubers in fertilised soil mainly carried chains of 4, 5 & 6 tubers, etc.); for a full list of the counts made, see Appendix III. Occasionally a tuber chain would seem to develop at the expense of others, a string of 14 tubers being the maximum, found in a fertilised pot planted with 14 tubers.

The length of rhizome produced between mature tubers was also measured in some strings. Where such measurements were made (see Appendix III) it was noticeable that the length of rhizome between the mother and first tuber was usually shorter than the length between subsequent tubers. Rhizome sections between tubers varied from 2" to 7", with an average at about 4½". This gives a rough measure, when used in conjunction with rate of tuber production, to the degree of spread that can occur from a single mother tuber.

(ii) Distribution of tubers

The following are percentage distributions of tubers in the soil taken over three sites at I.C.T.A. (for actual figures of tubers found see Appendix II).

Table 3: Tuber distribution in the soil (St Augustine loam)

	Site A	Site B	Site C
Depth	4 borings	4 borings	15 borings
0-3"	84%	57%	48%
3-6"	10%	36%	28%
6-9"	6%	6%	21%
9-12"	0%	1%	0.5%

More borings at sites A and B could have been taken to get a more certain idea of the distribution. Both these sites occurred on a piece of land rarely cultivated, though burning of Gliricidia trimmings often took

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place on site B and this may account for the lower distribution in the top 3 inches as compared with site A. Site C was regularly cultivated, the percentage distribution being an indication of this.

The borings were made, after considerable efforts to find a suitable instrument, with a 6" diameter steel (3/16" thick) cylinder. This borer was made 2'6" in length and one end was coarsely toothed and sharpened to facilitate penetration when the whole cylinder was screwed into the soil by means of handles attached at the opposite end. It was found easier to extract each 3" sample in turn rather than trying to take a complete 12" bore at one time which then had to be divided into the respective sections. For fuller details of these borings and method of taking them, Scaife (1960) should be consulted.

The above percentages compare favourably with those found by other workers elsewhere. Smith and Fick (1937) on a sandy loam found that 92.5% of the tubers occurred in the top 8" of soil; Cruzado and Muzik (1950) give the figure of 95% for the top 6", very few tubers occurring below 9"; and Andrews (1940) in the Gezira similarly showed that the bulk occurred in the top 6" on most soils. Soil type obviously influences penetration and both Andrews (1940) and du Preeze (1944) found tubers down to depths of 24" on river silts.

(iii) Shoot formation and the factor of Apical Dominance

It has been shown that there is no correlation between the number of overground shoots and the tuber population in the soil, other than the obvious one of a large number of shoots suggesting many tubers in the soil. The results of the pot experiments (Appendix III) fully support such facts. It has previously been explained how from a single tuber a tuber string is produced, by the initial production of a surface seeking rhizome which results in leaf production, and then subsequent growth of subterranean rhizomes with formation of tubers at intervals. The tuber system so built up exhibits apical dominance, as has been proved by most workers. This results in the new tubers generally being unable to throw rhizomes which can terminate in shoot growth.

Deviation from this general rule is fully reported in the extensive work of Cruzado and Muzik (1950). They showed that polarity in a tuber system

was a function of auxin distribution and that the polarity of such a tuber system could be upset by placing the tuber string horizontally or inverting it. This treatment resulted in most of the tubers producing rhizomes which terminated in shoot formation. Under field conditions the formation of horizontal rhizomes, producing tubers and shoots will account for the increase in shoot number over a period (Table I).

If the apical dominance is broken by the severing of the rhizome, then the tuber immediately below the break will throw a shoot forming rhizome. This fact accounts for the heavy infestation of nut-grass that often occurs after cultivating land which previously showed no or little signs of nut-grass population and also stresses the importance of obtaining a complete kill of the weed when attempting to eradicate it.

Cruzado and Muzik also demonstrated that polarity exists within each tuber, those buds at the tuber apex always sprouting first. In handling tubers in the various studies made in this report there has been no evidence to show that this is not the case. Such polarity as exists in a tuber even on detachment is less easy to upset than that in a tuber string, the terminal bud sprouting no matter at what angle the tuber is planted. The profusion of shoots that arise from shallow tubers or tubers lying on the surface, as a result of cultivation etc., supports the findings of the above workers that the auxins producing polarity within a tuber or tuber string are destroyed by light, so that many axillary buds produce shoots and not just the terminal bud (or sub-terminal bud in the event of the terminal one having previously developed).

(iv) Tuber dormancy

This is very closely associated with the apical dominance found in a tuber system. Tubers lying in a chain will not produce a shoot forming rhizome unless the dominance of the apical tuber is removed. So long as soil conditions remain favourable such tubers can be expected to lie seemingly inactive for considerable periods. After dominance has been removed a tuber lying at depth in the soil may remain dormant if conditions are not completely suitable until a time when they become more favourable to sprouting. Soil aeration may be an important factor in this case, and Palmer and Porter (1959) have found that with high carbon dioxide and low

oxygen levels germination of tubers is poor, whilst at high oxygen and low carbon dioxide levels tuber sprouting can reach a very high percentage. Under the latter conditions they even found that apical dominance could be suppressed and that lower tubers on a string could be made to shoot. The aeration of soils by subsoiling after rigorous surface clearing of nut-grass infested land could conceivably hasten the recolonization of the land by encouraging deep seated tubers to grow.

Much work has been done on the degree of adversity that a tuber can withstand. The amount of desiccation (Smith and Fick, 1937; Du Preez, 1944), and the duration and intensity of temperatures (Smith and Fick, 1937) that can be withstood before shooting ability of dormant tubers is lost, are two such conditions which have been studied considerably in efforts to find a method of nut-grass control.

(b) Seeding

(i) Flower production

It was noticed in the pot experiments (Section IV) that the nut-grass had remained wholly vegetative, whereas in the area from which the tubers for planting had been obtained there had been profuse flowering. Andrews (1946) states that maximum flowering was related to periods of maximum humidity. In the above instance all tubers would have experienced the same level of atmospheric humidity, and thus it seemed that other factors must also play a part in flower initiation. The pot experiments were carried out in a plant house with open sides but with a roof cover which was 50% glass and 50% sheet iron. This resulted in considerable shading and also lower temperatures (both air and soil), and it was considered that these two factors, plus that of the nut-grass being grown under artificial conditions in pots might be responsible for the lack of flowering.

It was further observed that the number of leaves produced by the nut-grass shoots in the experiments were generally less than those plants which flowered outside. It was decided to examine whether there might be some correlation between the number of leaves produced and the time of flowering. Table 4 presents the numbers of plants found with respective numbers of leaves at flowering.

Table 4: Number of leaves produced at flowering

Leaf number	Number of plants
below 7	1
7	9
8	17
9	25
10	15
11	16
12	14
13	17
14	6
15	7
16	10
above 16	10

From the figures above it appears that flower initiation only takes place after the appearance of the seventh leaf (rarely before). Also there is indicated a peak of flowering at about the ninth leaf stage and this is supported by counts made when studying the overground development of nut-grass (Section II) when after 33 days growth, of 314 plants in flower almost 80% of these carried 8, 9 and 10 leaves. Such counts were taken in the wet season whereas those represented in Table 4 were made about two weeks after a period of heavy rain. This may account for a large number of plants flowering with more leaves than 10, if humidity has an effect on initiation, for during the dry season nut-grass plants tend to remain vegetative, not flowering but increasing their leaf number. It might be suggested that under ideal conditions most plants would flower between the 7th and 14th leaf, but a considerably larger number of plants other than that represented in Table 4 would have to be taken when examining this hypothesis.

(ii) Seed production

Varying degrees of seeding and subsequent germination have been reported in the literature. Ranade and Burns (1925) found the average number of seeds per inflorescence was 220, and sowing seed immediately after collection a germination percentage of only 1.5% was obtained. Andrews (1946) reports on considerable seed setting by nut-grass but gives no figures. He also observed that sowing when fresh gave hardly any germination, and he obtained all his seedlings from sifted soil obtained from nut-grass infested land. Smith and Fick (1937) and Du Preez (1944) could find no seed setting.

Under Trinidad conditions seeding does occur but not in very great amounts.

The only method employed to extract the small numbers of seed from the mature flower heads was to rub the heads between the hands (about 25 at a time), collecting seed and chaff on a piece of paper and then separating the seed mainly by placing the seed and chaff on a No.1, 24 cm., filter paper and rotating this at an angle. It was found that the seed, being heavier, tended to roll off of the filter paper before the majority of the chaff. By repeating this several times a fairly pure sample of seed was obtained. It was realised that this was a slow and tedious method and an effort was made to see if the chaff could be separated from the seed by alcohol floatation (Baldwin, 1923). This was unsuccessful as much chaff also sank along with the seed. Evans (1954) succeeded in separating good and bad grass seed by floatation with alcohol and it was found that from the samples of nut-grass seed obtained a proportion sank in 95% alcohol, the remainder floating. On separating the two sets of seeds it was found on examination that, although the floating seeds appeared superficially healthy, they were in fact all empty. In cutting open sunken seeds immediately after separation and later in the viability tests, about 1 seed in every 20 was found to be empty (5%).

It was decided to use only sunken seeds in the tests to be carried out.

Table 5 presents a list of the majority of seed that was collected.

Table 5: Seed setting of *Cyperus rotundus* (nut-grass)

No. of infls heads taken	No. of seeds by hand separation	No. of sunken seed in 95% alcohol	Seeds produced per 100 heads
100	186	used without further treatment	
100	122	65	65
100	198	94	94
200	376	166	83
200	118	63	32
200	195	68	34
200	358	282	141
300	375	192	64
300	420	used without further treatment	
500	1555	657	131
500	151	37	7

The figures show the reasonably small amount of seed setting that is produced in Trinidad. However, using the results of Table 1, where in 33 days 314 flowers were produced over a total area of 10,000 sq. cm. (10.8 sq.ft) seeds per 100 heads, and using the low average seed set of 50 \angle then over 630,000 seeds would be produced per acre on nut-grass infested land over a period of about 6-8

weeks. In relation to the Ranade and Burns (1925) figure of near 60 million, this is small, but it must be remembered that such a seed production could occur more than once a year.

(iii) Seed germination

Having obtained seed it was desirable to obtain seedlings. Only two methods were tried:-

(1) Placing seed on damp filter papers in petri dishes

Twenty seeds were used per dish, the filter paper being kept damp by means of a wick running over from an adjacent water reservoir. Twelve petri dishes were used, six contained seeds that sunk on alcohol separation, three with seed that floated and three with unseparated seed. The water reservoirs were filled up every day and one drop (0.1 cc) of Aretan fungicide (1/8 oz in 1 pint water) was added every 5th day to keep the seed and filter papers clean of fungi. After 10 weeks no germination had occurred but on making viability tests with Tetrazolium salt solution on the seeds the following percentages were obtained:

Sunken seed	=	62.5% viable
Float seed	=	1.6% viable
Unseparated seed	=	47% viable

(The small percentage viable float seed was due to one full seed which proved viable.)

(2) Sowing seed into a standard soil compost

A standard compost was used in case the work was to be repeated in the future. The John Innes seed compost (Lawrence and Newell, 1939) was chosen. Andrews (1946) suggests that higher germination results under soil conditions due to fungal and bacterial action on the seed coat. With this in mind both sterilised and unsterilised soil were used in two separate mixings (for compost details see Appendix II), 350 seeds that sunk in alcohol, 250 seeds that floated and 250 unseparated seeds were sown separately in boxes, both in the sterilised compost and in the unsterilised. After two months no germination had resulted. The seed was too small to be found in the boxes to make viability tests.

It has been generally found with tropical grass seed that under artificial sowing very poor germination often results, whereas in nature a fairly high seedling population can be found. It appears that nut-grass

seed may show similar properties, especially under conditions of artificial sowing.

Possible reasons for low seed germination

(a) Climate

Both Ranade and Burns (1925) and Andrews (1945) found that highest seed germination percentage were obtained at the beginning of the rains, and concluded that both soil moisture and high atmospheric humidity were required. All the nut-grass seed sowings in the germination tests described above were done during the dry season. The seed boxes will be watered well into the approaching wet season in order to see if any germination will result.

(b) Hard impermeable fruit coat and testa

Cutting the seed, or more correctly the one seeded fruit, shows the very substantial pericarp (fruit coat) which encloses the small nut-grass seed (Fig. IV). It can be expected that only after prolonged soaking and possible bacterial and fungal activity attacking the tissues, will they be broken down sufficiently to allow penetration of water and subsequent seed germination. That viability still exists in the seeds kept on moist filter paper for 10 weeks supports this supposition.

(c) Seed dormancy

This is the most probable reason why fresh seed does not germinate on sowing. Andrews (1946) found that the largest percentage of seed in a sample germinated 5-7 years after collection and storage in bottles. It is hoped that enough seed can be collected so that similar tests can be made under Trinidad conditions. The type of seed dormancy is difficult to assess except on close study, but if the length of dormancy is as long as Andrews suggests then the seed most probably has to undergo a physiological change either in the embryo or endosperm, or in the fruit coat, or in both.

(d) Seed viability

Being unable to obtain germination of the seed it was essential to assess whether the seed was viable or not. On cutting seed which sank on alcohol separation longitudinally, a plump healthy looking embryo was noticed embedded in mealy endosperm. It was decided to use the Tetrazolium salt solution test (Davies and Winstanley, 1957) to test viability. Accepted

methods of making the test were reported as using a 1% solution of the salt (2,3,5-Triphenyl tetrazolium chloride or T.T.C.) and placing into it the longitudinally cut seed which had previously been soaked whole in water for several hours. After a period of a few hours in the salt solution the seed was removed and checked for results. In the presence of viable tissue the T.T.C. solution is reduced forming an insoluble red compound (diphenyl formazan). Seeds are considered viable if the embryo and surrounding endosperm are coloured pink.

Tests were made over a considerable period because those tried first were unsuccessful. At first unsoaked seeds were cut and tested with no results. Then seeds that had been in germination tests in petri dishes under damp conditions for seven weeks were tried, again with no results, although the embryo and endosperm still appeared healthy. On restudying the report of Davies and Winstanley (1957) it was noted that workers using small grass seeds slightly punctured the fruit coat before putting the seed to soak in water, prior to the T.T.C. solution test, to allow penetration of water. Satisfactory results were obtained this way. Following this method a few nut-grass seeds were nicked at the stylar end to remove just the fruit coat. These seeds were left soaking in water for 10 days and then put into T.T.C. solution. On removal and cutting the seed open after 24 hours the majority had become so soft, due to the prolonged soaking in water, that it was difficult to keep the seed contents intact. Out of 12 seeds three showed embryos which had turned bright pink and there were signs of further coloration in some of the other seeds.

With this encouraging result further tests were made reducing the time of soaking in water. It appeared that the best results could be obtained by soaking the nicked seed for 24-36 hours in water before making the test in T.T.C. salt. Usually the seeds were left in the salt solution for 24 hours before being checked, for shorter periods did not give better results.

With two samples of 50 seeds, 29 and 28 seeds, respectively, gave pink embryos indicating viability, whilst 21 and 22 remained uncoloured. This indicates a viability of 58% and 56% in the sunken seeds.

This viability test was used on the seed in the germination test carried out in filter papers (see above).

(iv) Factors affecting seed production

Having only been able to collect a relatively small amount of seed, it was considered worthwhile to examine some of the possible reasons why this was so. The immediate aim was to understand the mechanism of flowering and this was later followed by pollen viability tests.

1. Mechanism of flowering

In making this study, plants with an inflorescence appearing in the basal cluster of leaves were dug up and potted. The following is a summary of the stages of flowering that were noted during subsequent observations.

The inflorescence spikes are at first short and held tightly together. As the flowering stalk lengthens these spikes also lengthen and open out. When fully spread the stigmas commence to lengthen and protrude from the lower bracts of each spikelet. At this time the inflorescence head is held well above the leaves and the flower stalk continues to lengthen well on into anthesis. The stigmas appear to curl and commence to shrivel after 3-4 days (indicating that they are no longer receptive); 4-5 days after protrusion of the stigmas anthesis commences. Flowers open from the bottom of the spikelet upwards, 2-4 flowers opening daily, thus on an average sized spikelet stigmas can be found in a receptive state towards the top of the spikelet when there are anthers at the base. Pollen is produced copiously on protrusion of the anthers, being light, smooth surfaced and about 0.03 mm (30 μ) in diameter. It is concluded that nut-grass is dependent on wind for pollination and is cross fertilised.

2. Pollen viability

The method used to test pollen viability was that of the hanging drop (White, 1954). A small glass ring (about 1 cm. in diameter and $\frac{1}{2}$ cm. in depth) was attached by petroleum jelly to a microscope slide and a small volume of distilled water placed inside. A cover slip, carrying a drop of sucrose solution with pollen grains, was then inverted and placed on top of the glass ring which had previously been greased. By applying slight pressure to the cover slip an air-tight seal was obtained between the cover slip and glass ring. The water previously placed inside the ring produced a saturated atmosphere which is desirable for pollen tube growth.

Reports that the concentration of sucrose solution was critical for optimum values of pollen germination and varied for different plant

species meant that different concentrations of the sucrose would have to be tried in order to find the correct solution. Three series of tests were made using varied sucrose concentrations as follows:

- Test 1. % concentrations: 40, 20, 13.3, 10
- Test 2. % concentrations: 20, 13.3, 10, 8, 6.6
- Test 3. % concentrations: 20, 13.3, 10, 6.6, 2 and distilled water

In all tests, under microscopic examination no pollen germination could be found. In these tests single anthers had been used in each drop, and it was considered desirable to use a mixed sample of pollen in a further test.

Inflorescences gathered in the evening had all anthers removed. By morning all fresh protruding anthers were collected and pollen teased out. This extracted pollen was submitted to Test 4 which was identical to Test 3 with an additional 1% solution. On examination after 24 hours one grain was found to have germinated and two more showed signs of germination in the 6.6% solution.

Believing this to be in proximity to the concentration required for pollen germination a further test was devised:

- Test 5. % concentration: 8, 7, 6, 5, 6, 5.5, 5, 4, 3.

Pollen was obtained in a similar way. After prolonged scrutiny no germinated pollen could be found in any of the drops. It was decided to discontinue the tests.

It had been noted whilst making the tests that a large proportion of the pollen was shrivelled and empty. With full grains it had been expected that placing them in strong and weak sucrose solutions would have resulted in the grains plasmolysing and bursting respectively, but there had been no evidence of either taking place.

The results described above would indicate that the majority of pollen is non-viable. That 70% of the pollen is not viable was proved when making slides of extracted pollen grain and staining with cotton blue in lactophenol. On making a large number of counts at random only 30% of the grains had taken up the dye. Whether all of this 30% of pollen produced is viable would appear doubtful from the tests above. That some seed is produced means that some pollen must be alive. It is interesting to note that with the numbers of seed obtained (Table 5), the highest collections were obtained from heads where nut-grass was found in profusion. All the small collections came from

small isolated communities. This would be expected in the case of a wind pollinated plant and more so where pollen viability is very low.

(v) Shattering of seed

Other seed setting Cyperus spp. drop their glumes when the seed is ripe and the seed falls to the ground. No signs of this property was found with nut-grass. The inflorescence usually stays intact after flowering for a considerable period and if it is allowed to remain standing, final breaking up is by separation of the inflorescence spikes from the main flower stalk. That little seed is lost whilst such inflorescences remain standing was proved by collections made immediately and at two months after seed ripening. There was no reduction in the seed number obtained per 100 inflorescences (131 and 141 respectively; see Table 3).

(vi) Seed dispersal

Andrews (1945) regards irrigation water and strong gusty winds as the main methods of seed dissemination in the Sudan. In Trinidad methods of dispersal (if any) can only be conjectured. Soil, carrying the seed, transferred from one place to another either purposefully or on implements, shoes, etc., would almost surely be the only method of spread over large distances. Irrigation water is only used in limited areas, but in such areas may be an important method of dispersal. Elsewhere drainage water after heavy rains would serve much the same purpose. High winds are infrequent but occasionally occur in strong enough gusts to carry seed short distances. Birds have been suggested as carrying the seed but this is very unlikely, mainly because of the small quantity of seed produced, and there have been no instances of birds seen feeding on mature nut-grass heads.

Section IV

COMPETITIVE EFFECT OF NUT-GRASS

(a) Competition experiment

The importance of nut-grass as a weed has been fully realised throughout the tropics, but there are few references to the actual depression it causes in crop yield and the associated economic loss. In India the estimated reduction in yield was given as 25-30% (Ranade and Burns, 1925) but little has been reported elsewhere. In talking to local peasant farmers the impression gained was that they regarded nut-grass purely as a nuisance weed in the early stages of a crop. Once the crop was established they made little or no effort to control it.

It was decided to run a small experiment to discover if nut-grass offered any serious competition to crops, and if so to what degree. As such an experiment would be in progress at the same time as general observations were being made, it was essential that it should be simple and yet give worthwhile results.

(i) Experimental design

It was decided to have a pot experiment using 8" pots where the treatments would be a varying number of nut-grass plants growing with two crops of similar height, one being broad leaved and the other narrow leaved. Crops which were quick maturing had to be chosen because of the restricted time available. After considerable discussion the two crops chosen were Morei radish (Raphanus sativa var. radicula) and Finger millet (Eleusine coracana). It soon became apparent that an experiment set up using a standardised soil (John Innes potting compost was contemplated) purely to discover if competition was present, would supply a limited number of results, which being obtained in an artificial compost of good texture and high nutrient status would hardly bear any relation to field conditions. By adjusting the design of the experiment, and using a field soil with a low nutrient status, which was not inclined to pan too badly, much more informative results could be obtained. Such results could give a definite indication as to the type of competition that occurred. The soil chosen was a River Estate sandy loam which is recognised (Chenery, 1949) as being low in nutrients.

On the above basis a factorial experiment was designed which consisted of:

- two levels of nutrient status - unfertilised and fertilised pots,
- two levels of watering - adequate and restricted watering,
- four levels of nut-grass - 28, 14, 7 and 0 tubers per pot,
- two replications.

Such an experiment was to be repeated for each crop, resulting in a total of 64 pots. The constant number of crop plants per pot was to be decided after seed germination.

Problems were soon envisaged in trying to apply water restrictively and yet uniformly and in order to keep the experiments as simple as possible it was decided to replace the levels of watering with two harvesting periods. It was hoped that this would indicate whether the degree of competition offered by the nut-grass affected crop equally throughout the life of the crop.

Thus the final design of the experiments was to have two levels of soil nutrients, two harvesting periods, four nut-grass levels, all of which were replicated twice in each experiment. The analysis of variance for such an experiment was adequate (see Appendix III).

(ii) Site

A plant house with open sides and a roof half glass and half sheet iron was available for the experiment. It was hoped that the degree of shade thrown by the roof would not affect the outcome of the experiments, but rather offer the pots some protection as the experiments were to be conducted in the dry season. An area in the centre of the house was selected, where it was expected that conditions would be fairly uniform, and it was arranged to stand the pots on open grids placed about 6" off the plant house floor (see photo Appendix III).

(iii) Setting up experiments

To obtain the requisite number of nut-grass tubers for planting, a large number were collected from infested sawdust heaps, sorted to retain only those of medium size. They were then planted in seed boxes at the rate of about 300 per box. On planting up the experimental pots five days later with 28, 14, 7 and no tubers respectively, only tubers with one or two vegetative shoots were selected from the seed boxes. In this way it was hoped to use the most uniform material as possible.

In applying fertiliser to the soil for the high nutrient pots, it was

suggested that the rates used should be equivalent to 5 cwts per acre of sulphate of ammonia, 4 cwts of potassium sulphate and 6 cwts of super phosphate. Enough soil was mixed to fill 36 pots giving a safety margin for the 32 pots required, the amounts of fertiliser added being 32.5 gm sulphate of ammonia, 26.0 gm potassium sulphate, and 39.0 gm super phosphate (for calculations see Appendix III).

Before addition of the fertiliser and filling the 64 pots with soil (32 with plain soil and 32 with soil plus added fertiliser) the soil was all passed through a $\frac{1}{2}$ " sieve. Since the 8" pots were hand made and varied in size a measure was used in filling the pots so that all pots should contain the same amount of soil.

Over the drainage hole of each pot was placed a 3" square of $\frac{1}{4}$ " painted wire gauze, on top of which was added a thin layer of fine gravel (retained on a $\frac{1}{4}$ " sieve having passed a $\frac{1}{2}$ " sieve). A large measure of soil was then added and firmed, the tubers placed on top of this and then covered by a further depth of soil (about $\frac{1}{2}$ "). This surface was levelled and firmed before the crop seeds were sown on it. The radish seed had given a germination percentage of 88, and the finger millet 96%. Sowings were thin and the seed was covered by a very thin layer of $\frac{1}{4}$ " sifted soil. All pots were carefully labelled and placed in their respective experiment sites at random on the iron grids. For layout and labelling used see Appendix III.

(iv) Progress of experiments

All pots were watered twice daily with a hose pipe. During the seedling growth of the crops a fine rose was attached to prevent damage. After 3 days many nut-grass shoots were showing and the majority of the crop seeds had germinated. A gradual thinning of the crop seedlings was made over the first few days, a final thinning on the 10th day leaving 9 radish seedlings and 14 finger millet seedlings per pot. Considerable difficulty was encountered with the radish seedlings which became etiolated probably as a result of the shady house and too shallow sowing. By careful watering the seedlings managed to get well rooted and stiffen up, though their stems did not thicken as expected and the leaves were held very high.

Signs of insect damage after about two weeks on both the radish and finger millet made it necessary to dust with B.H.C. This practice was

was continued at about ten day intervals throughout the course of the experiments. Pots were kept weeded during the first three weeks, after this period no weeding was found necessary. Harvests of the radish experiment took place five weeks after sowing and when plants started to flower (eight weeks). The millet experiment was harvested at seven weeks and at twelve weeks when the grain started to ripen. When harvesting, the pots were knocked out and soil broken up carefully. The crop plants were extracted with as much root as possible, washed to remove soil, and then dried in an oven for twenty four hours at about 95°C. Dry weight was then taken. With the nut-grass, the shoots with strings of tubers attached, were knocked free of the majority of the soil. The shoots were counted and cut off about $\frac{1}{2}$ " above the cormlike swelling, washed and oven dried for thirty six hours before being weighed.

The number of leaves produced by the crop plants were counted, and in the second harvest of the radish experiment these were weighed separately to the remainder of the plants. The grain heads of the millet were also removed when making the second millet harvest and these were likewise dried and weighed separately.

That plants were pot bound was very noticeable when making the final harvestings and it was felt that the pot size had hardly been adequate. Insect damage in some of the millet pots had reduced the number of crop plants, but such pots contained the higher populations of nut-grass tubers and it was considered a treatment effect.

(v) Results (see Appendix III for details and analysis tables)

That nut-grass does offer severe competition under the conditions of the experiments is indicated by the dry weights of crop yields. Below are set out the percentage yields occurring under the four nut-grass levels.

Table 6: % Yield (dry weight basis) of crop plants

Number of tubers per pot	% Yield Radish		% Yield Millet	
	Unfertilised soil	Fertilised Soil	Unfertilised soil	Fertilised soil
0	100% = 8g	100% = 15g	100% = 25g	100% = 45g
7	68%	57%	47%	43%
14	42	52	26	25
28	38	27	16	4

The reduction of yield in the broad leafed radish experiment appears proportionately less than that for the narrow leafed millet and it might be suggested that the radish could stand up to the competition offered by the nut-grass better than the millet.

Besides reduction in total plant weight increasing density of nut-grass significantly reduced radish and millet leaf number and also the yield of millet heads. By adding fertilisers to the soil increase in crop growth was obtained, but it did not counteract the competitive effect of the nut-grass to any degree. Leaf number was ~~only~~^{also} increased for the radish plants. The fertilised soil pots maintained an equal amount of leaf production on all plants no matter what the nut-grass population was, as shown by the non significance of the nut-grass/fertiliser interaction. This, as expected, was not the case for total plant yield.

Harvesting periods did not show significantly different numbers of leaves for the radish, showing that full leaf production had taken place by the time of the first harvest after five weeks of growth. The subsequent three weeks of the eight weeks growth being a period of maturation and flower production. The non significant interaction between harvesting periods and nut-grass levels, for radish plant yields indicates that proportionate growth occurred with the crop plants under all conditions. With millet this was not the case, the increase in dry weight between first and second harvests being far less in relation to the dry weight at the first harvest with plants growing in a high population of nut-grass, than with those in clean soil or soil with a low nut-grass population. This further reflects the powers of radish to withstand the competition of nut-grass better than the millet.

That no interactions appear significant for leaf number in the crop plants, indicates, that, although plant growth is greatly affected by the different treatments, leaf production within each treatment carries on at a uniform rate.

Tuber number was found to be significantly greater in the fertilised pots. There was, however, no difference in mean tuber weight and barely any between mean shoot weight. It would seem that no competition between nut-grass plants had occurred, though from previous studies it would appear that the nut-grass plant will stabilise its overground growth as a result of

of self competition and this could also account for a fairly constant shoot weight.

In analysing the various results obtained from the above experiments, it was advised that unless the errors present for each harvest period were of the same order, showing that figures obtained were done so under equivalent conditions, then the harvest periods should be analysed separately. When calculating results it was felt that such errors were of the same order and that to analyse the harvests together as one experiment, as was originally planned, would be justified.

(b) Cover crops

It has earlier been reported that nut-grass will not flourish under shade or in association with taller vigorous vegetation. Work on a weed succession (Haggarty, Grime, 1960) showed that the very heavy infestation of nut-grass which appeared shortly after rotovating declined in importance as other weeds developed. After three months it had become completely swamped and it was difficult to find aerial shoots. The suppression of nut-grass growth either by allowing natural regeneration of the vegetation or by purposeful sowing of strong vigorous cover crops has been realised for many years. Loustalot and Delgado (1948) accidentally found that the rather open sward that nut-grass develops allowed germination and subsequent growth of velvet beans (Stizolobium aterrimum), a strong growing annual, such that after the first two months of the rainy season the nut-grass had all been shaded out. This illustrates that heavily infested areas of nut-grass can be used successfully but without eradicating the weed. To obtain eradication cover cropping should be used in association with dry season tillage of the soil over a period of a few years. The tillage results in tuber desiccation and death, whilst the cover crop suppresses any growth from tubers left alive in the soil.

(ii) Herbicides

A vast number of herbicides have been tried in attempts to eradicate the weed. None have been found completely successful if applied at economic rates. The hormonal herbicides, especially the amines and esters of 2,4-D,

Section V

THE CONTROL OF NUT-GRASS

Sparrow (1958) gives a detailed review of the methods employed to control the weed, and it only remains to give a short summary of the present position.

(a) Peasant methods

During the preparation of the land an effort may be made to collect visible tubers, but this is obviously a fruitless task. The main control relies entirely on hand hoeing especially during the establishment of a crop. With ground level crops (lettuce, etc.) hand forking is sometimes used around the plants to remove adjacent tubers. After establishment little concern is shown and the nut-grass is often allowed to grow unchecked, surface clearing taking place infrequently. These methods probably do more harm than good by inducing underlying tubers to shoot and build up a larger nut-grass population.

(b) General agricultural methods

(i) Cultural

This appears to be the cheapest way of controlling the weed, if it is done properly and successfully. A failure with such methods can only lead to worse trouble than before. The general principle of cultural control relies on the killing of tubers by desiccation after deep ploughing and subsequent harrowing to dry out the soil in the dry season. It implies that land must be fallowed for a period and this may mean the sacrifice of a cropping season. The use of cover crops in the wet season to suppress any nut-grass growth that may result from persistent tubers after deep ploughing, and then repeating the process in the following dry season can usually lead to a higher level of eradication.

Continued surface cutting of shoots at short intervals (1-2 weeks) has been found to weaken the plant, but needs to be prolonged in order to gain a control.

(ii) Herbicidal

A vast number of herbicides have been tried in attempts to eradicate the weed. None have been found completely successful if applied at economic rates. The hormonal herbicides, especially the amines and esters of 2,4-D,

have been found most promising, but tend only to reduce tuber number and have to be used repeatedly to obtain a control. Soil fumigants (methyl bromide) have been found highly successful on small areas, but are limited to such by nature of their application.

(iii) Combination of cultural and herbicidal methods

A high degree of control has been attained by the repeated cultivation of infested nut-grass land during the growing season, to induce shooting of tubers. Each cultivation followed when growth has started, by a herbicidal application. The control gained this way can be achieved over a fairly short period.

(c) Difficulties of eradicating nut-grass

The main obstacle in ridding land of nut-grass is the depth of the soil to which tubers penetrate, and the reserves of food material which they contain enabling them to withstand unfavourable conditions and yet take immediate benefit when such conditions change and growth is possible.

With cultural control the aim must be to sever all root connections of even the lowest tubers to prevent the tapping of deep water supplies, so that desiccation can be successful. However if the thorough drying out of the topsoil is not attained during the cultivations applied, the severed tuber systems will result in a higher nut-grass population than was previously present. Cultural control is consequently largely at the mercy of the weather.

For herbicidal applications to be successful, the herbicide must likewise kill all the tubers in the soil. The hormonal herbicides seemed most promising from this aspect as they would be translocated throughout the plant. Muzik and Cruzado (1950) found that the fault with 2,4-D was that the translocation was too slow and that only the top two tubers of any system were killed. They realised that the problem was to find a herbicide which would be translocated quickly to reach and kill even the lowest tuber. No herbicide with such properties has yet been found. The use of soil fumigants has partly solved the problem for with adequately sealed soil covers after application, they can penetrate freshly moved soil to a depth of up to one foot, but as stated above their use is limited to small areas.

Section VI

CONCLUSIONS

From the account in this report of the limited studies made on Cyperus rotundus, nut-grass, it would appear that the problem which it presents in Trinidad is not widely different from that found elsewhere in the world.

The distribution of tubers in the soil in the vicinity of the College (St Augustine loam) was found to be almost entirely in the top nine inches. The production of new tubers in the soil is about three weeks from an isolated tuber and about every two weeks once a tuber string has been formed. These rates of new tuber formation when recognised with the fact that inter-tuber rhizome lengths averaged about $4\frac{1}{2}$ " , give an indication as to the speed of the underground spread of the plant and the potential the plant possesses for infecting clean land after it has first gained entry. The development of an extensive underground tuber system occurs without any visible evidence because of the apical dominance phenomenon which exists, preventing low lying tubers producing the type of rhizomes which result in shoot production. Counts of ground level shoots will however give an idea of the number of tuber strings in the ground, but these will carry a variable number of tubers. Longer strings being obtained in underpopulated soils, becoming shorter as the degree of infestation increases. Cultivation breaks up these tuber strings, upsets the apical dominance and allows deep seated tubers to throw leaf producing rhizomes. Aeration of the soil will also occur and this may also encourage dormant tubers to sprout.

It was found that under good growing conditions only one month would elapse between shoot emergence and flowering. Flowering generally occurred after production of the seventh leaf and, under ideal conditions, before the fourteenth leaf. With poor growing conditions, only leaf production occurred and this at a very slow rate. When full growth could be resumed, as at the beginning of the rains, flowering would take place. These facts indicate that the plant has a definite vegetative phase, as a prelude to flowering. In adverse conditions only leaves are produced and a few plants with over twenty leaves have been found in the dry season. On return of favourable conditions flowering results. Humidity would be one of the most important factors influencing floral initiation, but is not the sole factor. Light

and, or temperature may exert a controlling influence.

Flowering commences before the scape has fully lengthened. The individual flowers on the spikelet open from the bottom upwards, two or four flowers per spikelet opening daily. The stigmas protrude first, remaining receptive for about three days, followed four to five days later by the anthers, which on emergence produce copious pollen. From counts made 70% of this pollen is empty and of the remaining 30% little viability could be shown. A sucrose solution of around 6% seemed to be the most likely concentration for getting pollen to germinate by the hanging drop method. The fact that seeds are formed indicates that there must be some degree of viability.

The amount of seeding shown by the plant is small. In areas of heavy infestation an average of just over one seed per inflorescence was produced, but in isolated and small communities this dropped to under half this rate. The majority of empty and incompletely formed seed was separated from that collected by floatation in 95% alcohol. Of the sunken seeds, a viability of about 55-60% was shown by use of the Tetrazolium salt test. Using this test the highest viability was obtained by soaking seed in water for 24-36 hours before emerging in a 1% salt solution for 24 hours. Before soaking in the water the pericarp was punctured at the stylar end. After the period in the salt solution the seed was removed, cut open and a note made of any coloration of the embryo and surrounding endosperm indicating viability of the seed.

No germination of seed could be obtained either after ten weeks on damp filter paper or after twelve weeks in both sterilised and unsterilised soil composts. The probable reason for this is the presence of the very thick and hard fruit coat, or the need for a dormancy period, or a combination of both. Very little seed shattering from the inflorescence head appears to occur, and means of seed dispersal, if any, is not known.

From the competition experiments it would appear that nut-grass can offer a high degree of competition when it is found in large numbers. The results were obtained under artificial conditions in a restricted soil volume, but it can be expected that similar effects would be obtained in field conditions, but at a lower level. Soil of higher fertility appears

to hasten tuber development giving rise to a larger tuber population, and speedier underground spread of the plant. Tuber size would seem to be fairly constant under all conditions. Of the two crop plants used in the experiments, the broad leafed radish seemed to be able to withstand the nut-grass competition better than the narrow leafed millet, though in both cases a considerable reduction in yield occurred with increasing nut-grass population. The nut-grass naturally seems to present a balance between shoot production and the varying restrictive effects of the competitive environment after colonising an area.

Under competition from strongly growing vegetation nut-grass is suppressed. This has been noticed by most workers and forms the basis for the use of cover crops on nut-grass infested land.

By way of control the only point that can be drawn from the above studies is that eradication of the weed should be attempted before flowering and subsequent seed set. The small amounts of seed produced must contribute to dispersal and be a potential method of infecting clean land. Methods of control used will vary from district to district but those most likely to give the best results under Trinidad conditions should be based on either extensive cultivations in the dry season followed by cover cropping in the wet, or, the joint use of a series of cultivations in the wet season with a parallel series of hormonal herbicide application on the induced young shoot growth.

Summary of conclusions

1. The nut-grass problem in Trinidad is not widely different to that found elsewhere in the tropics.

2. Distribution of tubers in the soil at the College was almost entirely in the top nine inches. The factor of apical dominance which is found in the underground system allows underground spread of the plant to take place without obvious increase in shoot production. Severing of tuber strings breaks this apical dominance and leads to considerable overground shoot production and further spread. New tubers form at about fortnightly intervals on existing tuber strings.

3. The swelling which occurs at the junction of rhizome and leaves is best referred to as cormlike. It is not a 'basal bulb'.

4. Under favourable conditions, flowering occurs in one month after shoot emergence. It occurs after a definite vegetative phase.

5. The solitary flowers occurring on spikelets of the umbel like inflorescence expose their stigmas first, followed after about five days by the anthers. Flowers are cross and wind pollinated.

6. Viability of the pollen is very low.

7. Seeding does occur to a limited degree (about 1 seed per inflorescence). Full seeds showed a viability of 50-60% and will not germinate when fresh as a result of a very hard fruit coat, or the need for a dormancy period, or both.

8. Nut-grass offers severe competition to annual crops. Of the two crops millet and radish, the latter could withstand the competition best, but even then suffered greatly with increasing nut-grass population.

9. More nut-grass tubers are produced under more fertile soil conditions. Size and weight of tubers, however, remains fairly constant.

10. Control of nut-grass weed should be made before flowering and seeding. The use of cover crops to suppress the weed, and cultivation in the dry season to desiccate tubers probably suggests the best method of control.

RECOMMENDATIONS

Throughout the studies described in this report certain problems have arisen. Some of these were given preliminary examination, but further investigations into these and other points would add to the understanding of the nut-grass plant. Below are presented the points on which further study might be worthwhile.

Ranade and Burns (1925) report different forms of geotrophy in the rhizomes. Whether the difference in rhizome habit is a result of geotrophy or purely an effect produced by better aeration, soil, temperature or light on the surface layer of soil is not known and would be of interest to discover. Higher oxygen levels were found by Palmer and Porter (1959) to break tuber dormancy, and even upset apical dominance on a tuber string, so that tubers would produce shoot forming rhizomes. The factor of soil aeration may play an important part in shoot production, and may largely account for the high proportion of aerial growth after cultivating infested land. The breaking

of apical dominance in the tuber system by the severing of rhizomes is mainly responsible for this.

The formation of the cormlike swelling at the junction of the rhizome and leaves has been regarded as important for full leaf production. Whether it actually forms before leaf production or as a result of leaf production has not been considered. The fact that it is a rhizomatous swelling, presumably containing stored food products may be an indication that it forms as a result of leaf production. Workers have further stated that other factors, such as light, have a controlling influence on its formation. The actual conditions of formation of this swelling might well be clarified along with an anatomical study of the nodes. Because of its importance in the vegetative life history of the plant this knowledge may have an important bearing on timely control of the nut-grass weed. Likewise the factors affecting flower initiation, whether humidity is the all important factor or whether it is related to other climatic and soil factors, could well be determined.

In further considering the flowering of nut-grass, it would be of interest to find whether this breaks the apical dominance found in a tuber system. That it disturbs the polarity of the cormlike swelling, is shown by the formation of several shoots. If the same disturbance results both in the underlying tubers and tuber system flowering may be important in relation to subsequent vegetative spread. The indication that flowering occurs after a definite vegetative phase of the aerial shoot and that there may be a peak within certain limits of leaf production under favourable growing condition leads to the suggestion that further studies should be made to verify these statements.

More estimates as to the amount of viable seed produced would be worthwhile. In particular, monthly figures would determine if a particular period or season of the year is favourable to seed set. The cause of non-germination of freshly collected seed should be ascertained. This will almost surely lead the worker into considerations of seed dormancy and the breaking down of the thick, hard fruit coat. Further treatment of seed by acid, heat, storage, etc. should also be made in trying to obtain germinations.

Efforts to obtain values of pollen viability were unsuccessful. That some viable pollen is produced is shown by the production of seed. It may be that the correct conditions were not found for pollen growth, and that

on repeat of the tests if the hanging drop method again appears unsuccessful, an agar culture might be worth trying.

In conclusion, in order to obtain a full understanding of the plant under Trinidad conditions, a full ecological survey much along the same lines as that reported by Rochecouste (1958) is required. This would also give an indication as to which soils and areas are potentially suitable for nut-grass infestation, so that cultural methods could be used at intervals to keep present clean land free from the nut-grass weed.

My thanks are also due to Dr G. K. Mallikant and Mr I. J. Bayford of the Regional Research Centre (Soils) for their advice on crop plants to use in the competition experiments, suggestions as to the design of the experiments, and for obtaining the soil used from River Estate.

Mr G. A. Madgett for discussing the statistical analysis of the competition experiments.

Miss I. Aasing for the typing of this report.

The Junior Staff of the Botany department for the carrying out of menial tasks which assisted the smooth running of the investigations made.

S. L. M.

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Mr G.E. Hodnett for discussing the statistical analysis of the competition experiments.

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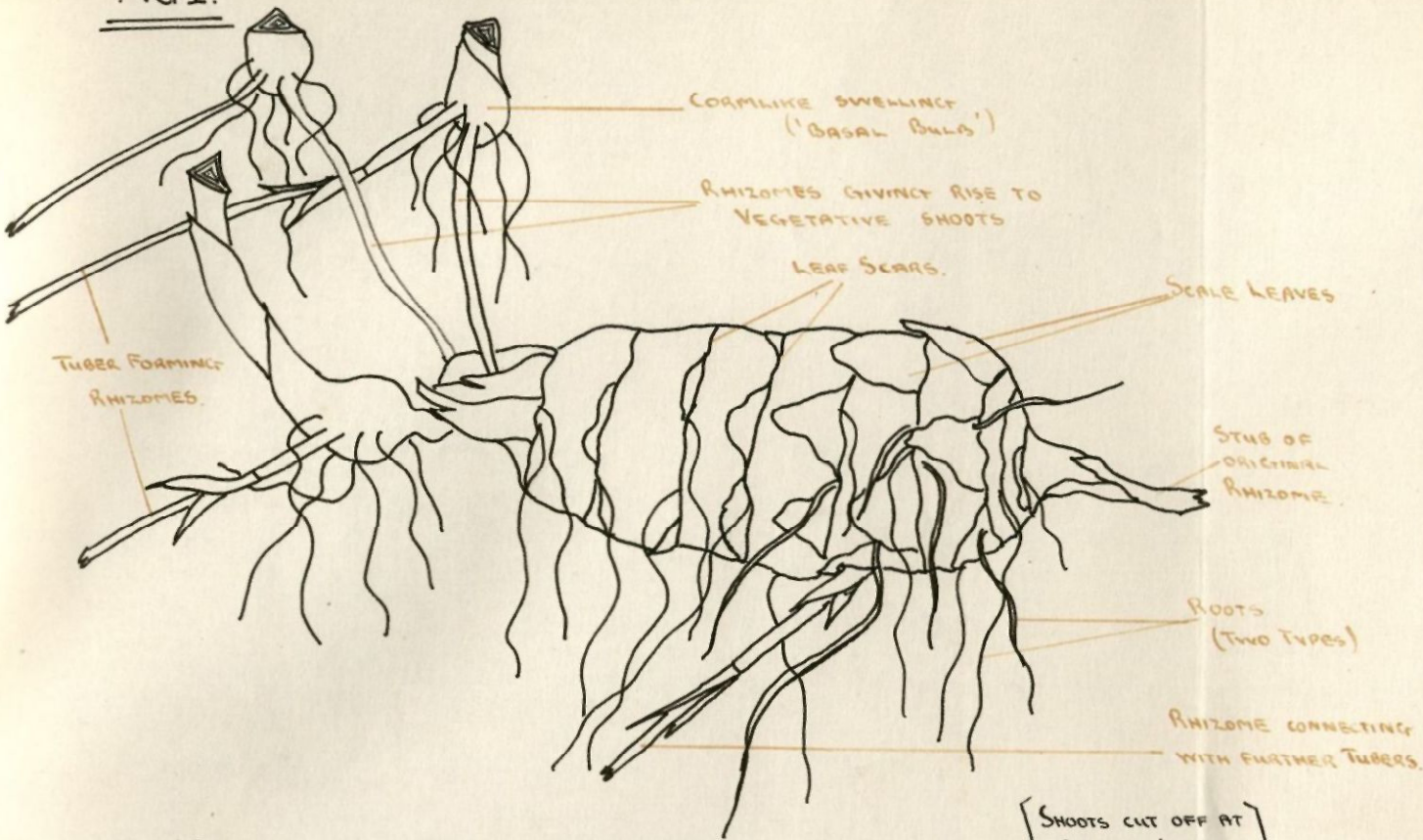
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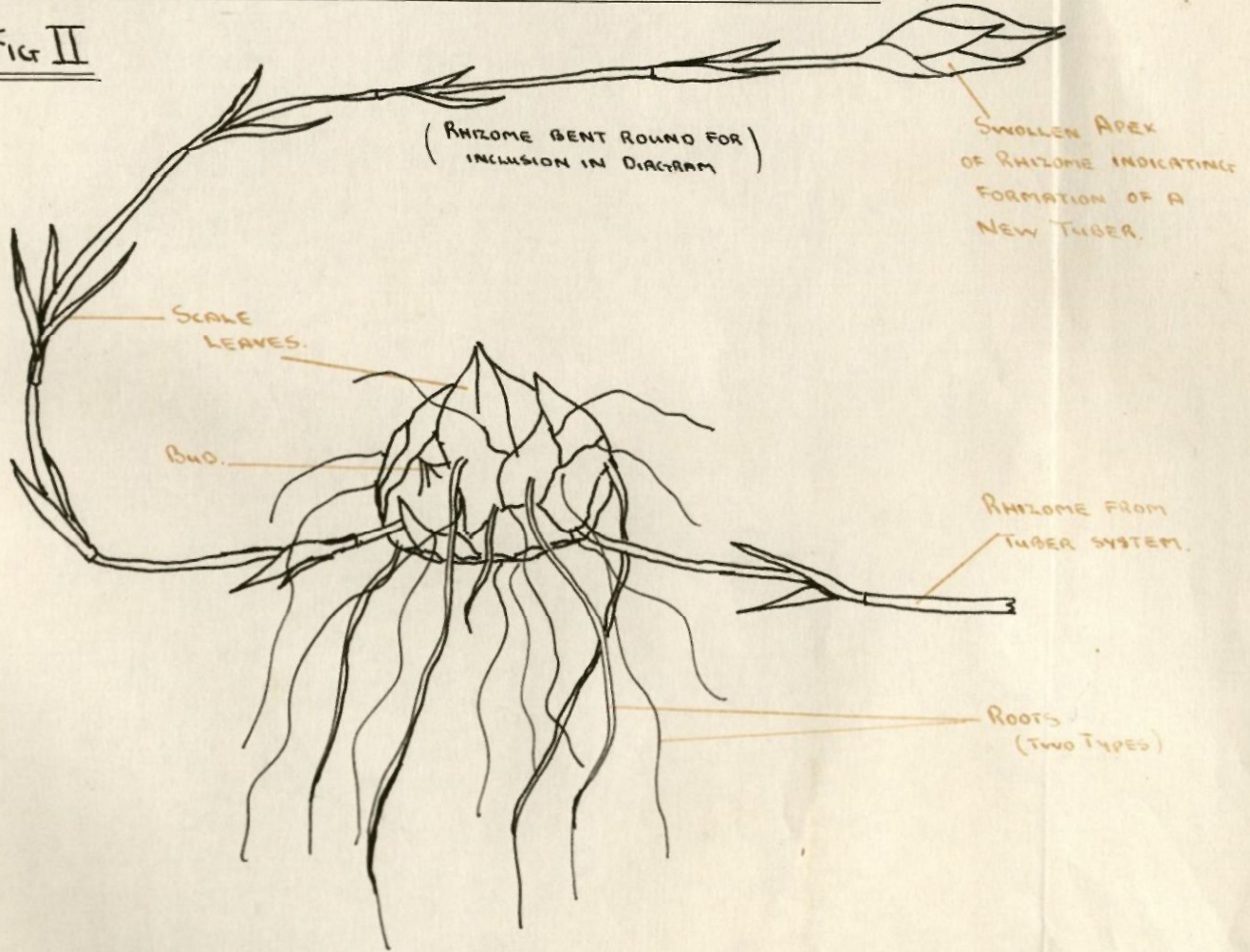
APPENDIX I.

FIG I.



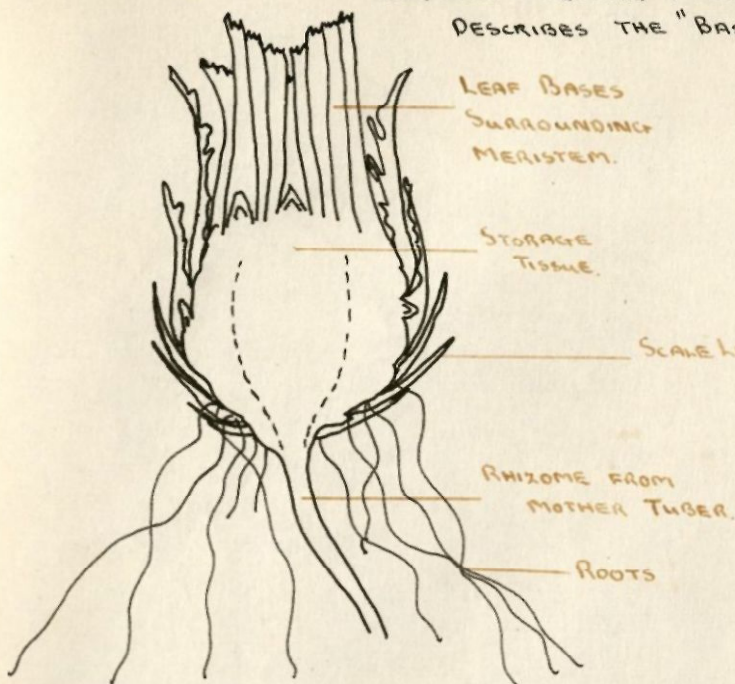
OLD TUBER SHOWING PRODUCTION OF VEGETATIVE SHOOTS (X2)

FIG II

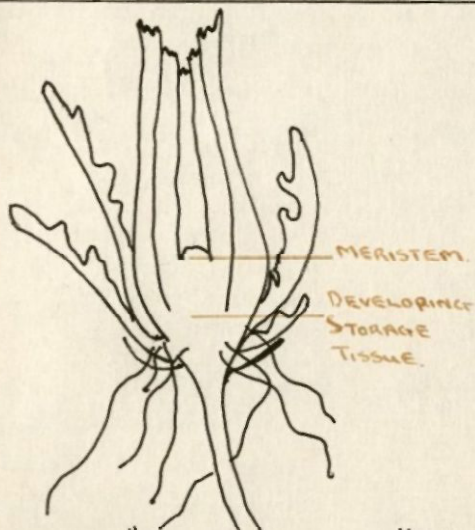


FINAL TUBER IN A TUBER SYSTEM WITH SUBSEQUENT RHIZOME GROWTH,
AND DEVELOPING NEW TUBER (X2)

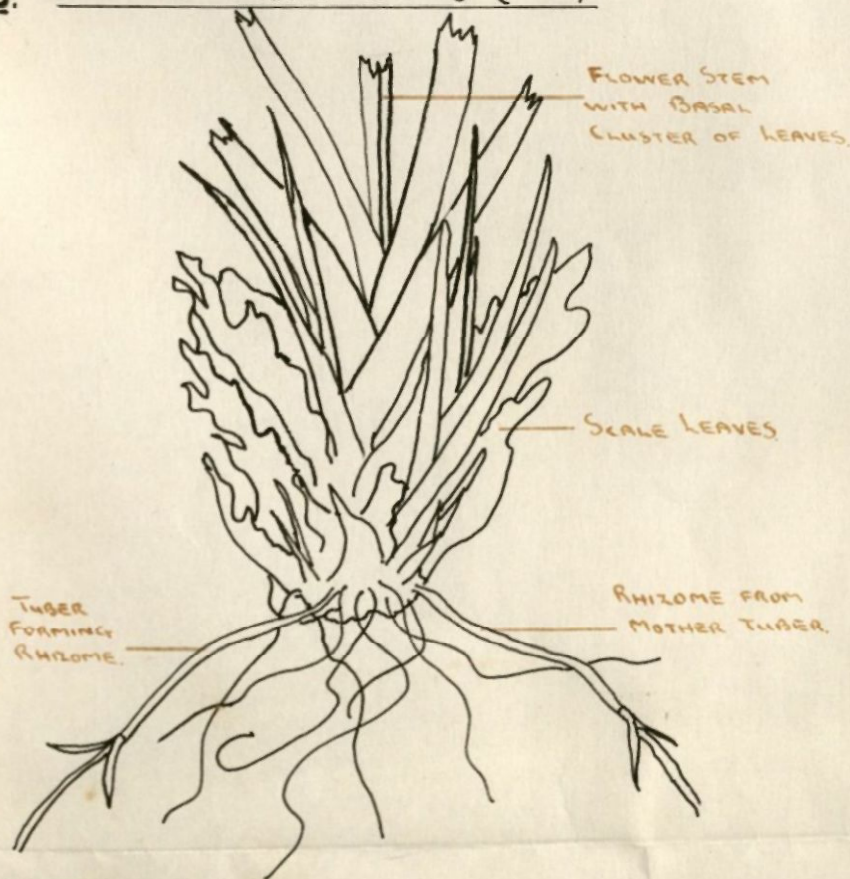
* CORNLIKE SWELLING MORE ACCURATELY DESCRIBES THE "BASAL BULB".



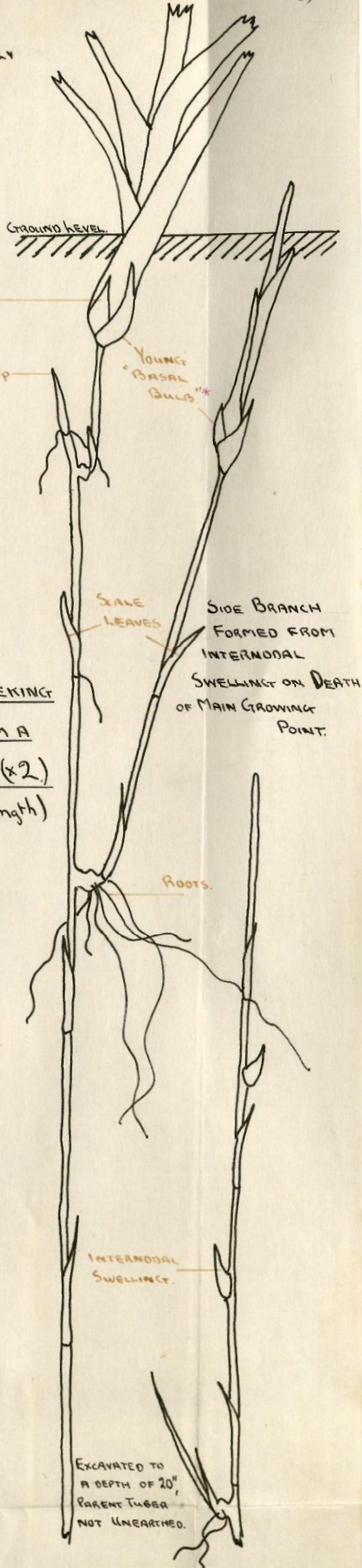
A. MATURE "BASAL BULB" (x4.)



B. YOUNG "BASAL BULB" (x4.)



C. "BASAL BULB" SHOWING PRODUCTION OF NEW SHOOTS AFTER FLOWERING (x3.)

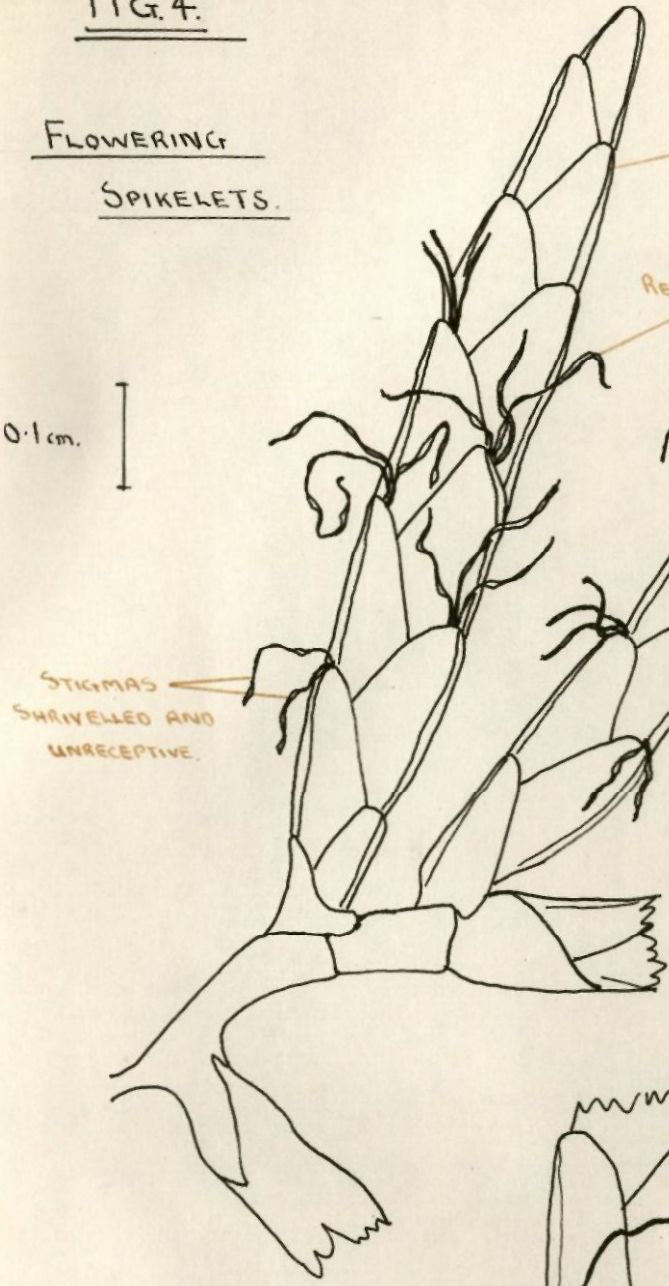


D. SURFACE SEEKING RHIZOME FROM A DEEP TUBER (x2) (over 2' in length)

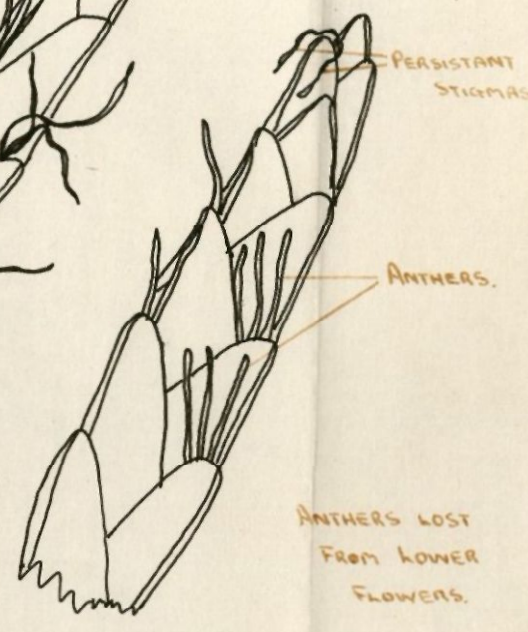
FIG. 4.

FLOWERING SPIKELETS.

0.1cm.



SPIKELET AT ANTHESIS



SINGLE FLOWER.

(GLUME AND STAMEN PULLED BACK)

GLUME OF ABOVE FLOWER.

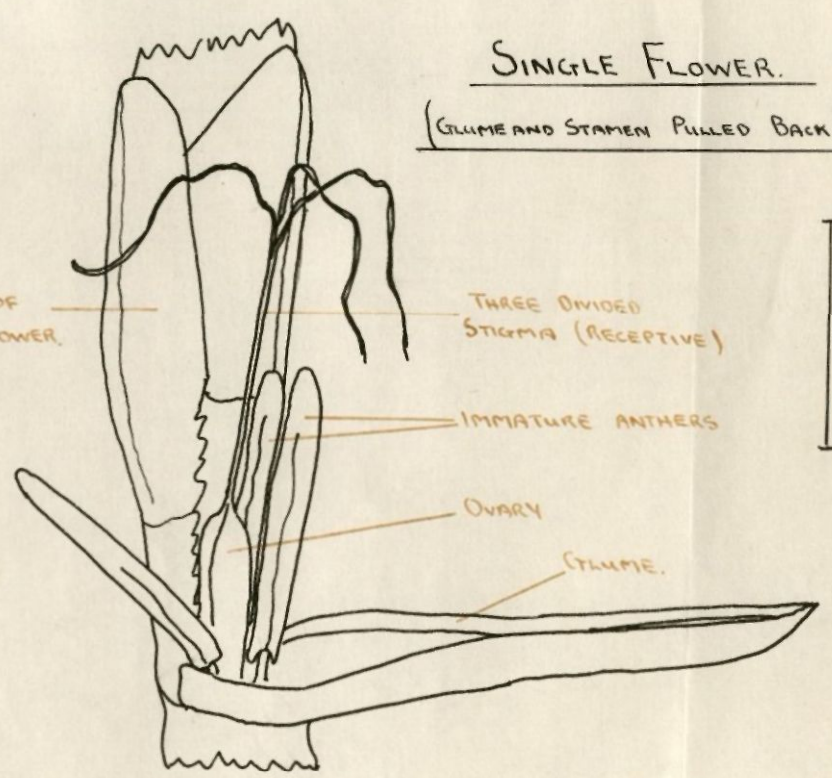
THREE DIVIDED STIGMA (RECEPTIVE)

IMMATURE ANTHERS

OVARY

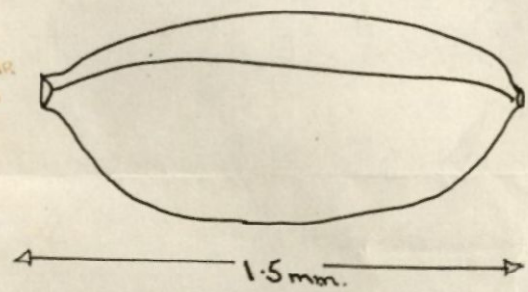
GLUME.

0.1cm.



FRUIT (ACHENE)
(single seeded)

STYLAR END



FRUIT. T.S.

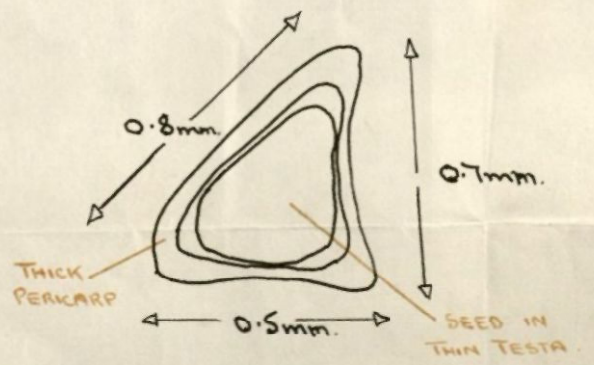
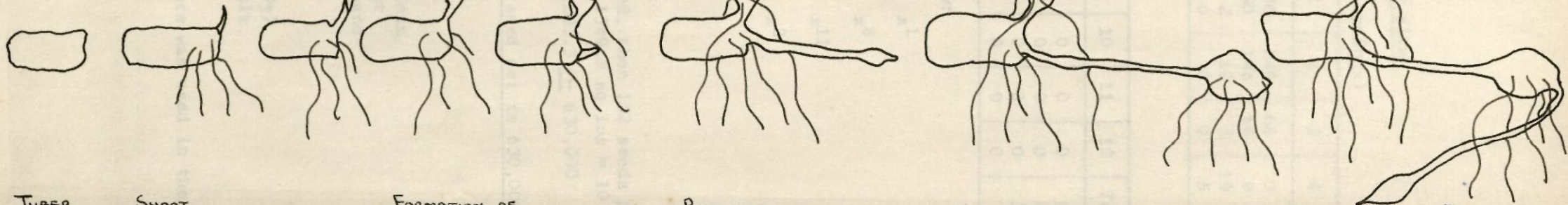


FIG. V

DEVELOPMENT OF NUT-GRASS FROM
A SINGLE DORMANT TUBER.

GROUND LEVEL



TUBER
PLANTED

SHOOT
DEVELOPMENT

FORMATION OF
CORMLIKE SWELLING

RHIZOME
DEVELOPMENT

MATURATION OF
NEW TUBER.

FLOWERING AND FURTHER
UNDERGROUND DEVELOPMENT.

2 DAYS

4 DAYS

6 DAYS

10 DAYS

2-2½ WEEKS

2½-3½ WEEKS.

4 WEEKS.

APPROXIMATE TIME SCALE.

Appendix II

(i) Distribution of tubers in the soil at three sites

Site A (4 borings)

	1	2	3	4	Total
0-3"	3	10	0	114	127
3-6"	0	6	0	11	17
6-9"	0	6	1	4	11
9-12"	0	0	0	0	0

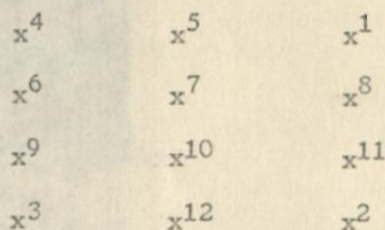
Site B (4 borings)

	1	2	3	4	Total
0-3"	186	140	66	0	392
3-6"	80	146	16	9	251
6-9"	2	19	3	19	43
9-12"	0	0	0	5	5

Site C (12 borings)

	1	2	3	4	5	6	7	8	9	10	11	12	Total
0-3"	29	1	4	27	16	0	2	9	0	0	0	0	84
3-6"	1	0	6	21	15	0	1	5	0	0	0	0	49
6-9"	1	0	0	31	5	0	0	0	0	0	0	0	37
9-12"	0	0	0	0	1	0	0	0	0	0	0	0	1

Site C borings made on a square as shown below:



(ii) Calculation for degree of seed setting

314 flowerheads produced in 33 days.

Assuming half of this number produces one seed, then 152 seeds produced. This occurred on 10,000 sq.cms (4 x 2,500) = 1549.8 sq.ins = 10.8 sq.ft.

Then seeds per acre = $\frac{157 \times 43,560}{10.8} = 633,233.3 \approx 630,000$

Therefore average seed produced per acre per seed set is 630,000

(iii) Seed compost used

- 2 parts by loose bulk medium loam
- 1 part " " " good peat
- 1 part " " " coarse sand

To each bushel of this mixture are added:

- 1½ oz. superphosphate (16% P₂O₅)
- ¾ oz. ground limestone or chalk.

N.B. 1 kerosene tin holds ½ bushel and this measure was used in the mixings.

Appendix III

Competition experiments - Layout

(i)



Left (looking North):

Showing spacing of pots on the wire grids and degree of shade thrown by the roof of the plant house.

(ii)

M.O.28	*M.F.28	M.O.0	*M.O.7
M.F.0	*M.O.7	M.O.7	*M.O.28
M.F.28	*M.F.0	*M.F.0	M.O.14
M.F.14	*M.O.14	*M.F.14	*M.F.14
*M.F.28	M.O.14	M.F.28	*M.F.7
M.F.7	M.O.0	*M.O.0	M.F.14
*M.O.28	M.F.7	M.F.7	M.O.28
*M.O.0	M.O.7	M.F.0	*M.F.14

*Taken for first harvest

R = Radish

M = Millet

F = Fertilised

O = Unfertilised

0 = No tubers planted

7 = 7 " "

14 = 14 " "

28 = 28 " "

57 to 64 49 to 56

41 to 48 33 to 40

R.F.0	*R.O.7
R.F.0	*R.O.28
R.F.28	R.F.7
R.O.0	*R.F.14
R.O.14	*R.O.14
R.O.0	R.F.7
R.O.28	R.F.14
R.O.7	*R.F.28

*R.F.14	R.F.28
R.O.7	*R.O.28
R.O.28	*R.F.28
R.O.14	*R.F.0
*R.F.0	R.F.14
*R.O.0	*R.O.0
*R.O.14	*R.F.7
*R.O.7	*R.F.7

25 to 32 17 to 24

9 to 16 1 to 8

Pot Numbers (reading upwards)

(iii) Calculations for amounts of fertiliser to be used

Recommended rates: 5 cwts/acre Sulphate of ammonia
6 cwts/acre Superphosphate
4 cwts/acre Potassium sulphate

An 8" pot was found to contain about 8 lbs of soil.

Enough soil was mixed up to fill 36 pots \equiv 288 lbs of soil.

$$288 \times 453 = 131376 \text{ g. (131400 g. approx.)}$$

1 cwt per acre is recognised as a ratio of 1/20,000.

\therefore in amount of soil mixed equivalent of 1 cwt per acre = 6.5 g./131400.

Then

5 cwts/acre	Sulphate of ammonia	is 32.5 g. in 288 lbs soil
6 cwts/acre	Superphosphate	is 39.0 g. " " " "
4 cwts/acre	Potassium sulphate	is 26.0 g. " " " "

(iv) Number of tubers per string

Counts made at second harvest of millet experiment. Unbroken strings of more than three tubers recorded.

M.O.7	5,8,6
M.O.7	4,8,5,8
M.O.14	6,6,8,5,8,5,5,5,5
M.O.14	5,5,4,4
M.O.28	5,4,4,6,5
M.O.28	6,5,5,6,5,6

M.F.7	4,11,9,5,6
M.F.7	8,5,7
M.F.14	14,7,4,4,7,6,6,5
M.F.14	5,6,9,5,5
M.F.28	5,5,4,4,5,4,5
M.F.28	7,5,5,5,6,5,5,5

(v) Rhizome lengths between mature tubers

Counts made on a selection of strings (measurements in inches)

M.O.7	5,4 $\frac{1}{2}$,3 $\frac{1}{2}$ *
M.O.14	5,6 $\frac{1}{2}$,5 $\frac{3}{4}$,2 $\frac{1}{2}$ *
	4,3*,4*,5 $\frac{1}{2}$,3 $\frac{1}{2}$
M.O.28	4 $\frac{3}{4}$ *,6,7,
	5 $\frac{1}{2}$,3 $\frac{1}{2}$ *,2 $\frac{1}{2}$ *,5 $\frac{1}{4}$
	3 $\frac{1}{2}$,7 $\frac{1}{4}$,7 $\frac{1}{2}$

M.F.7	5 $\frac{3}{4}$,1 $\frac{1}{4}$,2 $\frac{3}{4}$ *,4 $\frac{1}{2}$ *,5 $\frac{1}{4}$,5 $\frac{1}{2}$
	3,3 $\frac{1}{2}$,4 $\frac{1}{4}$,2 $\frac{1}{4}$ *
	5,4 $\frac{3}{4}$,3 $\frac{1}{2}$ *,2 $\frac{1}{2}$ *
	4,5 $\frac{1}{2}$,5,5 $\frac{1}{2}$ *,2 $\frac{3}{4}$ *,4 $\frac{1}{2}$,3 $\frac{1}{2}$
M.F.14	5 $\frac{3}{4}$,7,5 $\frac{3}{4}$ *,3 $\frac{3}{4}$ *,6

*Rhizome from mother tuber

(vi) Competition experiment I (Radish) Results (all weights in g.)

Pot No.	Pot Type	No. of tubers	Wt of tubers	Mean tuber wt	No. of nut-grass shoots	Wt of shoots	Mean wt of shoots	No. of crop leaves	Wt of leaves	Wt of stem	Total Plant
* 3	0.0	-	-	-	-	-	-	54			2.56
* 11	0.0	-	-	-	-	-	-	52			2.35
27	0.0	-	-	-	-	-	-	53	2.56	1.52	4.08
29	0.0	-	-	-	-	-	-	51	2.79	1.09	3.88
* 9	0.7	13	5.5	0.46	9	1.64	0.21	45			2.06
* 24	0.7	15	7.0		7	1.70		51			1.96
15	0.7	37	13.5	0.41	16	2.50	0.23	48	2.03	1.13	3.16
25	0.7	38	17.0		12	4.02		44	1.38	0.91	2.29
* 10	0.14	33	14.0	0.48	29	3.66	0.15	39			1.34
* 20	0.14	33	17.5		20	3.82		40			1.42
13	0.14	48	25.5	0.52	21	4.88	0.23	38	1.15	0.66	1.89
28	0.14	55	28.0		23	5.03		37	1.02	0.44	1.46
* 7	0.28	49	23.0	0.51	44	6.22	0.16	46			1.00
* 23	0.28	57	31.5		38	6.55		40			1.40
14	0.28	88	42.0	0.48	47	7.44	0.19	37	0.70	0.41	1.11
26	0.28	99	48.5		36	8.32		42	1.16	0.76	1.92
* 5	F.0	-	-	-	-	-	-	65			4.40
* 12	F.0	-	-	-	-	-	-	65			4.96
31	F.0	-	-	-	-	-	-	60	4.11	2.46	6.57
32	F.0	-	-	-	-	-	-	59	4.81	3.54	8.35
* 1	F.7	21	8.5	0.43	14	2.27	0.21	51			2.75
* 2	F.7	31	14.0		16	4.05		54			2.30
19	F.7	46	25.0	0.50	13	4.90	0.29	54	2.03	1.42	3.45
22	F.7	43	19.5		18	4.17		63	3.02	2.10	5.12
* 16	F.14	27	16.5	0.57	19	3.85	0.24	47			1.82
* 21	F.14	40	22.0		22	5.94		54			2.73
4	F.14	58	22.5	0.43	26	5.06	0.22	59	2.74	2.10	4.84
18	F.14	57	27.0		27	6.76		42	1.58	1.38	2.96
* 6	F.28	54	41.0	0.62	50	11.79	0.21	44			1.22
* 17	F.28	55	33.5		48	8.30		45			1.65
8	F.28	104	49.0	0.50	39	10.18	0.24	43	1.28	0.72	2.00
30	F.28	107	57.0		49	10.53		34	1.11	0.88	1.99

*1st Harvest

(vii) Analysis of competition experiment I (Radish) Results

Total radish plant weight

First harvest

	<u>D.F.</u>	<u>S.S.</u>	<u>M.S.</u>	<u>F.</u>	
Replicates	1	0.16	0.16	Not significant	
Nut-grass levels	3	11.14	3.71	36.57 ^{xxx}	\bar{x} = 2.25
Fertiliser levels	1	3.74	3.74	36.88 ^{xxx}	C.of V. = 13.03
Nut-grass x Fertiliser	3	2.33	0.78	7.65 ^x	S.E. = 0.32
Error	7	0.71	0.10		
Total	15	18.08			

Second harvest

Replicates	1	0.05	0.05	Not significant	
Nut-grass levels	3	33.87	11.29	14.32 ^{xx}	\bar{x} = 3.44
Fertiliser levels	1	15.00	15.00	19.03 ^{xx}	C.of V. = 25.74
Nut-grass x Fertiliser	3	4.73	1.58	Not significant	S.E. = 0.89
Error	7	5.52	6.79		
Total	15	59.16			

Both harvest periods

Replicates	1	0.19	0.19	Not significant	
Nut-grass levels	3	41.91	13.64	37.10 ^{xxx}	\bar{x} = 2.89
Fertiliser levels	1	16.86	16.86	45.88 ^{xxx}	C.of V. = 20.17
Harvesting time	1	11.46	11.46	31.18 ^{xxx}	S.E. = 0.61
Nut-grass x Fertiliser	3	6.68	2.23	6.06 ^{xx}	
Nut-grass x Harvesting	3	3.10	1.03	Not significant	
Harvesting x Fertiliser	1	1.88	1.88	5.11 ^{xx}	
Error	18	6.62	0.37		
Total	31				

Radish leaf weight

Replicates	1	0.01	0.01	Not significant	
Nut-grass levels	3	13.83	4.61	18.28 ^{xxx}	\bar{x} = 2.09
Fertiliser levels	1	3.89	3.89	15.39 ^{xx}	C.of V. = 20.98
Nut-grass x Fertiliser	3	1.19	0.40	Not significant	S.E. = 0.50
Error	7	1.77	0.25		
Total	15	20.69			

Radish leaf number

	<u>D.F.</u>	<u>S.S.</u>	<u>M.S.</u>	<u>F.</u>
Replicates	1	3	3	N.S.
Nut-grass levels	3	1224	408	18.55 ^{xxx}
Fertiliser levels	1	464	464	21.09 ^{xxx}
Harvesting time	1	24	24	N.S.
Nut-grass x Fertiliser	3	159	53	N.S.
Nut-grass x Harvesting	3	32	11	N.S.
Fertiliser x Harvesting	1	2	2	N.S.
Error	18	397	22	
Total	31	2305		

\bar{x} = 48.63
 C. of V. = 9.64
 S.E. = 4.69

Nut-grass tuber number

Replicates	1	70	70	N.S.
Nut-grass levels	2	9599	4800	223.26 ^{xxx}
Fertiliser levels	1	330	330	15.35 ^{xxx}
Harvesting time	1	4845	4845	225.36 ^{xxx}
Nut-grass x Fertiliser	2	52	26	N.S.
Nut-grass x Harvesting	2	638	219	10.19 ^{xx}
Fertiliser x Harvesting	1	5	5	N.S.
Error	13	279	21.5	
Total	23			

\bar{x} = 50.8
 C. of V. = 9.13
 S.E. = 4.64

Mean tuber weight

Nut-grass levels	2	122	61	N.S.
Fertiliser levels	1	29	29	N.S.
Harvesting time	1	43	43	N.S.
Error	7	199	28.4	
Total	11	393		

\bar{x} = 0.49
 C. of V. = 13.58
 S.E. = 0.053

Mean nut-grass shoot weight

Nut-grass levels	2	26	13	N.S.
Fertiliser levels	1	48	48	8.617 ^x
Harvesting time	1	40	40	7.181 ^x
Error	7	39	5.57	
Total	11	153		

\bar{x} = 0.22
 C. of V. = 10.97
 S.E. = 0.024

(viii) Competition experiment II (Millet) Results (all weights in g.)

Pot No.	Pot Type	No. of tubers	Wt of tubers	Mean tuber wt	No. of nut-grass shoots	Wt of shoots	Mean wt of shoots	No. of crop leaves	No. of crop plants	Wt of ears	Plant wt	Total plant wt
* 43	0.0	-	-	-	-	-	-	95	14			5.07
* 57	0.0	-	-	-	-	-	-	98	14			5.04
48	0.0	-	-	-	-	-	-	75	14	4.76	6.27	11.03
51	0.0	-	-	-	-	-	-	68	14	2.90	11.55	14.45
* 40	0.7	26	17.0	0.70	13	3.8	0.28	36	8			0.37
* 55	0.7	25	18.5		13	3.8		85	14			2.15
47	0.7	46	30.0	0.64	15	3.72	0.21	53	14	2.11	2.32	4.43
49	0.7	38	24.0		14	2.33		58	14	3.43	4.13	7.56
* 37	0.14	44	21.5	0.50	21	4.61	0.21	85	14			1.13
* 53	0.14	41	21.0		24	4.81		85	14			1.73
38	0.14	77	40.5	0.54	25	4.84	0.20	57	14	2.15	2.09	2.32
52	0.14	77	42.0		25	5.14		66	14	1.03	1.29	2.32
* 39	0.28	76	42.5	0.53	40	7.73	0.18	33	11			0.11
* 58	0.28	71	36.0		42	7.38		72	13			1.05
34	0.28	123	63.5	0.57	50	7.66	0.17	57	14	0.79	0.90	1.69
64	0.28	120	75.0		44	8.00		47	13	1.06	1.45	2.46
* 46	F.O	-	-	-	-	-	-	107	14			10.09
* 54	F.O	-	-	-	-	-	-	114	14			9.11
41	F.O	-	-	-	-	-	-	87	14	8.19	17.12	25.31
63	F.O.	-	-	-	-	-	-	63	14	8.91	12.39	21.30
* 36	F.7	33	20.0	0.51	18	4.76	0.25	76	14			2.26
* 50	F.7	42	18.5		17	3.97		108	14			7.95
42	F.7	51	22.5	0.57	16	3.30	0.24	57	14	4.25	6.49	10.74
59	F.7	53	37.0		15	4.01		44	14	3.27	6.24	9.51
* 33	F.14	47	23.5	0.57	25	4.71	0.21	84	14			1.94
* 45	F.14	49	31.0		28	6.61		77	13			1.58
35	F.14	90	52.0	0.57	27	6.66	0.24	66	14	2.77	3.69	6.46
61	F.14	75	42.0		25	5.56		37	14	2.65	2.46	5.11
* 56	F.28	72	40.0	0.56	50	9.13	0.20	55	12			0.29
* 60	F.28	99	55.5		50	10.96		74	14			1.07
44	F.28	135	79.5	0.57	54	10.50	0.20	40	11	0.58	0.63	1.21
62	F.28	136	76.5		44	9.44		51	11	0.35	0.44	0.79

* 1st Harvest

(ix) Analysis of competition experiment II (Millet) Results

Total Millet plant weight

First harvest

	<u>D.F.</u>	<u>S.S.</u>	<u>M.S.</u>	<u>F.</u>
Replicates	1	4.43	4.43	N.S.
Nut-grass levels	3	104.87	34.96	16.52 ^{XX}
Fertiliser levels	1	19.45	19.45	9.19 ^X
Nut-grass x Fertiliser	3	16.11	5.37	N.S.
Error	7	14.81	2.12	
Total	15	159.67		

\bar{x} = 3.18
 C. of V. = 45.75
 S.E. = 1.46

Second harvest

Replicates	1	0.16	0.16	N.S.
Nut-grass levels	3	616.94	205.65	63.61 ^{XXX}
Fertiliser levels	1	64.84	64.84	20.05 ^{XX}
Nut-grass x Fertiliser	3	71.15	23.72	7.33 ^X
Error	7	22.63	3.23	
Total	15	775.73		

\bar{x} = 8.04
 C. of V. = 22.37
 S.E. = 1.80

Both harvest periods

Replicates	1	1.45	1.45	N.S.
Nut-grass levels	3	615.08	205.03	67.07 ^{XXX}
Fertiliser levels	1	77.78	77.78	25.44 ^{XXX}
Harvesting time	1	188.52	188.52	61.67 ^{XXX}
Nut-grass x Fertiliser	3	72.67	24.23	7.92 ^{XX}
Nut-grass x Harvesting	3	106.73	35.58	11.64 ^{XXX}
Harvesting x Fertiliser	1	6.67	6.67	N.S.
Error	18	55.02	3.06	
Total	31	1123.92		

\bar{x} = 5.61
 C. of V. = 31.16
 S.E. = 1.75

Millet head weight

Replicates	1	0.26	0.26	N.S.
Nut-grass levels	3	65.28	21.76	40.48 ^{XXX}
Fertiliser levels	1	10.22	10.22	19.02 ^{XXX}
Nut-grass x Fertiliser	3	14.48	4.83	8.98 ^{XX}
Error	7	3.76	0.54	
Total	15	94.00		

\bar{x} = 3.07
 C. of V. = 23.89
 S.E. = 0.73

Millet leaf number

	<u>D.F.</u>	<u>S.S.</u>	<u>M.S.</u>	<u>F.</u>
Replicates	1	220	220	N.S.
Nut-grass levels	3	5049	1683	8.09 ^{xxx}
Fertiliser levels	1	153	153	N.S.
Harvesting time	1	4005	4005	19.26 ^{xxx}
Nut-grass x Fertiliser	3	473	158	N.S.
Nut-grass x Harvesting	3	476	159	N.S.
Fertiliser x Harvesting	1	631	631	N.S.
Error	18	3743	208	
Total	31	14750		

\bar{x} = 69.06
 C. of V. = 16.46
 S.E. = 14.42

Nut-grass tuber number

Replicates	1	2	2	N.S.
Nut-grass levels	2	17215	8608	193.44 ^{xxx}
Fertiliser levels	1	580	580	13.03 ^{xx}
Harvesting time	1	6534	6534	146.83 ^{xxx}
Nut-grass x Fertiliser	2	60	30	N.S.
Nut-grass x Harvesting	2	1129	565	12.69 ^{xxx}
Fertiliser x Harvesting	1	0	0	N.S.
Error	13	578	44.5	
Total	23	26098		

\bar{x} = 68.58
 C. of V. = 9.73
 S.E. = 6.67

Mean tuber weight

Nut-grass levels	2	80	40	N.S.
Fertiliser levels	1	7	7	N.S.
Harvesting time	1	14	14	N.S.
Error	7	228	33	
Total	11	329		

\bar{x} = 0.57
 C. of V. = 10.10
 S.E. = 0.057

Mean nut-grass shoot weight

Nut-grass levels	2	66	33	7.5 ^x
Fertiliser levels	1	3	3	N.S.
Harvesting time	1	7	7	N.S.
Error	7	31	4.4	
Total	11	107		

\bar{x} = 0.21
 C. of V. = 9.94
 S.E. = 0.021