AGRICULTURAL RESEARCH COUNCIL

WEED RESEARCH ORGANIZATION

TECHNICAL REPORT No. 37

STUDIES ON IMPERATA CYLINDRICA (L.) BEAUV. AND EUPATORIUM ODORATUM L.

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October 1975

Price

UK and overseas surface mail - £1.75
Overseas airmail - £3.20

BEGBROKE HILL, YARNTON, OXFORD

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STUDIES ON IMPERATA CYLINDRICA (L.) BEAUV. AND EUPATORIUM ODORATUM L.

by

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Weed Research Project R 2552, 1971-1973

SUMMARY Under the 2-year Weed Research Project sponsored by ODM at the Department of Agronomy, University of Ibadan the distribution, biology and control of *Imperata cylindrica* and *Eupatorium odoratum* were studied in a series of field, laboratory and greenhouse investigations. *I. cylindrica* was found to be most abundant in the derived savanna zone, where it is a serious weed of maize, cassava and other arable crops. Control by cultivation is possible if tractor-drawn implements are operated deeply enough to break up the majority of the rhizomes under conditions promoting loss of viability by drying. Dalapon was found to give lasting control at a dose of 15 kg (a.e.)/ha, being best applied to the regrowth developing after ploughing. Glyphosate was also a promising herbicide and there are control possibilities with asulam and TFP. *E. odoratum* is especially troublesome in the forest zone as a weed of young oil-palm and fallow land. Biological control has been under investigation for several years but is likely to need reinforcing by other measures such as uprooting, cutting and spraying. Application of relatively high doses of 2,4-D to young regrowth kills a large proportion of the roots and can be used as a pre-planting treatment. A mixture of picloram and 2,4-D was found considerably more effective and could be a promising alternative used prior to the growing of crops resistant to picloram residues. Established *E. odoratum* plants were also killed by relatively high doses of atrazine.

Biological work centred on rhizome studies of *I. cylindrica*, including their response to fragmentation, burial and desiccation, and on various aspects of the seed biology of *E. odoratum*. Suggestions are given for practical control measures sufficiently promising for promotion by the extension services.

1. INTRODUCTION

1.1 General

This report gives an account of a series of studies on the biology and control of two perennial weeds of major importance in West Africa, *Imperata cylindrica* (L.) Beauv. and *Eupatorium odoratum* L., sponsored by ODM under Research Scheme R 2552. The work was carried out at the University of Ibadan, Nigeria between 1971 and 1973.

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1.2 The problem of Imperata cylindrica

I. cylindrica (speargrass) is distributed throughout most tropical and sub-tropical parts of the world. It is of particular importance in South-East Asia, where it forms a major weed problem of plantation and arable crops. In West Malaysia, for example, Basnayake (1966) estimated that 4,000,000 acres of rubber plantation were infested and very extensive infestations exist in Indonesia and the Philippines (Soerjani 1970). The Asian grass is *I. cylindrica* var. *major* (Nees) C E Hubbard, which extends to Madagascar and parts of East Africa and is stated by Hutchinson and Dalziel (1972) to be more aggressively rhizomatous than the common West African var. *africana* (Anderss.) C E Hubbard. A third variety, var. *cylindrica*, distributed in North Africa, the Mediterranean region and the Middle East, also extends into northernmost Nigeria but is of less importance as a weed.

I. cylindrica var. *africana* extends throughout tropical and southern Africa and in West Africa is common from Senegal to the Cameroon Republic. Within this area it occurs in a wide range of habitats from the coast to the Sudan zone in the north, but it is most characteristic of the savanna woodland and often the dominant grass in seasonally swampy areas. Its presence is generally associated with the frequent occurrence of grass fires. In the weed control literature *Imperata* is referred to mostly as a weed of oil-palm and coconuts in West Africa and it can seriously check the growth of young trees in new plantations. However, it constitutes a far more extensive problem in areas of arable farming, where the lack of adequate equipment for cultivating and the decreasing duration of fallows combine to make it a very persistent weed.

Although no information is available on the magnitude of crop losses due to *Imperata*, there is little doubt that such losses are considerable. The traditional hand hoeing of the small scale subsistence cultivator gives temporary control of the weed and normally allows a crop to be obtained, though yields are generally low in *Imperata* areas. Under larger scale crop production systems using mechanical equipment, unless particular care is taken in land preparation, even greater losses may occur due to difficulties in achieving adequate interrow cultivation.

Work on the control of *Imperata* has been largely based on finding methods suitable for use against var. *major* in rubber plantations. Success has been achieved with repeated application of sodium arsenite, followed by wiping with herbicidal oils (Childs 1956) and, more recently, with dalapon, either alone (Riepma 1968) or with subsequent application of paraquat (Seth 1970).

Less information exists on var. *africana*. In the Ivory Coast, Guillon (1968) reported good results in coconut plantations with dalapon applied at 20 kg/ha, followed 4 weeks later by a further 10 kg/ha. In northern Nigeria Watson (1959) obtained effective control for 5 months with a single low dose of 6 lb/acre (6.7 kg/ha) of dalapon though, in the south, Sheldrick found that, with doses below 18 lb/acre (20 kg/ha), healthy new shoots were emerging after 3 months (WAIFOR 1962). No work appears to have been done on control of *Imperata* in relation to arable farming systems.

1.3 The problem of Eupatorium odoratum

E. odoratum (Siam weed) is a perennial, composite shrub, native to the West Indies and tropical America but now widely distributed in the tropics.

It was first noted in Nigeria growing near Enugu in a forestry plantation of Gmelina arborea. The trees had been grown from seed imported in 1937 from Ceylon, where it was already well established, and it is assumed to have arrived as a contaminant of this shipment (Odukwe 1965). The initial spread of the weed was slow but, after about 1955 when it was observed to have crossed the river Niger, it appears to have spread rapidly westwards through the forest areas of the Mid-West and Western states, being recorded in the vicinity of Lagos in 1960. It is a very prominent weed of roadsides in the forest zone and extends into the forest in the wake of clearing operations. It now occupies large areas of land cleared for crop production or forest planting and is still spreading as suitable new sites are opened up.

E. odoratum grows very rapidly under favourable conditions, reaching a height of up to 3 m from seed in a single season, and forms a serious weed problem in young plantations, especially of oil-palm. As it produces very large numbers of light, wind-borne seeds in the first season, dense infestations can build up in two or three years. Regrowth after cutting is no less rapid and, in newly planted oil-palm, cutting must be done two or three times annually to prevent the weed from shading the palms and dominating the leguminous cover crop normally planted in the inter-rows. As few plantations in Nigeria are suitable for mechanical maintenance, weed slashing is normally done by hand and the operation is slow and expensive. The benefits of keeping Eupatorium under control, however, are shown by Sheldrick's (1968) observation that palms started fruiting two years earlier where the weed was kept in check than in neighbouring areas which were less well maintained.

Eupatorium is also a common weed of arable land in the forest zone and, although its seedlings are readily destroyed by cultivation, fallow land soon develops into Eupatorium thicket in many areas. Problems arise in the preparation of such land for cropping when stumps of the weed become re-established after the initial cultivation and have to be dug out expensively by hand.

The weed cannot survive when shaded by taller-growing plants, so that it does not grow in closed forest and is normally shaded out of forest tree plantations in a few years. Claims have been made that Eupatorium in forest plantings prevents invasion by Imperata and that it can even invade and suppress this grass. Imperata certainly appears to be a more serious problem in young plantations, where it reduces tree growth and increases the fire hazard so that, in the context of forestry, Eupatorium is regarded more as a cover crop than a weed.

The possibility of controlling E. odoratum biologically was first suggested in 1961 by Simmonds (1961) and, from 1967 onwards, funds have been made available by the Nigerian government to sponsor an investigation of possible control agents by the Commonwealth Institute of Biological Control in Trinidad. The funds have been administered by a Coordinating Committee on Siam Weed Control Projects, which also supports studies on the weed at several centres within Nigeria.

There are few references in the literature to chemical control, though George (1968) reported that the high dose of 7 kg/acre (17.3 kg/ha) of 2,4-D was needed to kill E. odoratum in India. In Nigeria Sheldrick (1968) also reported regrowth from below ground 5 months after the aerial parts had been killed by 2,4,5-T or a 2,4-D/2,4,5-T mixture at 5 lb/acre (5.6 kg/ha) but found that plants were killed by atrazine or diuron at 4-5 lb/acre (4.5-5.6 kg/ha). Little practical use of herbicides, however, has been made for Eupatorium control in Nigeria.

2. RESEARCH STUDIES

2.1 Surveys of distribution

The results of observations made in the course of numerous journeys by road through the southern parts of Nigeria are summarised in Fig. 1. I. cylindrica is recorded from all parts of the country but presents the worst problems in the derived savanna zone, where extensive areas are heavily infested. It is especially prominent in farm and fallow land in the Oyo, Iseyin, Lanlate area of Oyo district in the Western State and ubiquitous through much of the Tiv and Wukari divisions of Benue-Plateau State. In addition it was recorded as a major weed of farmland in a number of districts south and west of Jos during survey work by P Tuley for the Land Resources Division of ODM. In drier country, to the north of the line of 50 in. (2370 mm) mean annual rainfall, I. cylindrica is still common, but more restricted to wetter areas and a less important agricultural problem. It also extends into the forest zone and can be troublesome in long-established, cropped clearings. However, it does not appear to invade as rapidly after clearing as E. odoratum and is rarely a problem in the 'taungya' farming system, whereby land cleared of forest is cropped for one or two years before being replanted with trees.

E. odoratum is more characteristic of the forest zone, though it also extends into the derived savanna, particularly in the densely populated eastern districts where forest clearance has been most extensive. The majority of heavily infested areas occur where the annual rainfall exceeds 60 in. (1500 mm). The western and eastern limits are respectively the Dahomey border and the Katsina Ala river, beyond which, further eastwards spread would appear to be possible. In the drier country further north the weed does not appear to be able to survive among tall savanna grasses, which are burnt annually, and the few infestations reported are mostly on rocky, often thicketed hills, where the grass is shorter and fires less intense. Any major extension of the E. odoratum zone to the north thus appears unlikely.

In view of the suggested possibility that Eupatorium has value in suppressing Imperata, particular attention has been paid to areas where the species are associated. As shown in Fig. 1 there is little overlap in the west but the two species grow together in parts of the east, mostly in areas of 60-80 in. (1500-2000 mm) annual rainfall. These tend to be areas where intensive cultivation limits the extent and intensity of grass fires. Thus if replacement of Imperata by Eupatorium occurs, this may be more a result of protection from fire allowing succession to proceed towards the re-establishment of forest, rather than of a strong competitive ability on the part of the Eupatorium.

An experiment to obtain information on this question has been initiated at Yandev Crop Research Station, Benue-Plateau State, in cooperation with the Institute of Agricultural Research, Samaru. The plots are sited in an area of mixed Imperata and Eupatorium and the treatments include cutting, burning and dalapon spraying, the first two expected to favour the grass, the third to favour the Eupatorium. Results of this experiment are not yet available.

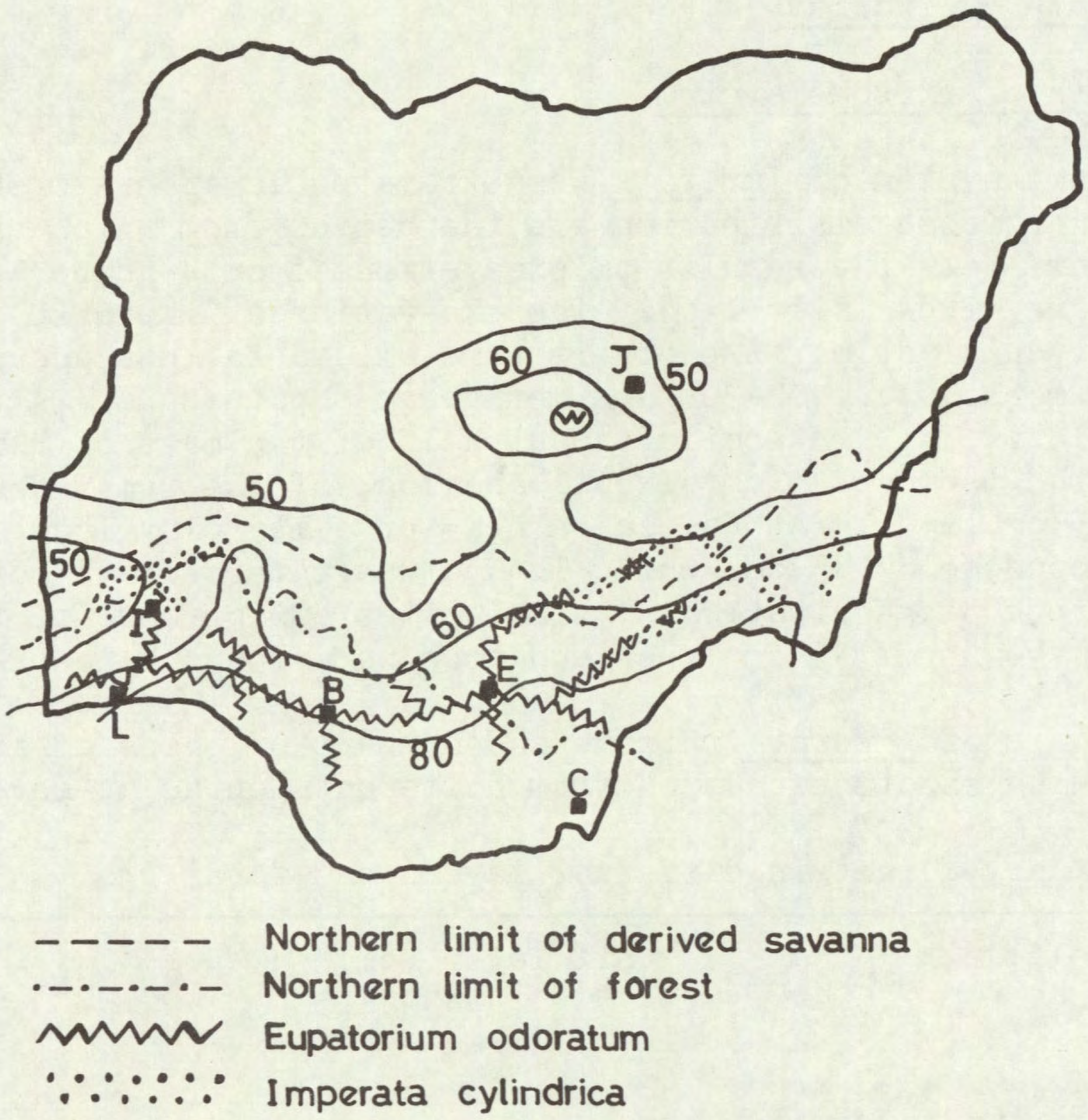

Fig. 1. Map of Nigeria showing limits of 50, 60 and 80 in. mean annual rainfall, the northern limits of the derived savanna and forest zones and areas densely infested with Eupatorium and Imperata. (Principal towns L = Lagos, I = Ibadan, B = Benin, E = Enugu, C = Calabar, J = Jos)

2.2 Biological studies, laboratory and greenhouse work

2.2.1 Imperata cylindrica

2.2.1.1 Depth of rhizome system

The rhizome system of Imperata was excavated in order to obtain information on rhizome distribution and the depths from which shoots reached the surface. The results of excavations from a number of typical infestations are given in Table 1. The excavation at Ilora (b) was done 2 months after cultivation, the others were all in fallows uncultivated for a year or more, with 100-200 emerged grass shoots/sq.m. At Ilora and Ilorin, on relatively light soils, about half of the mass of rhizomes was contained in the topmost 15 cm of soil and most of the remainder was found in the 15-22.5 cm layer. At Baissa, a heavier silty clay loam, little rhizome was found below 15 cm, while Ibadan was intermediate both in soil texture and depth of penetration. At all sites 80% or more of the shoots originated in the upper 15 cm layer and none were found below 22.5 cm.

Table 1. Weights of Imperata rhizome and numbers of bases of actively growing shoots excavated from different depths at several sites

% dry weight in different layers and total g/m^2

	Soil layer (cm)				
Site	0-7.5	7.5-15	15-22.5	22.5-30	Total
Ibadan	36	42	22	0	138
Ilora (a)	14	33	49	4	441
Ilora (b)	8	70	22	0	205
Ilorin	18	32	49	1	216
Baissa	46	50	4	0	187

% shoot bases in different layers and total $number/m^3$

	Soil layer (cm)				
Site	0-7.5	7.5-15	15-22.5	22.5-30	Total
Ibadan	82	16	3	0	207
Ilora (a)	58	22	20	0	336
Ilora (b)	11	83	6	0	288
Ilorin	47	45	8	0	226

(a) site not cultivated for more than 12 months
(b) site rotavated 2 months previously

It is significant that cultivation to a depth of about 7.5 cm at Ilora (b), while reducing the number of live shoots growing from above this level, appeared to have stimulated the production of shoots from below. The observations thus provide an explanation of why the normal ploughing or digging of Imperata fallows, which rarely disturbs the soil below about 10 cm, only temporarily checks the growth of the grass. They also suggest that a considerably greater degree of control would be expected to result from increasing the cultivation depth to 15 cm or more.

2.2.1.2 Fragmentation, burial and desiccation of rhizomes

By contrast with Agropyron repens (Johnson and Buchholtz 1962) small fragments of Imperata rhizome do not have a high degree of viability. In an experiment with sections of different length kept moist in petri dishes only 4% of 2-node sections sprouted in 4 weeks and the proportions both of sections and nodes producing shoots increased steadily with increasing section length, reaching 24% with the 6-node sections (Table 2). The table also shows the results of a similar experiment with rhizomes planted in pots at a depth of 7.5 cm. Most 2- and 3-node sections rotted in 2 months and none produced shoots above the soil surface, while 25% of 5- and 9-node sections grew healthy shoots and smaller numbers rotted.

Table 2. Effect of fragmentation on viability of Imperata rhizome sections

Number of nodes per section	In petri-dishes (4 weeks) % with shoots		In pots (2 months)	
	Sections	Nodes	% sections with shoots	% sections rotting
2	4	2	0	77
3	6	2	0	84
4	12	4	-	-
5	17	6	25	31
6	24	8	-	-
9	-	-	25	0

The establishment of plants from rhizomes is also affected by the depth of the sections in the soil. In another pot experiment, for example, it was found that, when 6-node sections were planted at a depth of 15 cm, only 6% produced healthy shoots above the surface after 6 weeks, compared with 31% from those planted at 7.5 cm.

The effect of loss of moisture on the viability of rhizomes was investigated in the desiccation experiments summarised in Table 3, where sprouting of 5-node rhizome sections was studied after drying on the laboratory bench for varying periods. It is clear that exposure to air for one or two days is sufficient for loss of viability, especially when the scale leaves, which form a continuous sheath round the younger rhizomes, are removed. It appears that loss of moisture and sprouting ability were more rapid in the hotter, drier conditions of January (mean daily maximum temperature 33°C, relative humidity at 12.00 hours 51%) than in August (temperature 28°C, R.H. 78%). Further work will be needed, however, to explain why in January the moisture content of the rhizomes had to fall from 65% to 33% before viability was lost though, in August, reduction from 79% to 62% was sufficient.

The results of this series of experiments help to support the suggestion that effective control of Imperata should result from cultivating deeply enough to break up the majority of the rhizome system. Small and deeply buried fragments do not appear to regenerate easily and relatively little drying is sufficient for loss of viability. During the dry season most soils in Imperata areas dry out to a considerable depth and any rhizomes disturbed by cultivation at this time would be expected to lose their viability rapidly. Even in the rainy season disturbed rhizomes on the surface would be expected to die in short dry intervals and, in longer rainless spells, it is probable that the soil dries out deeply enough for many buried rhizomes also to lose their regenerative ability.

Table 3. Effect of desiccation on viability of Imperata rhizome sections

Period dried at room temperature	Petri dishes August 1972 4 weeks		Pots January 1973 10 weeks	
	Moisture % of FW	% sections sprouting	Moisture % of FW	% sections sprouting
Fresh, undried				
+ scales	73	25	65	15
- scales	79	55	64	15
1 day				
+ scales	69	35	41	30
- scales	73	40	33	0
2 days				
+ scales	64	25	-	-
- scales	67	45	27	0
3 days				
+ scales	52	5	-	-
- scales	62	0	34	0
4 days				
+ scales	44	0	-	-
- scales	51	0	26	0

2.2.1.3 Studies on rhizome growth and dormancy

In addition to observing the basic features of rhizome biology, investigations on the growth of Imperata from rhizome sections were made both as a means of establishing plants for laboratory or greenhouse studies and as a possible way of testing the viability of rhizomes after treatment with herbicides in the field.

In several experiments rhizomes collected from the field were divided into age groups and sections from the apical, median and basal parts planted shallowly in pots. The proportions of sections developing shoots are summarised in the first 3 columns of table 4.

In general, the best establishment was obtained from the apical sections, very few shoots being produced by the basal sections of younger rhizomes or by old rhizomes. In October and February the greatest proportion of sprouting occurred from apical sections terminating in an aerial shoot. In July, however, the proportion was small, possibly an indication of dormancy. It is of interest that the greatest degree of rhizome sprouting noted (last column of table 4) occurred when long rhizome sections dug from the field in November were kept in closed polythene bags without soil for 4 weeks. Attempts to duplicate this result were not successful.

It should be noted that the results quoted were obtained with unselected rhizome sections. On a relatively small number of sections, mostly in the apical region, large shoot buds 1-2 mm long were present at the time of excavation and a separate selection of these in the February trial gave a high sprouting percentage (71%). The great majority of buds on other parts of the rhizome system were considerably smaller. It should also be noted that, when sections were divided into 3 classes according to thickness, many more of the thick and medium classes produced shoots than of the thinnest class.

Table 4. Percentage sprouting of sections from different parts of <u>Imperata</u> rhizome system (see Fig. 2)

	In pots			In bags
Month excavated	July 1972	October 1972	February 1973	October 1972
Weeks to assessment	6	12	12	4
A. Young apex	-	50	45	-
B. Apex forming aerial shoot	9	62	56	85
C.* Median region	44	41	23	68
C1 Subdivided	-	47	-	-
C2 as in	-	44	-	-
C3 Fig. 2	-	33	-	-
D.* Basal region	-	-	5	27
E. Old rhizome	6	-	-	25
Number of nodes	6	5	6	Average 15

* Differences between young and medium aged rhizomes small and inconsistent; average values given

In experiments with 6-node rhizome sections planted 2.5-7.5 cm deep most shoots were produced from the apical parts of the sections. Table 5 summarises the results of observations on sections excavated from pots 1-2 months after planting and shows that the proportion of buds sprouting was greater from the second and third nodes than from the node nearest the apex. The table also shows the overall proportions of sections producing 1, 2 or more shoots in these experiments. A single shoot only was produced from the majority and successively smaller proportions developed 2 or more. These observations are similar to those made in work on <u>Agropyron repens</u> at the Weed Research Organization (Leakey, R.R.B., personal communication) and suggest that the apical dominance system in <u>Imperata</u> may be similar in type.

In September 1972 6-node sections of young rhizome were planted 5 cm deep in pots to determine the pattern of growth under greenhouse conditions. As is shown in Table 6, a third of the sections had sprouted in 4 weeks and the proportion eventually rose to about 50%. Most of the remainder were still healthy in appearance after 3 months but showing no signs of growth. By the time the shoots reached a height of about 25 cm, one or more buds from the underground portion grew out horizontally to form secondary rhizomes, which reached lengths of up to 40-50 cm after 3 months.

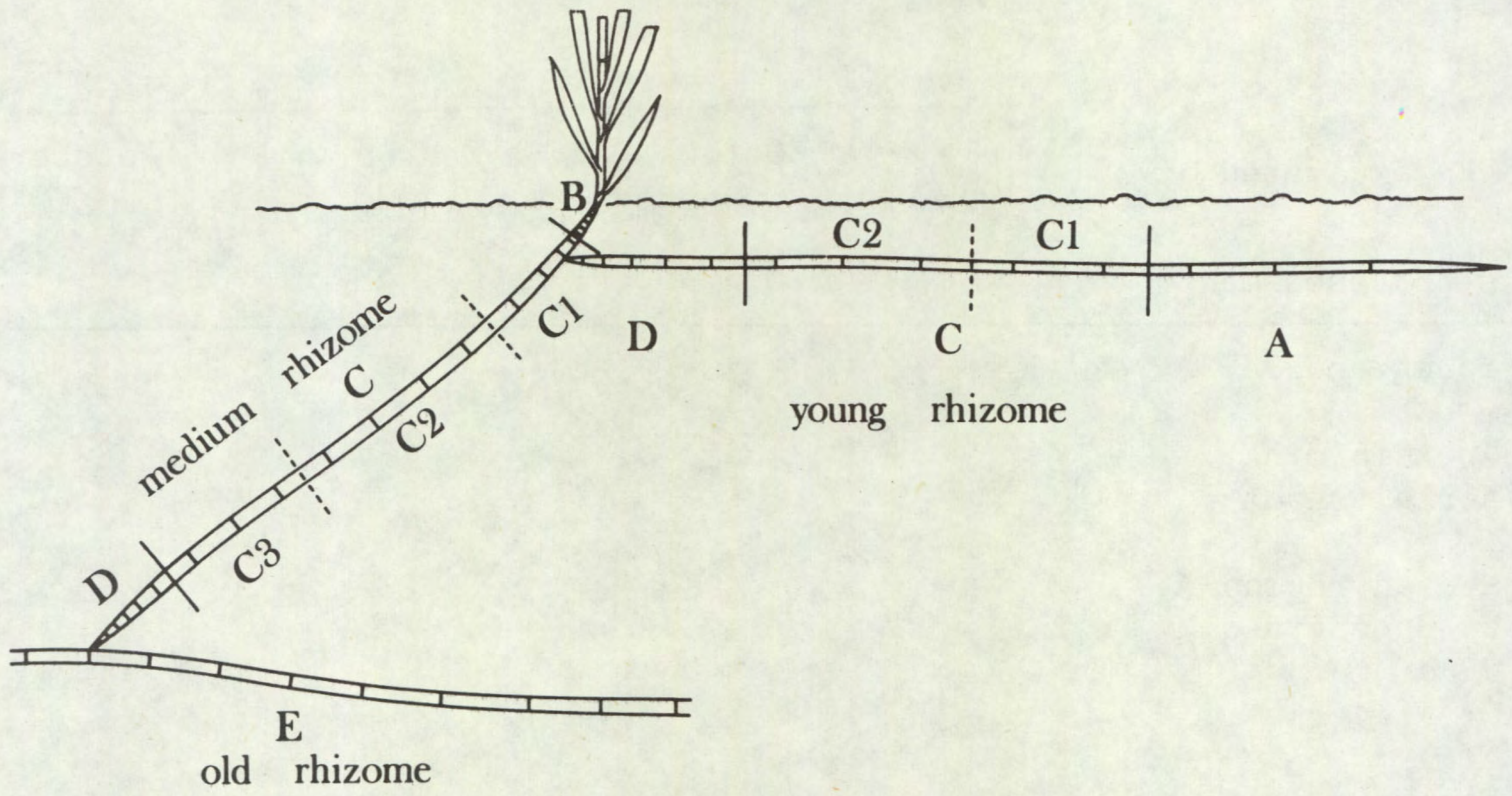

Fig. 2. Rhizome system of Imperata showing age classes and sections used in sprouting experiments summmarised in Table 4.

Secondary shoots and tertiary rhizomes were also produced and, at the time of the final observation, secondary shoots accounted for 25% of the total. The ratio of shoot to new rhizome remained more or less constant during the period of observation and no flowering occurred.

Table 5. Position of shoots on 6-node rhizome sections and numbers of shoots per section

Nodes numbered from apical end	1	2	3	4	5	6
Proportion with shoots (% of total shoots)	19	26	26	13	10	6
Number of shoots	1	2	3	4	5	6
% of sections with 1-6 shoots	54.9	29.3	11.7	3.7	0.4	0

A study was started on the possibility of using the growth regulators 'Ethrel' (2-chloroethylphosphonic acid) or chlorflurecol to break the dormancy of Imperata rhizome buds, but little success was obtained in the initial trials and this line of investigation was not pursued. At the doses tested (1.1 or 4.5 kg/ha applied to young plants as a spray or rhizome sections immersed in 25 or 250 ppm solutions for 24 hours before planting) chlorflurecol reduced or prevented shoot growth without increasing the production of rhizomes. Ethrel had no obvious effect as a spray at the same doses, and with immersion before planting a concentration of 100 ppm had no effect while 250-1000 ppm reduced both shoot and rhizome growth.

Table 6. Growth of 6-node sections of Imperata planted in pots

	Weeks after planting		
	4	8	12
% with shoots	33	51	48
% with new rhizome	13	42	46
Shoots			
Mean length	25 cm	71 cm	72 cm
Mean number/section	0.7	0.8	1.3
Dry weight/section	0.11 g	0.72 g	0.94 g
Secondary rhizome			
Mean length/section	2.1 cm	14.3 cm	23.8
Mean number/section	0.2	0.9	1.0
Dry weight/section	0.06 g	0.42 g	0.54 g

2.2.1.4 Flowering and seed biology

In addition to its ability of spreading vegetatively Imperata also has considerable powers of reproduction from seed. In Western Nigeria flowering occurs most commonly at the end of the dry season in February. The production of flowering shoots, however, is stimulated by burning (commonest in December) or by cutting and occasional flowering stands can be seen in almost any month, following the removal of foliage by one of these means. It is of interest that, in an experiment where the foliage had been repeatedly killed by application of paraquat, flowering was prevented though regrowth of foliage was little affected. This observation is interpreted as indicating that food reserves in the rhizomes were depleted as a result of repeated defoliation and that flowering was dependant on the high level of reserves that would normally be expected during the dry season.

The masses of fluffy hairs surrounding the florets of Imperata inflorescences conceal the seeds and make counting difficult but careful examination of ripe florets collected in February 1973 showed that 11% were fertile. Of the seeds removed from the florets approximately 25% germinated in petri-dishes. No complete counts of florets per inflorescence have been made but the number is probably of the order of 500-1000. As there are often 10-20 inflorescences per m^2 in a moderate infestation the production of viable seed could well reach several hundred per m^2. When soil collected from an Imperata infested area in March after most seed had been shed was watered in pots, numerous Imperata seedlings appeared and this appeared a practical method of establishing plants for greenhouse studies. The ripe florets can be carried a considerable distance by the wind and windborne seed is presumably responsible for the appearance of Imperata in new forest clearings distant from existing infestations.

2.2.2 Eupatorium odoratum

2.2.2.1 Effects of cutting

When established plants are cut near ground level, new shoots start to grow from the base after about one month and regrowth thereafter is rapid. In observations on a stand of 3-year old plants the average height of shoots was 0.45 m 2 months after cutting, 0.80 m after 3 months and 1.75 m after 5 months. After cutting flowering appears to take place at much the same time (ie December-January) as on intact plants. Regrowth developed from the base of the cut shoots above ground and from the shoot bases and root crown just below ground level. No new shoots appeared more than about 5 cm away from the root crown and no sucker growth from roots or spreading rhizomes was noted on the numerous plants examined.

In general, Eupatorium appeared to be a rather shallow rooted plant, which could be uprooted easily under moist soil conditions. When left lying in contact with moist soil, however, uprooted plants readily became re-established and branches in contact with the soil can also occasionally take root.

2.2.2.2 Seed biology

Fallow land in the forest zone is often dominated by prolifically seeding Eupatorium thicket (Olaoye estimates that one plant may produce up to 125,000 seeds - personal communication). When such thicket is cleared for arable cropping it has been observed that, although vast numbers of seedlings emerge while the land is being prepared for planting, very few are evident in the growing crop. This suggests that Eupatorium seed has little natural dormancy and the suggestion is supported by the results of several experiments.

For example, when soil was collected from various depths after clearing a patch of well established thicket in July about 4 months after seed had been shed approximately 4500 Eupatorium seedlings/m^2 appeared within 2 weeks when the soil was watered in pots. Of these, 53% came from the sample taken down to 1.2 cm, 36% from the 1.2-2.5 cm layer and 11% from 2.5-5.0 cm. When further samples were taken 4 months later, although numerous seedlings had grown in the cleared thicket, none emerged from the soil kept in pots for 10 weeks. The pots were watered for a further 5 months, the soil being stirred at intervals, but still no Eupatorium seedlings emerged.

A relatively short life of the seed in soil was also suggested in an experiment where pots of dry soil were shallowly sown with Eupatorium seed in February 1973 and watering commenced at monthly intervals. As shown in Table 7, the percentage germination declined to less than one third of the original after storage in dry soil for 5 months.

Table 7. Germination of Eupatorium planted in dry soil in greenhouse on 3.2.73 and stored for varying periods before watering

Date watering started	% germination after 2 months
3.2.73	58
3.3.73	32
3.4.73	22
1.5.73	24
1.6.73	20
1.7.73	16

Fresh seed collected in February showed no dormancy and germinated rapidly in petri-dishes on the laboratory bench at room temperature. Up to 56% germination was recorded in the first week, rising to a maximum of 68% in the second. The germination was not affected by storage for up to 4 months, either at room temperature or in a refrigerated seed store. In a sample stored at room temperature for 12 months, however, no seeds germinated for 2 weeks, after which there was a steady increase to 22% after 6 weeks suggesting that some degree of dormancy had been induced by long storage. The later germinating seeds exhibited an abnormal looping near the tip of the primary root, while the tip itself was brown, possibly the results of a build-up of toxic substances in the dishes but more likely indications of impaired viability of the seed.

Weerakoon (1972) has shown that the germination of Eupatorium is increased by exposure to light and this is supported by observations in Nigeria (Olaoye, personal communication). It is suggested that a light requirement may be the reason why seed on the ground under dense thicket may not germinate for several months after shedding, although moisture conditions are suitable. As mentioned earlier in this section, when thicket is cleared during the wet season (or killed by a non-persistent herbicide) many seedlings emerge within a short time, presumably stimulated by the increase in light intensity.

2.2.2.3 Biological control

The project did not become directly involved with the biological control of Eupatorium as this aspect was already under investigation in the Department of Agricultural Biology at Ibadan under the sponsorship of the Coordinating Committee on Siam Weed Control Projects. Studies by the

CIBC had suggested the moth Ammalo insulata, larvae of which are leaf feeders on Eupatorium, as a promising control agent and stocks of this insect were sent to Nigeria from India in 1970. Since that time colonies have been maintained both at the University of Ibadan and at the Federal Department of Agricultural Research and information has been obtained on host specificity and on the degree of defoliation caused to caged Eupatorium plants. In 1972 it was agreed that field releases should be made but, by this time, the vigour of the original colonies had become greatly reduced and releases could not be made in the field until fresh stocks were received in the following year.

A full account of biological control work in Nigeria is being prepared by S A Olaoye but preliminary results suggest that the effects of A. insulata in the field are likely to be very limited (personal communication). Colonies of the seed-eating beetle Apion brunneonigrum, suggested as another possible control agent by CIBC, have also been raised in Ibadan but no field releases had been made up to 1973 and experience in Sabah, East Malaysia offers little hope of greater effectiveness (CIBC 1973).

2.2.3 Germination studies on other weed seeds

The seeds of about 60 common weed species were collected between November 1972 and April 1973 and germination tests carried out both on filter papers in petri-dishes and in pots of soil in the greenhouse. The results showing varying degrees of dormancy are summarised in Table 8. Drawings were made of most species in the cotyledon and young seedling stages for inclusion in a West African weed flora being produced in collaboration with Drs Moody and Egunjobi.

2.3 Field experiments

2.3.1 Imperata cylindrica

2.3.1.1 Control with cover crops

A variety of fast-growing plants, mostly legumes have been recommended for the control of Imperata through competition (Soerjani 1970) and it is generally accepted that the establishment of a vigorous cover plays a large part in preventing the infestation of young plantations. In Nigeria, however, Imperata is not primarily a problem of plantation crops and there is little published information on the use of cover crops in arable situations. An experiment was accordingly started in April 1972 to test the effects of a number of species on an area of Imperata typical of many areas used for growing maize etc in the Western State. The land was cultivated, some plots with a disc plough, others with a rotary cultivator, 2 weeks before planting. The covers tested were the legumes, Calapogonium mucunoides, Centrosema pubescens, Pueraria phaseoloides and Stylosanthes guianensis, IB 8, a vigorous variety of Cynodon nlemfuensis developed at Ibadan, and Eupatorium odoratum.

S. guianensis was the only species to become satisfactorily established, forming a dense cover in patches of light Imperata and surviving in more heavily infested areas but not obviously affecting the growth of the grass. During the subsequent dry season, however, the experimental area was burnt and little S. guianensis was visible in the growing season of 1973.

It was concluded from this work that the range of cover species tested is of limited value for controlling Imperata in arable conditions. More successful establishment could no doubt have been obtained by better land preparation and by inter-row cultivation in the early stages of growth. This would be of little practical significance, however, in view of the fact that the same series of operations would enable a profitable food crop to be grown.

In this experiment it was observed that the only plants able to establish themselves successfully in Imperata after cultivation were some of the native savanna grasses such as Pennisetum polystachyon, tufts of which grew to a height of 2.5 m or more during the season. Single plants spread over circles about 1 m across, in which Imperata was strongly suppressed. In the absence of fire such patches would presumably continue to expand though, after burning, Imperata again became dominant.

Table 8. Germination of weed seeds in Petri dishes and pots

Species	% germination		Species	% germination	
	filter paper	soil		filter paper	soil
Acalypha ciliata	2	30-50	Gynandropsis gynandra	4	8
Acanthospermum hispidum	0	0	Launaea cornuta	25	14
" (chipped)	20	-	Mariscus alternifolius	9	30-50
Ageratum conyzoides	2	20	Melanthera scandens	0	-
Alternanthera pungens	95	70-90	Micrococca mercurialis	5	-
Amaranthus spinosus	38	50-70	Mikania cordata	0	25
" viridis	65	50-70	Oldenlandia corymbosa	75	-
Argemone mexicana	0	0	Phyllanthus amarus	28	-
Boerhavia coccinea	27	20-30	Physalis angulata	0	30-50
" diffusa	3	30-50	" micrantha	0	30-50
Cassia obtusifolia	10	0	Portulaca oleracea	53	12
" rotundifolia	21	5	Schwenckia americana	20	-
Celosia trigyna	6	10	Sida acuta	0	2
Cephalostigma	0	0	" rhombifolia	0	0
perrottetii			Solanum torvum	0	10-30
Cleome monophylla	0	4	Spigelia anthelmia	25	30-50
" rutidosperma	26	20-30	Stachytarpheta	0	37
" viscosa	0	-	cayennensis		
Commelina benghalensis	8	10	Synedrella nodiflora	79	50-70
Conyza floribunda	10	3	Talinum triangulare	2	30-50
Corchorus olitorius	52	2-5	Trianthema	8	10
Croton lobatus	0	5	portulacastrum		
Emilia sonchifolia	22	28	Tridax procumbens	19	30-50
Euphorbia heterophylla	46	20-30	Triumfetta rhomboidea	10	20
" hirta	8	13	Vernonia cinerea	53	50-70
Fleurya aestuans	4	8	Waltheria indica	12	
Grasses			Grasses		
Brachiaria distichophylla	1	5	Digitaria ciliaris	6	30-50
Chloris pilosa	11	-	Eleusine indica	11	30-50
Dactyloctenium aegyptium	1	50-70	Eragrostis tenella	0	3
			Rhynchelytrum repens	38	40

2.3.1.2 Mechanical control

There is a considerable amount of local experience of the effects of cultivation on Imperata. For example Adegbola et al. (1970) reported an experiment started at Fashola, near Oyo, Western State in 1960. They found that ploughing to a depth of 15 cm in December (early dry season), followed by a dry season fallow and seeding to Andropogon gayanus in May the following year, reduced the Imperata stand by 95% a year later. Aboaba (1967), working near Ibadan, obtained a similar degree of long-term control during the rainy season from cultivation alone, his most effective treatment being 3 rotavations at one month intervals to progressively greater depths (eventually to 20 cm).

However, existing information is not sufficient for it to be possible to specify the best implement, the depth of penetration needed and the best season for cultivating, and there are divergences of opinion on the practicability of dry season cultivation in different parts of the country. A series of experiments to obtain information on some of these questions was initiated in 1972 with the cooperation of the Institute of Agricultural Research, Samaru.

It was planned that the experiments should be conducted at 4 centres representative of different climatic zones from 150 to 500 km north of Ibadan. Because of difficulties in locating suitable sites and mechanical equipment only two experiments were started in 1972 (at Ilorin, Kwara State and Bida, North Western State). It is hoped that the other two have been started in 1973 (at Kontagora and Zuru, North Western State). The experiments were designed to compare the effects of disc ploughing, chisel ploughing and rotary cultivation treatments started in October (normally the end of the rainy season), November and December, assessments being made both on the weed and on a crop of maize planted in the following year.

Up to the date of the author's departure assessment reports had yet to be received and the only results available were from a preliminary assessment made on a visit to Ilorin in February 1973 (mid-dry season). At this time the average regrowth after the October, November and December cultivations, based on comparison with control plots was approximately 50%, 30% and 15% respectively. Under the very dry conditions prevailing, little growth appeared to be taking place but it was clear that further assessment would be needed at the beginning of the next growing season to provide a valid comparison between timings. Comparing the effects of the different implements, chisel ploughing appeared to result in somewhat less regrowth than disc ploughing, while the most regrowth occurred on the rotavated plots. This agrees with experience from the cover crop experiment at Ilora where a single rotary cultivation was followed by considerably more regrowth than disc ploughing.

2.3.1.3 Chemical control

Experiments started 1972. Successful control of Imperata is obtained in Malaysia with dalapon, alone or in combination with paraquat, and dalapon gave promising results in earlier work in Nigeria (Watson 1959, WAIFOR 1962). Little information was, however, available on the conditions under which this chemical is most effective under Nigerian conditions or on the length of time for which control can be expected. A series of experiments was accordingly started at Ilora Farm Settlement about 50 km north of Ibadan to obtain information on these points and to test several newer chemicals which had shown promise as perennial grass killers in other parts of the world. An account of experiments completed up to June 1973 was given in a paper presented at a meeting of the Nigerian Weed Science Group at Samaru in July 1973 (Ivens 1973).

In these experiments where the land was not cultivated after spraying, dalapon at 15 and 20 kg (a.e.)/ha gave a high level of control for at least 11 months. The best results were obtained by spraying young growth about 60 cm high which had grown after earlier cultivation. Somewhat less, but still acceptable, control was obtained from treatment of mature growth, not cultivated previously, in June (mid-rains) but with late rains treatment (September and October) there was a marked reduction in effectiveness.

Glyphosate at 4 kg/ha gave similar results to dalapon at 15-20 kg/ha but was less effective at lower doses. Asulam at 8 kg/ha plus a wetter gave only temporary control when applied to mature foliage though on young growth it was effective for a longer period. TFP (sodium 2,2,3,3-tetrafluoropropionate) acted slowly but resulted in a high kill after 5 months and appeared to be very persistent. TFP was also active applied as a soil treatment in contrast with dalapon, TCA ester (up to 36 kg/ha), metflurazone (up to 8 kg/ha) and monometflurazone (up to 8 kg/ha) which were all ineffective when applied to the soil.

Paraquat was tested both on its own and in combination with dalapon. At a dose of 0.5 kg/ha, repeated whenever new shoots had grown back to about half the height of the original, no lasting stand reduction resulted from a total of 7 treatments applied between September 1972 and April 1973. However, continued treatment with paraquat did appear to reduce the level of stored carbohydrates in the rhizomes as in January, when flowering occurred on control plots, no flowering shoots were produced on plots which had received 5 applications of paraquat. A combination of dalapon at 7.5 kg/ha followed 3 weeks later by sequential application of paraquat at 0.5 kg/ha had similar effects to dalapon alone at 15 kg/ha but, at the time of year these treatments were tested (September-October) neither gave good control. Application of paraquat in an attempt to stimulate new growth susceptible to dalapon application a month later was less effective than dalapon alone or followed by paraquat.

Experiments started 1973. A new series of experiments planned to continue for a further 12 months was started in 1973. One of these was designed to provide more detailed information on the most susceptible growth stage of *Imperata* and consisted of 3 herbicide treatments, dalapon, glyphosate and asulam plus wetter, applied at varying intervals after ploughing. Preliminary results are given in Table 9 and show that recovery from all treatments applied at the earliest growth stage was already taking place, probably because only a small proportion of the *Imperata* shoots had emerged at the time of spraying. The treatments applied at the later stages appeared to be having more effect but cannot properly be compared as the effects were still developing.

The practical value of a herbicide treatment will clearly be increased if a crop can be grown on the land in the same season as the application of chemical. An experiment was therefore started to determine the effect of cultivation at different intervals after applying dalapon, glyphosate and asulam plus wetter on the 15th May. It was intended that different plots should be cultivated 2, 4, 8 and 16 weeks later but due to lack of tractor availability, cultivations were only made 2 and 9 weeks after spraying. Again it is too early to judge the ultimate effects of the treatments but the results of an assessment on 1 August presented in Table 10 show some features of interest. As in previous experiments where mature foliage was sprayed asulam has given poor results in comparison with dalapon and glyphosate. The effects of dalapon appear to have been reduced by cultivating 2 weeks after spraying, while the activity of glyphosate has been unaffected, possibly an indication of more rapid translocation from leaves to rhizomes. Confirmation of these findings will require continued observation until the 1974 rains.

Table 9. Stand of Imperata on 1.8.73 after herbicide treatment at 3 dates following ploughing on 8.5.73. Assessed as % of unploughed stand

	Control	Dalapon 12.8 kg/ha	Glyphosate 4 gk/ha	Asulam 6 kg/ha
Sprayed 4.6.73 shoots 30 cm	80	35 R	35 R	50 R
Sprayed 18.6.73 shoots 60 cm	63	15*	5	22
Sprayed 2.7.73 shoots 75 cm	73	38*	10*	28*

R = recovery taking place
* = effects still increasing

Table 10. The effect of ploughing on the action of herbicides applied to Imperata on 15.5.73

	Control		% reduction from control		
	% reduction of original stand	Height regrowth (cm)	Dalapon 12.8 kg/ha	Glyphosate 3.6 kg/ha	Asulam 5.4 kg/ha
Not ploughed	0	110	90	95	47
Ploughed after 2 weeks (1.6.73)	30	72	70	95	50
Ploughed after 9 weeks (18.7.73)	90	33	47	95	17

A third experiment on Imperata started in 1973 consisted of a comparison between the normal water-soluble sodium salt formulation of asulam both as single and split applications (plus wetter) and an oil-soluble formulation ARD/13/09. Preliminary results suggested that the single doses were very similar in their effects to split applications with 3 weeks between the sprayings and that the oil-soluble formulation applied in diesel oil at a volume of 110 l/ha was considerably less effective.

Assessment of Imperata. In all the experiments described the effects on Imperata were assessed visually by comparison with control plots. This method had the advantages of being rapid and making few demands on labour and was considered to be satisfactory as long as observations were continued long enough to record the extent of recovery. More objective assessment techniques were also tested on a limited number of plots. In one experiment, for example, live foliage was clipped from 2 x 0.75 m square quadrats from certain plots 5 months after treatment. Mean reductions in dry weight compared with control were 66, 99 and 98% with dalapon 10 and 20 kg/ha and glyphosate 4 kg/ha respectively, compared with 82, 93 and 82% estimated visually. It was evident that considerably larger numbers of quadrats would have been needed for adequate assessment.

Rhizome samples were also taken from selected plots by boring with a 10 cm diameter auger but, even with treatments where all foliage was dead 4 months after spraying and few, if any, new shoots emerged in the following 6 months, little obviously dead rhizome was found. When the rhizomes of normal appearance were collected from 5 auger holes per plot and planted in pots a rough correlation was obtained between the number of sections sprouting and subsequent regrowth on the plots. It was concluded, however, that at least 4 times this number of samples would have been required to overcome the high degree of variability encountered.

2.3.2 Eupatorium odoratum

2.3.2.1 Establishment in forest plantings

Forest tree plantings are often made in areas where Eupatorium is abundant. The weed is not thought to hinder the establishment of the species most commonly planted but experimental evidence is lacking and a series of experiments was started in collaboration with the Federal Department of Forest Research to obtain more definite information on this question.

In May 1972 a newly cleared area of forest at Ore, Western State, was planted with seed of Gmelina arborea at two different spacings and Eupatorium seed was broadcast over the plots at the same time. At the end of the growing season Eupatorium and other weeds formed a dense cover up to 3 m high which slightly exceeded the height of the tree seedlings. In accordance with normal forestry practice the weeds were slashed during the dry season and 12 months after planting the trees had grown to 3.7 m, about twice the height of the Eupatorium regrowth. The preliminary results of this long term experiment demonstrated that, even when established by direct seeding, a single slashing is sufficient to release Gmelina from the competitive effects of Eupatorium and that, although growth may possibly be reduced by the weed, satisfactory establishment is possible with the minimum expenditure on control.

A similar experiment on the slower growing Terminalia superba was started in March 1972 by sowing Eupatorium into plots of widely spaced trees planted 3 years earlier. A weed cover was established which continued to thicken during the next 12 months, but observations will need to be continued for several years to determine how long it persists and whether tree growth is significantly affected.

2.3.2.2 Chemical control

The results of herbicide experiments started in 1972 have been discussed by Ivens (1974). The main findings were that application of a mixture of picloram and 2,4-D amines (Tordon 101 = picloram 6.5% a.e. (w/v) + 2,4-D 24% a.e. (w/v)) at 2 kg/ha resulted in a virtually complete kill of regrowth up to 2.5 m high after 4-6 months in comparison with the same doses of 2,4-D or 2,4,5-T esters, which gave only partial control followed by recovery. Atrazine, and to a lesser extent diuron, were also shown to have a considerable contact effect and at 5 kg/ha atrazine gave a high degree of control of regenerating plants up to 0.9 m high after cutting 3 months previously.

In 1973 a wider range of doses of Tordon 101 and 2,4-D was tested, together with the other chemicals listed in Table 11, on younger regrowth 0.3-0.6 m high 2 months after cutting. Preliminary estimates of percentage kill of plants 2 months after spraying and of the development of regrowth from seed are given in the table. Although the final effects of the treatments must await an assessment 6 months after spraying the results available to date suggest that very high percentage kills can still be obtained by reducing the dose of picloram + 2,4-D to 1 kg/ha, but that doses lower than this are considerably less effective. The higher doses of 2,4-D either as ester or amine were giving reasonable control but the final effect will depend to a large extent on the degree to which the surviving plants recover. From the August assessment glyphosate appeared to be very promising at a dose of 4 kg/ha and, if no recovery occurs, could prove a useful alternative to the mixture containing picloram, without the persistence problems of the latter. The formulation of atrazine and oil showed no marked advantage over the wettable powder formulation tested earlier and bentazon, suggested as of possible value in leguminous cover crops, was disappointingly ineffective on established Eupatorium.

Table 11. Effects of herbicides 2 months after application to Eupatorium odoratum regrowth 0.3-0.6 m high in June 1973

Treatment	Dose (kg/ha)	Plants % apparently dead	Seedling regrowth
picloram/2,4-D*	2	88	0
"	1	92	0
"	0.5	33	0
"	0.25	20	++
"	0.125	0	++
2,4-D amine	4	78	+
"	2	60	+++
"	1	20	+++
2,4-D ester	4	77	+
"	2	50	++
"	1	27	+++
asulam	4	27	+++
glyphosate	4	90	+++
atrazine + oil†	4	13	0
bentazon	4	0	++

* Tordon 101
† Oleo-gesaprim

Picloram is known to be one of the more persistent herbicides and Tordon 101 or other picloram formulations could not be recommended to kill Eupatorium without information on soil persistence under Nigerian conditions and on the effects of residues on the crops likely to be grown after its application. In the 1972 experiment samples of soil to a depth of 15 cm were taken from treated plots at intervals after spraying and the residues determined by bioassay, using Phaseolus vulgaris as a test plant. In a calibration experiment it was found that doses of Tordon 101 down to about 0.003 kg/ha in a 7.5 cm layer of soil could be determined by this method. Test plants showed marked injury when planted in samples of soil taken from field plots 5 months after application of 2 kg/ha, this being one of the driest periods of the year (135 mm of rain between spraying and sampling). In samples taken after 7 months slight symptoms developed (270 mm rain) and there were no effects in samples taken after 9 months (537 mm rain). More information on persistance is clearly required. However, by reducing the dose to 1 kg/ha, detectable residues would be expected to disappear after 3-6 months depending on rainfall. Although such persistence would delay the planting of susceptible crops such as legumes, there would appear to be little risk of injuring maize and other resistant crops by planting in the standard manner after land clearing with the aid of Tordon 101 and cultivation.

2.3.3 Miscellaneous field work

Tithonia diversifolia is a leafy perennial Composite growing to a height of up to 3 m which has been introduced at the Ilora Farm Settlement, probably as a garden escape, and is now a local but serious problem in maize. It is propagated by seed and, once established, rapidly outgrows the crop and is strongly competitive. Control is normally by slashing but is only partially effective as regrowth is very rapid. Fortunately the seed is not wind-borne, or Tithonia might rival Eupatorium as a weed, but the plant is persistent and the infested area is gradually expanding. At the request of local farmers an observation trial was conducted on this weed and it was demonstrated that 2,4-D ester at 1 kg/ha gave very effective control at all stages of growth and was a practical post-emergence treatment in maize.

3. CONCLUSIONS AND RECOMMENDATIONS

3.1 Interim recommendations for control

3.1.1 Although no costing studies have yet been made, on the basis of existing knowledge it appears that the most economical method of controlling Imperata is by efficient cultivation. In order to break up as much of the rhizome system as possible the cultivation depth should be at least 15-20 cm and the best results can be expected from cultivation under dry conditions. With much of the equipment available it is probable that at least 2 cultivations will be needed to reach a sufficient depth. On soils which can only be worked when moist, more frequent cultivation will be needed to promote desiccation of the rhizome fragments.

3.1.2 Tractor drawn implements are regarded as essential for effective control of Imperata by cultivation and the use of hand tools for this purpose as impractical except for very small areas. Extended availability of the service of tractor hiring units is likely to offer the best chances for efficient cultivation by the subsistence cultivator.

3.1.3 Of the herbicides tested on Imperata, dalapon is currently the most effective and economical. For use prior to growing a crop of maize the best results can be expected from ploughing at the start of, or somewhat before, the onset of the rains, applying a dose of 12-15 kg (a.e.)/ha (16-20 kg commercial product/ha) when the new shoots have grown to an average height of 60 cm (4-6 weeks after ploughing) and harrowing about 6 weeks later to kill dicotyledonous weeds and form a seed-bed.

3.1.4 Dalapon may also have a potential for eradicating Imperata on small-holdings where hand tools are used for cultivation. In this situation the most practical treatment would be application of 15 kg (a.e.)/ha early in the rains, while the grass shoots are still young and growing actively, without prior cultivation but followed about 6 weeks later by the normal processes of field preparation. The introduction of a costly herbicide treatment to subsistence farming is only likely to be successful if it is combined with other measures designed to allow cropping on a permanent basis.

3.1.5 Unless more effective methods of biological control can be developed, control of Eupatorium will have to rely largely on uprooting, cutting and the use of chemicals. Pulling out by hand can be useful for limited areas of lightly infested land to prevent the build up of denser infestations and should be done well before flowering occurs. Uprooted plants should also be disposed of in a manner which prevents re-establishment.

3.1.6 The timing of cutting can be important where dense infestations are being cleared. The best time would appear to be at the end of the rains, in October or November before flowering, thus avoiding the production and shedding of large quantities of seed which is likely to occur if clearing is left until later. Regrowth may develop before burning is possible but the shoots should be killed back again when the area is burnt.

3.1.7 The picloram + 2,4-D formulation Tordon 101 was the outstandingly effective herbicide on Eupatorium. However, until more information is available about the effects of picloram residues on crops planted subsequently, 2,4-D must remain the chemical of choice for clearing uncropped areas. Either amine or ester formulations may be used and the most complete kill of roots can be expected from applying a dose of 4 kg/ha on young shoots 60-90 cm high which have grown after slashing.

3.1.8 Atrazine is probably the best herbicide for controlling Eupatorium and other seedling weeds in the circles round young oil-palm. Paraquat can also be used for this purpose if applied with a sprayer shielded so as to keep the chemical off the palm leaves. At present, however, there is no satisfactory herbicide treatment for controlling Eupatorium growing amongst leguminous cover crops being established in the inter-rows of plantation crops.

3.1.9 It is suggested that weed problems are now sufficiently acute in Nigeria and the prospects of achieving major advances in control sufficiently good that there is a need for officers with specialist training in weed science to be appointed in the extension services to advise on modern weed control techniques. A series of simple trials conducted by extension workers is needed both to provide information on the relative costs and returns in terms of increased yield using alternative weed control methods and also to provide demonstrations of the results that can be achieved.

3.2 Recommendations for further research

3.2.1 Continued research is required on the control of *Imperata* by cultivation. Points requiring special attention are the feasibility of dry season cultivation in different soils, determination of the most suitable implement for relatively deep cultivation and investigation of the number of cultivations required to achieve control under different rainfall conditions.

3.2.2 Effective control of *Imperata* has been shown to be possible with dalapon and work should be continued on the best way of fitting dalapon treatment into different cropping schemes. The possibility of reducing the cost of treatment by reducing the volume of liquid applied (eg by mistblower application) should be studied.

3.2.3 Asulam can also control *Imperata* under favourable conditions and with changes in economic circumstances may come to compare more favourably with dalapon than at present. Work with this herbicide should thus be continued on an experimental scale and also with glyphosate which, although unpriced and not as yet marketed, shows great promise against perennial grasses as well as many other types of weed.

3.2.4 Cover crops have so far shown little ability to suppress *Imperata* but *Stylosanthes guianensis* would be worth testing sown together with maize in the crop preceding reversion to fallow. Under these conditions it is thought to have a better chance of establishment and of preventing domination of the fallow by the weed. Several other cover crops would also be worth testing including *Tephrosia purpurea* which has been found to smother *Eupatorium* and most other weeds in Ceylon (Salgado 1972).

3.2.5 Introduction of the insects currently being tested for biological control of *Eupatorium* is regarded as unlikely to have drastic effects on this weed. Attempts to obtain establishment in the field should, however, be continued and the combined effects of *Ammalo insulata* and *Apion brunneonigrum* investigated. The Commonwealth Institute of Biological Control should be consulted regarding the possibility of finding more effective alternatives.

3.2.6 Work with chemicals on *Eupatorium* should be continued with the aim of finding effective and economical treatments both for clearing fallow land intended for arable cropping and for use in the establishment of plantation crops.

3.2.7 In fallow land a comparison should be made between 2,4-D and picloram + 2,4-D (Tordon 101) as regards both effectiveness at doses of equivalent cost and the effects on a range of subsequently planted crops including maize, rice, cassava and legumes.

3.2.8 Experience on commercial plantations in Nigeria has shown that 2,4-D can be used for *Eupatorium* control prior to planting oil-palm without damage to the seedlings. Work is needed to determine whether picloram + 2,4-D can be safely used in the same way. Young oil palms are known to be sensitive to the effects of 2,4-D or other growth-regulator herbicides so that these chemicals are not safe for controlling *Eupatorium* for the first few years after planting. In the Ivory Coast, however, 2,4-D is a recommended treatment in plantations more than 7 years old (Coomans 1971) and such treatments should also be tested under Nigerian conditions.

3.2.9 The rapid establishment of a leguminous cover is one of the most important factors in controlling weed growth in the inter-rows of newly planted oil-palm and other plantation crops. A dense growth of Eupatorium seedlings can greatly hinder the early development of cover crops and a herbicide which could be used to control Eupatorium selectively in Pueraria phaseoloides, Calapogonium mucunoides and Centrosema pubescens would be of value in many situations. Although it has shown little effect on established Eupatorium plants, bentazon would be expected to succeed better on seedlings as a pre- or early post-emergence treatment and there is scope for screening work with a number of newer herbicides.

3.2.10 Biological studies on Imperata could most profitably be continued along the following lines:

(a) investigation of seasonal variations in the sprouting ability of rhizomes, in the ability of the rhizomes to withstand desiccation and in the ability of the shoots to reach the surface from different depths in relation to changing levels of carbohydrate content:

(b) investigation of the system of apical dominance in rhizome shoot systems together with the effects of mineral nutrients and growth regulators on bud dormancy and growth:

(c) investigation of the pattern of regrowth after different types and timings of cultivation to determine whether new shoots develop mainly from disturbed rhizome fragments or from the lower, undisturbed rhizomes and to establish the fate of severed fragments under different soil moisture conditions.

3.2.11 In addition to biological control studies on Eupatorium one aspect of seed biology requiring attention is the persistence of seed in the field under different soil and climatic conditions. Associated work under controlled conditions should pay particular attention to the effects of alternating wet and dry periods of varying duration on germination, establishment and growth.

ACKNOWLEDGEMENTS

The author is grateful to Professor A A A Fayemi and the University of Ibadan for the provision of facilities; to the Ministry of Agriculture and Natural Resources, Western State for providing experimental sites and assistance; to Mr J E A Ogborne and the Institute of Agricultural Research, Samaru for help in conducting trials in the northern states and to Dr R Lowe, Federal Forest Research Department for his collaboration. Assistance in plant identification by Drs J Lowe and J B Hall, University of Ibadan, is gratefully acknowledged. Dr K Moody, IITA, Ibadan, helped and encouraged the project in many ways and acknowlegement is due to the firms who kindly provided samples of herbicide.

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LIST OF ABBREVIATIONS AND CHEMICAL NAMES

CIBC	Commonwealth Institute of Biological Control
IITA	International Institute of Tropical Agriculture
NIFOR	Nigerian Institute for Oil-palm Research
ODM	Ministry of Overseas Development
WRO	Agricultural Research Council Weed Research Organization
a.e.	acid equivalent
a.i.	active ingredient
amitrole	3-amino-1,2,4-triazole
asulam	methyl(4-aminobenzenesulphonyl)carbamate
atrazine	2-chloro-4-ethylamino-6-isopropylamino-1,3,5-triazine
bentazon	3-isopropyl-2,1,3-benzothiadiazin-4-one 2,2-dioxide
2,4-D	2,4-dichlorophenoxyacetic acid
dalapon	2,2-dichloropropionic acid
diuron	N'-(3,4-dichlorophenyl)-N,N-dimethylurea
glyphosate	N-(phosphonomethyl)glycine
metflurazone	4-chloro-5-(dimethylamino)-2-(3-trifluoromethylphenyl) pyridazine-3(2H)-one
monometflurazone (SAN 9789)	4-chloro-5-methylamino-2-(2'-trifluoromethylphenyl) pyridazine-3(2H)-one
paraquat	1,1'-dimethyl-4,4'-bipyridylium
prometryne	4,6-bisisopropylamino-2-methylthio-1,3,5-triazine
2,4,5-T	2,4,5-trichlorophenoxyacetic acid
TCA	trichloroacetic acid
TFP	2,2,3,3-tetrafluoropropionic acid

Chemical concentrations are given throughout in terms of % weight/volume of a.e. or a.i.

ABBREVIATIONS

ångström	Å
Abstract	Abs.
acid equivalent*	a.e.
acre	ac
active ingredient*	a.i.
approximately equal to*	$\simeq$
aqueous concentrate	a.c.
bibliography	bibl.
boiling point	b.p.
bushel	bu
centigrade	C
centimetre*	cm
concentrated	concd
concentration	concn
concentration × time product	ct
concentration required to kill 50% test animals	LC50
cubic centimetre*	cm^3
cubic foot*	ft^3
cubic inch*	in^3
cubic metre*	m^3
cubic yard*	yd^3
cultivar(s)	cv.
curie*	Ci
degree Celsius*	^{o}C
degree centigrade*	^{o}C
degree Fahrenheit*	^{o}F
diameter	diam.
diameter at breast height	d.b.h.
divided by*	÷ or /
dry matter	d.m.
emulsifiable concentrate	e.c.
equal to*	=
fluid	fl.
foot	ft

freezing point	f.p.
from summary	F.s.
gallon	gal
gallons per hour	gal/h
gallons per acre	gal/ac
gas liquid chromatography	GLC
gramme	g
hectare	ha
hectokilogram	hkg
high volume	HV
horse power	hp
hour	h
hundredweight*	cwt
hydrogen ion concentration*	pH
inch	in.
infra red	i.r.
kilogramme	kg
kilo ($\times 10^3$)	k
less than	<
litre	l.
low volume	LV
maximum	max.
median lethal dose	LD50
medium volume	MV
melting point	m.p.
metre	m
micro ($\times 10^{-6}$)	µ
microgramme*	µg
micromicro (pico: $\times 10^{-12}$)*	µµ
micrometre (micron)*	µm (or µ)
micron (micrometre)*[×]	µm (or µ)
miles per hour*	mile/h
milli ($\times 10^{-3}$)	m
milliequivalent*	m.equiv.
milligramme*	mg
millilitre	ml

× The name micrometre is preferred to micron and µm is preferred to µ.

millimetre*	mm
millimicro* (nano: $\times 10^{-9}$)	n or mμ
minimum	min.
minus	-
minute	min
molar concentration*	M (small cap)
molecule, molecular	mol.
more than	>
multiplied by*	×
normal concentration*	N (small cap)
not dated	n.d.
oil miscible concentrate	o.m.c. (tables only)
organic matter	o.m.
ounce	oz
ounces per gallon	oz/gal
page	p.
pages	pp.
parts per million*	ppm
parts per million by volume*	ppmv
parts per million by weight*	ppmw
percent(age)*	%
pico (micromicro: $\times 10^{-12}$)	p or μμ
pint	pint
pints per acre	pints/ac
plus or minus*	±
post-emergence	post-em.
pound	lb
pound per acre*	lb/ac
pounds per minute	lb/min
pound per square inch*	lb/in^2
powder for dry application	p. (tables only)
power take off	p.t.o.
precipitate (noun)	ppt.
pre-emergence	pre-em.
quart	quart

relative humidity	r.h.
revolution per minute*	rev/min
second	s
soluble concentrate	s.c.
soluble powder	s.p.
solution	soln
species (singular)	sp.
species (plural)	spp.
specific gravity	sp. gr.
square foot*	ft^2
square inch*	in^2
square metre*	m^2
square root of*	$\sqrt{\ }$
sub-species*	ssp.
summary	s.
temperature	temp.
ton	ton
tonne	t
ultra-low volume	ULV
ultra violet	u.v.
vapour density	v.d.
vapour pressure	v.p.
<u>varietas</u>	var.
volt	V
volume	vol.
volume per volume	v/v
water soluble powder	w.s.p. (tables only)
watt	W
weight	wt
weight per volume*	w/v
weight per weight*	w/w
wettable powder	w.p.
yard	yd
yards per minute	yd/min

* Those marked * should normally be used in the text as well as in tables, etc.

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7. Flame cultivation experiments 1965. October 1966. G.W. Ivens. Price - £0.25.

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9. The post-emergence selectivity of some newly developed herbicides (NC 6627, NC 4780, NC 4762, BH 584, BH 1455). December 1967. K. Holly and Mrs A.K. Wilson. Price - U.K. and overseas surface mail - £0.25; overseas airmail - £0.50.

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11. Raising plants for herbicide evaluation; a comparison of compost types. July 1968. I.E. Henson. Price - £0.25.

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13. Changes in the germination capacity of three Polygonum species following low temperature moist storage. June 1969. I.E. Henson. Price - £0.25.

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15. Methods of analysis for herbicide residues in use at the Weed Research Organization. December 1970. R.J. Hance and C.E. McKone. Price - U.K. and overseas surface mail - £0.25; overseas airmail - £0.50.

16. Report on a joint survey of the presence of wild oat seeds in cereal seed drills in the United Kingdom during Spring 1970. November 1970. J.G. Elliott and P.J. Attwood. Price - £0.25.

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21. An automatic punching counter. November 1972. R.C. Simmons. Price - U.K. and overseas surface mail - £0.30; overseas airmail - £0.50.

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