*INVESTIGATIONS WITH PARAQUAT (GRAMOXONE) AS A HERBICIDE FOR WEED CONTROL IN LOW-GROWN TEA

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Paraquat at 0.125 and 0.25 lb (half and one pint of Gramoxone), per acre controlled weeds two months old effectively, and less so at 0.063 lb per acre. The three-month-old stand of weeds was very profuse in growth, yet some control was obtained at 0.25 and 0.125 lb per acre. In weeds four months old, grasses and creepers were so dense that even 0.25 lb per acre failed to give effective control, and regeneration took place.

Paraquat at the dose of 0.125 and 0.25 lb per acre combined with 50 and 100 gallons water per acre were used on a dense stand of *Paspalum conjugatum*; 0.25 lb in 50 gallons of water appeared to be the optimum level. At rates of 0.125, 0.25 and 0.5 lb per acre of paraquat in 50 gallons of water, repeating the application after ten days was more effective than after 20 days. A significant decrease in the viability of seeds of *P. conjugatum* was observed at 0.25 lb paraquat per acre when the spray volume was increased from 50 to 100. Seeds from the untreated plots were significantly more viable than those from the treated plots.

Ten ppm of paraquat in the soil was not phytotoxic to young tea and growth of plants was normal. At 50 ppm and above, there was servere phytotoxicity and retardation of growth; phytotoxic residues were available for uptake by plants even six months after treatment.

The following conclusions are drawn :

1 — Bi-monthly applications of paraquat at 0.125 lb per acre were found necessary except perhaps during dry weather when the growth of weeds is less. Delaying the paraquat sprayings beyond two months may result in a build-up of weeds which may then be difficult to control even at a level higher than 0.125 lb per acre.

2 — More than 0.125 lb paraquat per acre and a repeat application before regeneration sets in may sometimes be necessary in the control of *P. conjugatum*.

3 — There is no danger of paraquat being available for root absorption at the levels used in weed control in tea; the adsorptive capacity of the soil used was found to be between ten and 50 ppm paraquat.

Introduction

Paraquat, a complex bipyridylium derivative (1,1'dimethyl, 4-4'-bipyridylium-2A) is an effective contact herbicide which is now being widely used to control weeds in mature tea. Its uptake by green parts of the plant and the subsequent herbicidal action are extremely rapid. The rapid killing of tissues that come into contact with the herbicide is in a way disadvantageous as it may restrict movement of the chemical to other parts of the plant (Slade & Bell 1966). This may result in incomplete killing and certain species may regenerate from the unaffected parts. It is, therefore, to be expected that conditions favourable to the entry of the herbicide into the plant, and translocation within it, should improve the biological activity; high humidity, darkness soon after treatment and low soil moisture are accordingly important (Slade & Bell 1966; Brian 1966). A humid, gloomy day if practicable, late afternoons or evenings with increased humidity and darkness to follow should, therefore, be ideal for paraquat application in the field.

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Paraquat has advantages over other contact herbicides in that it has no residual effects through the soil at the usual rates of application on account of it being immobilized in the soil by being adsorbed on the clay fraction through the process of base exchange (Springett 1965). It is also readily adsorbed by the leaf surfaces, and this is useful in practice as it will considerably reduce the chances of the chemical being washed off by rain falling soon after spraying (Brian 1967).

Routine bi-monthly applications of paraquat have been satisfactory for the control of most weeds in tea. The first experiment reported herein was an attempt to determine whether satisfactory control could be achieved more economically by altering the rate and /or frequency of application. Attempts to control *Paspalum conjugatum* by varying the herbicide level, spray volume and the interval between applications are reported in the second experiment. Symptoms of leaf scorch in tea have sometimes been attributed to root absorption of paraquat. The third experiment was accordingly undertaken to investigate this aspect.

Experimental & Results

Doses of paraquat on weed populations of different ages—(*Experiment 1*)

Four doses of paraquat, *viz* 0.25, 0.125, 0.063 and 0.032 lb per acre (1, ½, ¼ and ⅛ pints Gramoxone per acre) were combined factorially with three weed populations, two, three and four months old. The treatments were accommodated in a randomized block, replicated four times, in a field of old seedling tea infilled with clonal tea, and now having about 3000 bushes per acre.

Knapsack sprayers fitted with flood jet nozzles (FLJ 078) were used for spraying the plots and the spray pressure was between 10 and 20 lb per in. The spray was directed at the weeds avoiding the tea.

The stand of weeds was dense and the common species present were *Cyperus tenuiculmis, Digitaria adscendens, Ipomoea* spp., *Mikania scandens, Paspalum conjugatum, Scoparia dulcis* and *Spermacoce latifolia.* The fresh and dry weights of weeds in the plots 30 days after the paraquat applications, were assessed in each of five quadrats (2 ft x 2 ft) placed at random in each plot. Observations of the weed population 30 days after treatment are summarized in Table 1.

The two-months-old stand of weeds was controlled effectively at 0.25 and 0.125 lb of paraquat. At lower doses the degree of control was not so good. Weed growth in the plots unweeded for three months was dense; trailing species such as *P. conjugatum* and *S. latifolia* formed dense mats on the ground while *Gynura* sp. grew above the tea. A fair degree of control was, however, obtained at 0.25 lb, and also at 0.125 lb. In the stand of weeds four month old, the composition of the weed flora changed. Most of the short-lived species died out but *P. conjugatum M. scandens* and *Ipomoea* spp. became so well established that even the highest dose of paraquat used, failed to effect control. The higher doses (0.25 and 0.125 lb), however, gave better control of weeds than the lower (0.063 and 0.032 lb) doses.

When the stand of weeds was dense, the degree of injury caused by paraquat especially at the lower doses was insufficient to kill the more hardy weeds. On such weeds the chemical appeared to cause defoliation and discontinuous injury on stems. As a result, creeping types regenerated from axillary buds which had escaped contact with paraquat. Leaves and the exposed portions of stems of *P. conjugatum* were scorched and the sheathing leaf bases protected the intercalary meristems which later regenerated.

TABLE 1—*Weeds present 30 days after treatment of three stands of weeds with four doses of paraquat*

Treatment Dose of paraquat (lb per acre)	Age of Weeds (months)	Dry weight of weeds per 20 sq. ft (g)	Paraquat treatment Mean
0.25	2	43.8	
	3	70.8	
	4	123.8	79.4
0.125	2	85.3	
	3	106.3	
	4	114.8	102.1
0.063	2	122.0	
	3	143.3	
	4	172.3	145.9
0.032	2	175.5	
	3	193.3	
	4	186.5	185.1
LSD (P = 0.05)		86.4	49.8
SE		± 30.2	± 17.4

Age of weeds (months)	Means for stands of weeds
2	106.7
3	128.4
4	149.3
LSD (P = 0.05)	43.2
SE	± 15.1

Control of *Paspalum conjugatum* with paraquat—(*Experiment 2*)

Two aspects were investigated;

a—The effects and interactions of doses of paraquat and spray volumes on the control of *P. conjugatum*

b—The effects and interactions of doses of paraquat and the interval between two applications on the control of *P. conjugatum.*

In each experiment the treatments were in randomized blocks in four replicates. The plots (2 ft × 4 ft) were demarcated in grass without tea. In experiment 2*a* paraquat at 0.125 lb and two spray volumes, 50 and 100 gallons per acre per application, and in experiment 2*b* an additional level of paraquat *viz* 0.5 lb per acre per application with two intervals between two sprayings, were tested. Paraquat was sprayed with a Fix sprayer (capacity 350 ml) fitted with a hollow-cone nozzle. The grass was uprooted in one half of each plot and a random sample of eight oz was drawn from it. The live material was then separated from the dead and the degree of kill was assessed in terms of the oven-dry weight of the live fraction of grass in the plots. The assessments were done 28 and 20 days after treatment in experiments 2*a* and 2*b* respectively. In experiment 2*a* three days after treatment and germinated in petri dishes in the laboratory in order to determine whether paraquat had affected their viability. Fifty seeds were used per treatment and each treatment was replicated ten times.

Experiment 2a

The results on grass control are summarized in Table 2 and are inconclusive because the kill is rather inadequate. Increasing the paraquat concentration from 0.125 to 0.25 lb per acre in 50 gallons of water appears to have given better control than the other treatments. Increasing the spray volume did not improve the kill of grass, perhaps because of dilution at the higher volume. Fifty rather than 100 gallons of water per acre appear closer to the optimal spray volume required at these doses of paraquat.

TABLE 2—*Effects and interactions of doses of paraquat and spray volumes on the control of* P. conjugatum

Weight of herbicide (lb per acre)	Spray volume (Gallons per acre)	Dry weight of live fraction per 8 oz (fresh weight) Sample of grass assessed 28 days after spraying (g)	Paraquat treatment mean
0.125	50	19.5	
	100	19.1	19.3
0.25	50	15.8	
	100	18.3	17.32
0 (Untreated control)		21.75	
LSD at $P = 0.05$		5.46	3.86
SE		±1.78	±1.26

(Gallons per acre)	Means for spray volumes
50	17.65
100	18.97
LSD at $P = 0.05$	3.86
SE	±1.26

The results obtained on the viability of seeds of *P. conjugatum* are given in Table 3. Paraquat killed a high propotion of seeds which were attached to the plants, the differences between the control and each of the herbicide treatments being highly significant. At the higher dose of paraquat there was an inprovement in the kill of seeds at the increased spray volume. This may have been because of better wetting and also better movement of herbicide from neighbouring tissues into seeds following dilution of the herbicide.

TABLE 3—*Effects and interactions of doses of paraquat and spray volumes on the viability of seeds of* P. conjugatum

Weight of herbicide (lb per acre)	Spray volume (gallons per acre)	Mean number of seeds germinated per petri dish	Paraquat treatment Mean
0.125	50	6.4	
	100	7.3	6.9
0.25	50	8.6	
	100	5.9	7.3
Untreated control	—	18.1	
LSD at $P = 0.05$		2.6	0.9
$P = 0.01$		3.5	

Gallons per acre	Means for spray voulumes
50	7.5
100	6.6
LSD at $P = 0.05$	0.9
$P = 0.01$	1.3

Experiment 2b

In this experiment, an extra dose (0.5 lb per acre) of paraquat was used and there were two intervals between sprayings.

The results are summarized in Table 4.

The second application of paraquat ten days after the first was more effective than when it was done 20 days after the first.

TABLE 4—*Effects and interactions of doses of paraquat and the interval between two applications on the control of* P. conjugatum

Weight of herbicide (lb per acre)	Interval between the two applications (days)	Dry weight of live fraction per 8 oz (fresh weight) Sample of grass assessed 20 days after the repeat application (g)	Paraquat treatment mean
0.125	10	7.80	
	20	15.98	11.89
0.25	10	1.70	
	20	5.68	3.69
0.5	10	0.68	
	20	10.25	5.81
Untreated control		24.95	
LSD at $P = 0.05$		4.86	3.44
$P = 0.01$		6.65	4.71

Interval between the two applications (days)	Mean for interval between applications
10	3.39
20	10.64
LSD at $P = 0.01$	3.86

The dose of 0.25 lb of paraquat per acre gave a better kill of grass than that of 0.125 lb, but 0.5 lb per acre was not significantly better than 0.25 lb. The use of doses higher than 0.25 lb appears unwarranted and uneconomic in the control of *P. conjugatum*. The poor kill at 0.5 lb paraquat when the second spraying was given 20 days after the first is not easily explicable. In this experiment, all paraquat treatments gave a significantly better degree of kill of grass than the untreated control.

Phytotoxicity of soil-incorporated paraquat on young tea plants and persistence of its residues in the soil—(*Experiment 3*)

The treatments were randomized in blocks in six replicates. The appropriate quantities of paraquat were incorporated into lots of air-dried and sieved blackish loamy soil collected at St Joachim so as to obtain 0 (control), 10, 50, 100 and 1000

ppm by weight of the active chemical in the soil. The soil was packed in roughly cylindrical pots, one foot diameter and one foot deep, and plants of clone TRI 2023, eight months old, were planted, one in each pot. The plants were lightly shaded for 30 days and watered regularly. The plants were fertilized with T200 fertilizer mixture, which was composed of 100 lb ammonium sulphate, 50 lb saphos phosphate, 25 lb muriate of potash and 25 lb kieserite.

The plants were uprooted five months after treatment and the dry weights of the leaves, stems and roots were determined. One month later, (*ie* six months after the incorporation of paraquat into the soil) 15 seeds of *Phaseolus radiatus* were planted in each pot and one week later the seedlings were thinned out to five per pot. Plants were uprooted 28 days after planting of the seeds and their dry weights determined.

The foliage and the green parts of the stem of plants receiving 1000 ppm of paraquat were very severely scorched the day after the treatment and the plants died a few days later. At 100 and at 50 ppm the mother leaf (*ie* the leaf associated with the cutting at planting time) of all plants were scorched, and fell off subsequently. At these doses the leaves higher up also were damaged. Injury was apparently more at 100 ppm. Plants with 10 ppm paraquat remained healthy and were comparable with those of the untreated control.

The results of an assessment of the plants are expressed as treatment means in Table 5.

TABLE 5—*Effect of soil-incorporated paraquat on the growth of young tea*

Concentration of paraquat in soil (ppm)	Equivalent soil surface application (lb paraquat per acre)	Mean dry wight per replicate (g)			
		Root	Stem	Leaf	Total
0	0	6.97	10.74	8.90	26.60
10	48	7.12	9.60	7.82	24.54
50	240	3.23	10.07	7.12	20.41
100	480	1.81	7.72	4.72	14.26
1000	4800		All plants died		
LSD at $P = 0.05$		1.26	2.60	2.87	6.61
$P = 0.01$		1.74	2.60	3.97	9.10

At 10 ppm, paraquat did not affect the growth of any plant component, but at 50 and 100 ppm there was a significant decrease in the root growth. Roots appeared to be comparatively more severely affected than stems or leaves, which gave significantly lower dry weights only at 100 ppm than the untreated control. It is likely that at 50 ppm and above, paraquat not only impeded the growth of roots but also may have damaged the existing roots at the time of transplantation in the pots. The total dry weights of treated plants showed a significant decrease below the control only at 100 ppm. This was because at levels of paraquat lower than 100 ppm stems and leaves which constituted the bulk of the total dry weight were not significantly different in their weights from that of the control.

The results of the assay of paraquat residues in the soil six months after treatment, using *P. radiatus* as the indicator plant are expressed as mean dry weight of 15 plants (28 days old) per treatment in Table 6.

TABLE 6—*Effect of paraquat incorporated in the soil six months before planting, on the growth of* Phaseolus radiatus

Treatment Concentration of paraquat in the soil (ppm)	Mean dry weight per 15 Phaseolus plants, 28 days old (g)
0	3.50
10	3.47
50	1.97
100	1.00
1000	—
LSD at $P = 0.05$	0.13
$P = 0.01$	0.18

The differences between treatments are very highly significant. At 10 ppm, as seen earlier in the dry weights of young tea plants, paraquat was not available for uptake by *P. radiatus,* and the dry weight was comparable with that of the untreated control. At 50 and 100 ppm there had been a severe retardation of the growth of plants, which is clearly reflected in the dry weights, indicating that paraquat residues were available in the soil for uptake by plants even after six months at such rates of application. At 1000 ppm the seeds of *P. radiatus* failed even to germinate.

Discussion

While 0.125 to 0.25 lb paraquat (*ie* ½ to 1 pint Gramoxone) can satisfactorily control weeds two to three months old there is evidence that delaying the spraying rounds and thereby allowing the weeds to overgrow may lead to difficulties in their control. The consequences of leaving a field unweeded for a long period are revealed in the results of treatments where the spraying was delayed for four months. This results in the formation of dense mats of creepers preventing the spray from reaching their stoloniferous stems beneath the mats. Paraquat kills, therefore, only the top growth, and new shoots grow out subsequently from the unaffected stems at ground level. Further, the fact that such weeds are rooted to the soil at many places along their stems makes them less susceptible to paraquat than plants rooted to the soil only at one place, because even when parts of the stoloniferous stems are affected, regeneration can take place from the unaffected axillary buds. It is, therefore, necessary to spray paraquat bi-monthly except perhaps in very dry spells when weed growth is less vigorous and spraying could be delayed. Such regular spraying will prevent creepers and grasses from establishing. It is also important to look for pockets of these hardy weeds, and spray them thoroughly with paraquat or remove them using scrapers.

From the results of the experiments on the control of *P. conjugatum,* it is clear that the rate of 0.125 lb of paraquat (½ pint Gramoxone) in 50 gallons water per acre is inadequate to control this weed satisfactorily. The evidence so far available indicates that 0.25 lb in 50 gallons water is probably most effective and the control obtained is then satisfactory. When the stand of *P. conjugatum* is dense there is no doubt that a single application of the chemical cannot control it, and that as regeneration occurs (10 to 14 days after spraying) a repeat application has to be done in order to control this weed effectively.

Investigations on the phytotoxicity and residual effects of soil-incorporated paraquat on tea revealed that at ten ppm by weight there were no visible phytotoxic symptoms or retardation of growth of plants, and at this concentration all the paraquat is immobilized in the soil. At levels higher than 50 ppm, however, very severe toxic symptoms and growth retardation were observed, indicating

that all the paraquat is not adsorbed by the soil and that some of it is available for root uptake. This, however, should cause no alarm as even at 0.25 lb per acre of paraquat, (one pint Gramoxone) which is about the highest dose that is used in tea, the first six inches of the soil would have much less than 0.1 ppm by weight per application. The investigations revealed that the adsorptive capacity of paraquat of the soil used was between ten and fifty ppm. It may be mentioned that the adsorptive capacity of the loamy soil used appears to be much below that reported for a sandy loam elsewhere (Coats *et al.* 1966).

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References

BRIAN, R C. (1966). The bipyridylium quartenary salts. The effects of atmospheric and soil humidity on the uptake movement of diquat and paraquat in plants. *Weed Res.* **6**, 292-303.

BRIAN, R. C. (1967). The uptake and absorption of diquat and paraquat by tomato, sugar beet and cocks foot. *Ann. appl. Biol.* **59**, 91-99.

COATS, G. E., FUNDERBURK, H. H. Jr. LAWRENCE, J. M. & DAVIES, D. E. (1966). Factors affecting persistence and inactivation of diquat and paraquat. *Weed. Res.* **6**, 58-66.

SLADE, P. & BELL, E. G. (1966). Movement of paraquat in plants. *Weed Res.* **6**, 267-274.

SPRINGETT, R. H. (1965). The bipyridylium herbicides: their properties and use. *Outlook Agric.* **4** (5), 226-233.