

WEED CONTROL IN COFFEE IN THE NEW GUINEA HIGHLANDS

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ABSTRACT

Herbicides available in Papua New Guinea which are suited for use in coffee are briefly discussed. These include the foliar-acting herbicides paraquat, 2,4-D, MCPA, dalapon, amitrole and MSMA, and the soil-acting herbicides diuron, atrazine and simazine. Programmes for weed control, based on paraquat and diuron, are outlined and methods of control are given for specific weeds which are troublesome or can become so under these programmes. These weeds include Paspalum conjugatum, Cynodon dactylon, Commelina diffusa, Crassocephalum crepidioides, Ipomoea batatas, Lindernia spp. and Polygonum spp.

Two large-scale weed control trials being conducted at the Highlands Agricultural Experiment Station, Aiyura are described and the costs of treatments in the first 2 years of the trials are given. The first trial compares four methods of weed control under three shade situations on two sites. The treatments are (1) based on paraquat, (2) based on diuron, (3) hand-weeded, and (4) hand-weeded with a diuron application during the peak harvest period. Over the two-year period the paraquat-based treatment was the least costly on both sites and under all shade conditions, this being largely due to the large cost advantage of this treatment in the first year. In the second year, there were smaller differences in costs between the treatments and on one site under two shade situations the diuron-based treatment was more economical than the paraquat-based treatment, while the hand-weeded plus diuron treatment was comparable in cost to the paraquat-based treatment. No significant differences in coffee yields between the treatments have been obtained to date. The second trial, in unshaded coffee on one site only, compares treatments based on (1) paraquat and amitrole, (2) MSMA, (3) diuron plus amitrole, and (4) diuron plus paraquat. Treatment (1) was the most economical over the two-year period, but in the second year the costs of treatments (3) and (4) fell below that of treatment (1).

Examples of chemical weed control costs on other coffee blocks at Aiyura are given to further illustrate the large variations in costs that can occur.

I. INTRODUCTION

Prior to 1967, herbicides such as 2,4-D, dalapon and PCP had been used to a limited extent as a supplement to hand-weeding in coffee plantations but it was not until the introduction of 'Gramoxone' (paraquat) that herbicides began to appear feasible as an economic alternative to hand-weeding. Since then, rising labour costs and in some areas the low availability of labour, have given impetus to the rapid spread in the use of herbicides.

While paraquat has been and is the most widely used material, diuron ('Karmex', 'Diurex') has been gaining wider acceptance.

This article gives a brief description of the herbicides currently available, describes various weed control programmes, and gives details and results of trials in progress at Aiyura.

In the naming of herbicides, common names are used except where this would make statements of application rates ambiguous. The use of a brand name does not in any way imply endorsement of that product over a similar product of another manufacturer which is not mentioned, Table 1 lists the common and trade names of herbicides mentioned in this article.

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HERBICIDES

There are a number of herbicides readily available in Papua New Guinea which have been successfully used in coffee. No one material will control all the weed species present in high-land plantations, so that while paraquat or diuron is used as the basic treatment, both have to be supplemented in most situations by spot-spraying with other herbicides for specific weeds.

For descriptive purposes, herbicides may be classified according to whether they are absorbed through the leaves (*foliar-acting*) or through the roots (*soil-acting*). These divisions are often not mutually exclusive and it is not unusual for a herbicide which is mainly active via the foliage to have some effect through root uptake, especially at higher rates, or for a predominantly soil-acting herbicide to have some foliar activity.

1. *Foliar-acting Herbicides*

Since they act through the leaves, they are applied after the weeds emerge. They can be further subdivided according to whether their action depends on contact or translocation.

(a) *Contact*, i.e., their effect is predominantly due to a kill of contacted foliage, with little or no translocation (movement) through the plant.

Paraquat (Gramoxone) is the only herbicide in this category which is of present interest. It is active against a wide range of weed species, both grasses and broadleaves. While it kills most annual weeds, the exceptions being a few broadleaf species, it has only a transitory effect on perennial weeds, because they are able to regenerate from undamaged rootstocks. Paraquat acts very rapidly, and rain falling shortly after application will not inhibit its action. It is applied at concentrations of $\frac{1}{2}$ to 2 pints (of Gramoxone) per 45 gallons of spray. The formulation marketed in Papua New Guinea contains 2 lb of paraquat per gallon plus 10 per cent surfactant (wetting agent).

Paraquat has no action through plant roots because it is rapidly adsorbed onto the soil particles where it is tightly held and unavailable to plant roots. In mature coffee, paraquat

is unlikely to cause toxicity problems. The killing of a few lower leaves by direct contact will be of little importance. It is only when blanket applications are being made at the beginning of a spray programme that the possibility exists of contacting the green stems of suckers and incurring more serious damage. Once spraying has been reduced to spot applications, this danger should no longer exist if the sprayers take reasonable care. The other situation where care should be exercised is where, for any reason, large amounts of coffee feeder roots lie exposed on the soil surface. Without the protection of the soil, root uptake and subsequent damage to the tree is possible.

In young coffee in its first year or two in the field, there have been a number of cases where the paraquat spray has penetrated the thin bark and killed the underlying green tissue a few inches above the ground. This has a ringbarking effect which results in the death of the tree. The symptoms usually appear only after a number of applications have been made. For spraying in young coffee, there are three alternatives which avoid possible paraquat damage.

- (i) Spray along the middle of the rows with paraquat and hand-weed along the tree line.
- (ii) Spray along the middle of the rows with paraquat and use diuron along the tree line.
- (iii) Spray overall with diuron, but note the comments below concerning diuron.

(b) *Translocated*, i.e., herbicides which are absorbed into the plant (in this case through the leaves) and move through it to their site of action—the growing points of leaves or roots.

2,4-D ('Weedkiller D', 'Amoxone-50') is active against most broadleaf weeds. It has no effect when applied to the foliage of grasses. It is available in a number of formulations. The two products mentioned above are amine formulations, which with reasonable care are completely safe in older coffee. Both products contain 5 lb of active ingredient per gallon and are used in spot-spraying at concentrations of 1 to 4 pints per 45 gallons of spray. 2,4-D

Table 1.—Herbicides common, trade and chemical names

Common Name	Trade Name	Amount of Active Ingredient in Commercial Formulation	Chemical Name
Amitrole	Weedazol TL Plus	2.5 lb per gal	3-amino-1,2,4-triazole
Amitrole plus dalapon	Weedazol Total	10 per cent amitrole + 57.2 per cent dalapon on a weight basis	see amitrole and dalapon
Atrazine	Gesaprim-50	50 per cent on a weight basis	2-chloro-4-ethylamino-6-isopropylamino-1,3,5-triazine
2,4-D	Amoxone-50; Weedkiller D	5.0 lb per gal (amine salt)	2,4-dichlorophenoxyacetic acid
Dalapon	Basfapon; Dowpon; Gramavin	85 per cent on a weight basis (as the sodium salt)	2,2-dichloropropionic acid
Diuron	Diurex; Karmex	80 per cent on a weight basis	N'-(3,4-dichlorophenyl)-NN-dimethylurea
Fluometuron	Cotoran	80 per cent on a weight basis	N'-(3-trifluoromethylphenyl)-NN-dimethylurea
MCPA	Methoxone-30	2.42 lb per gal (as the sodium salt)	4-chloro-2-methylphenoxyacetic acid
Metobromuron	Patoran	50 per cent on a weight basis	N'-(4-bromophenyl)-N-methoxy-N-methylurea
MSMA	Ansar 529; Daconate	6.0 lb per gal; 4.98 lb per gal	monosodium methanearsonate
Paraquat	Gramoxone	2.0 lb per gal (of paraquat cation)	1,1'-dimethyl-4,4-bipyridylum dichloride
PCP	Weedkiller Q	1.0 lb per gal	pentachlorophenol
Simazine	Gesatop-50	50 per cent on a weight basis	2-chloro-4,6-bisethylamino-1,3,5-triazine

has some activity on weed seedlings from root uptake, but it only persists in the soil for a few weeks.

In mature coffee, if leaves on a lower lateral are contacted the only symptom that is observed is the twisting of the youngest leaf-pair on the lateral. Deliberate overall spraying of mature trees has caused defoliation and deliberate spraying of young suckers caused some twisting and limpness of stems and fairly severe twisting, limpness and yellowing of leaves, followed by slow death if the treatment was repeated. Damage from root uptake at least at the concentrations used (up to 4 pints per 45 gallons) is not likely.

MCPA ('Methoxone-30') is similar to 2, 4-D and also has no effect on grasses as a foliar spray. The product mentioned contains 2.4 lb of active ingredient per gallon and is usually used in spot-sprays at concentrations between 2 and 4 pints per 45 gallons.

Dalapon ('Gramevin', 'Dowpon', 'Basfapon') is a grass-killer effective against a number of hard-to-kill perennial grasses. It is used as a spot-spray at concentrations of 5 to 10 lb per 45 gallons. It is more effective applied in two equal applications about four weeks apart than as a single application at double the concentration. The three products listed above all contain 85 per cent of dalapon as the sodium salt.

While uptake is mainly through the leaves, root uptake can occur. Reasonable care in its use is required because excessive doses could cause damage to coffee through root uptake. This possibility is greater on lighter-texture soils. Spray concentrations should not exceed 10 lb (of product) per 45 gallons and concentrations of about 5 lb would be preferable, particularly in young coffee. In Kenya, applications of up to 8 lb of dalapon per acre (i.e., 9.4 lb of Gramevin or equivalent product) did not harm coffee provided the foliage was not sprayed (Wallis 1961), while toxicity symptoms from root uptake were recorded three months after an application of 10 lb dalapon per acre in bearing coffee (Wallis 1959), and three and a half months after an application of 13.6 lb dalapon (16 lb Gramevin or equivalent) in coffee which had recently been stumped (Wallis 1958).

It should be remembered that in spot-spraying it would be possible for a spray operator to spray double the intended rate to a given patch of ground. Thus, a spray containing 10 lb of Gramevin per 45 gallons could be applied to particular spots at a rate equivalent to 20 lb per acre.

In normal field use, damage to coffee from foliar contact has not been observed. However, deliberate overall spraying of mature trees has caused complete defoliation and, when young suckers on stumped coffee were sprayed, all suckers contacted were completely killed. Thus, contact with the foliage of young coffee should be carefully avoided, and reasonable care taken in older coffee.

Amitrole ('Weedazol TL Plus') has some effect on a wide range of grass and broadleaf weeds, although at the relatively low rates used in coffee it often only retards weed growth rather than achieving a complete kill. It is particularly effective against the perennial grass *Paspalum conjugatum* (thurston grass), and this has been its main use in the highlands. The Weedazol TL Plus formulation contains 2½ lb of amitrole per gallon plus an activator, ammonium thiocyanate. At the concentrations used—1 to 4 pints per 45 gallons—it appears to be safe in mature coffee, although contacted foliage will turn white and white leaves may also appear higher up the tree. This can look rather serious and it persists for a considerable period, but even on a block at Aiyura where amitrole has been the only herbicide used for 18 months, there has been no appearance of more advanced toxicity symptoms. However, in young coffee, more care is required. Fairly serious damage was caused at Aiyura from foliar contact. The herbicide accumulates at the growing points of the plant and can kill or seriously retard young suckers. The young trees that were damaged at Aiyura had been bent over in the Agobiada system to induce suckering, so that much of the foliage was at ground level and was contacted by the spray. In this instance, recovery occurred a few months after spraying had been suspended.

While root uptake is possible and was apparently the cause of toxicity symptoms reported in Kenya (Wallis 1958) from plots receiving 2 or 4 lb of amitrole (equivalent to 6.4 and 12.8 pints respectively of Weedazol

TL Plus), the main cause of all damage observed to date at Aiyura is considered to have been from foliar contact. The possibility of damaging mature coffee from root uptake when occasional spot-sprays are used would be very slight.

Another formulation, 'Weedazol Total', which is a mixture of amitrole and dalapon, is also active against a wide range of weed species and is more effective against most perennial grasses than amitrole alone.

MSMA ('Ansar 529', 'Daconate') is active against a number of grasses and broadleaves, although it is not effective against as wide a range of species as paraquat. It is particularly effective against several *Paspalum* species, including *P. conjugatum*. The Ansar 529 formulation contains 6 lb MSMA per gallon and the Daconate formulation 5 lb per gallon.

MSMA is an organic arsenical which, unlike inorganic arsenicals such as sodium arsenite, can be considered fairly safe to the user. Its use in food crops in developed countries is fairly strictly controlled and tolerance levels for arsenic residues in these crops have been established. It seems unlikely at present that any arsenic residues in coffee beans arising from the foliage being contacted with spray (root uptake is improbable) would exceed levels permitted elsewhere in food crops. However, as there is no set-up in Papua New Guinea for monitoring residues appearing in export produce, the indiscriminate use of MSMA would be unwise until further information is available. In non-bearing coffee or as a spot-spray under supervision, it should present no problems.

2. Soil-acting Herbicides

These materials are taken up from the soil by the weed seedling soon after germination and may be ineffective if applied after the seedling has emerged, although depending on the herbicide, the rate used and the weed species, larger seedlings may be killed. Soil-acting herbicides remain active in the soil for some time, and the longer-lasting materials are sometimes referred to as residual herbicides.

Diuron (Karmex, Diurex) is effective against a wide range of annual broadleaves and grasses and also some perennial grasses. Its

action against perennial grasses is unusual for a soil-acting herbicide, and even occurs with established plants of thurston grass, and in certain circumstances with couch grass. Both commercial products are wettable powders containing 80 per cent active ingredient (diuron). If used as recommended, i.e., at no more than 4 lb (of commercial product) per acre at the first application with subsequent applications at 2 lb per acre to give a total in the first year of use of about 8 lb per acre and about 4 lb per year thereafter, then there seems to be little likelihood in highland soils of residues ever accumulating to the point where they will become toxic to coffee. Occasional spray contact with the lower leaves has not been observed to cause any damage.

In young coffee, as an extra precaution, the maximum individual dose could be limited to 3 lb per acre, but with soil-applied treatments damage is unlikely. However care should be taken to avoid contacting the foliage. While contact may not kill the young coffee, it could, depending on the amount of foliage sprayed, cause a severe setback to growth. Symptoms of contact are a severe yellowing of leaves, except for the midrib and main veins, yellowing of sucker stems, death of tissue along the leaf margins and leaf-fall. This damage occurs even if the spray contains no added surfactant.

Simazine ('Gesatop') is active against a wide range of annual grasses and broadleaf weeds. It has no effect if applied to emerged weeds.

Atrazine ('Gesaprim') is similar to simazine, but has some foliar activity, so it can be applied successfully to small seedlings of annual weeds.

There are no other soil-acting herbicides available commercially in Papua New Guinea at present, although some which are undergoing evaluation in coffee are commercially available in Australia.

Some care should be exercised in the use of persistent soil-acting herbicides. If used at recommended rates, the annual rate of breakdown and loss from the soil will approximately balance the amount applied, so that there will be little likelihood that residues will build up in the soil to levels high enough to harm coffee. However a constant check should be

kept on how much is being applied, both over the whole plantation and also on smaller sections of it, to prevent overdoses being made.

II. HERBICIDE PROGRAMMES

At present there are two main alternative methods of chemical weed control. One is based on the use of the contact herbicide paraquat and the other on the soil-acting, residual herbicide diuron. These methods and some variations are discussed below. Whatever method is used, regular attention and treatment will be required if the programme is to be effective and economic.

1. Based on Paraquat

This is the herbicide programme with which most plantations have had some experience. In most situations it will be the least expensive method in the first year or so, and will probably remain so in the longer term. However, it does require regular applications at fairly short intervals, and can involve management difficulties when resistant weeds appear.

Initially blanket applications are made with a spray containing 1 pint of Gramoxone plus $\frac{1}{2}$ pint of non-ionic surfactant (such as 'Agral 60' or 'Nonidet WK') per 45 gallons of spray. This volume is sufficient to cover about one acre if spray nozzles giving a wide, coarse pattern are used. Respraying is carried out when the majority of the weeds from the next batch of germinating seeds reach a height of six to eight inches, but before they commence seeding. This usually results in an interval of about six weeks between sprayings, but can vary with rainfall and weed species. After two or three blanket applications, the weed germinations become patchy and it becomes feasible to spot-spray rather than apply a blanket application. At the same time, provided an adequate coverage of the weeds' foliage is made with the spray, it is usually possible to reduce the concentration of the spray from the initial 1 pint down to $\frac{1}{2}$ pint per 45 gallons of spray (the surfactant being retained at the initial concentration). After some time the $\frac{1}{2}$ pint of Gramoxone may be covering $2\frac{1}{2}$ acres or more, so that the amount being applied to each acre of plantation may only be $1/5$ th pint.

In most cases some resistant or partially resistant weeds will be present, and these will start to become more prominent once the

ground has become partly cleared of weeds. If action against the resistant weeds is delayed until they become firmly and widely established, then eradication becomes a more lengthy and costly process. The biggest problem is usually the perennial grasses *Cynodon dactylon* (couch grass) and *Paspalum conjugatum* (thurston grass). Other weeds which are less serious generally through the highlands, but which may become troublesome in particular areas, include the grasses *Paspalum orbiculare*, *Paspalum paniculatum*, *Pennisetum clandestinum* (kikuyu), *Pennisetum purpureum* (elephant grass), *Imperata cylindrica* (kunai), the sedges *Cyperus brevifolius* and *C. kyllingia*, and the broadleaves *Lindernia crustacea*, *L. anagallis*, *Portulaca oleracea* (pigweed) and *Commelina diffusa* (wandering jew—it is a monocotyledon so is not strictly a broadleaf weed, but by its superficial appearance and response to herbicides it is convenient to include it in this category).

Treating these weeds with other herbicides while continuing to apply paraquat at regular intervals to the susceptible weeds can involve difficulties, because if the other herbicide is slow-acting then it is necessary to avoid any contact of the treated weeds with paraquat until the other herbicide has had time to act. For example, when couch grass is treated with two applications of dalapon applied four weeks apart (and this gives better results than one application at double the rate), the couch grass should not be contacted with paraquat for at least a month after the second application. There is thus a period of up to 12 weeks (from the previous paraquat application 3 to 4 weeks before the first dalapon treatment until 4 weeks after the second dalapon treatment) when contact of couch grass with paraquat should be avoided. Where the couch grass is present in well-defined patches to the exclusion of all other weeds, the alternative spraying is relatively straightforward, but if the grass is more thinly distributed and in close association with other weeds, some modification of the spray programme may be necessary. Thus, if it is thought that ceasing paraquat treatments during the period, thereby allowing weeds to mature and produce seed, will not seriously increase the weediness of the block and the subsequent control costs, then this could be a

feasible solution. Alternatively the couch could be sprayed with paraquat at the same time as it becomes necessary for the other weeds. This would result in a poorer kill of couch grass and would necessitate further treatments, but control of all weeds would be maintained while the couch grass was being gradually eradicated. Another possibility would be to replace the paraquat treatment during the period around the dalapon applications with a herbicide which, if it contacts the couch grass, does not interfere with the action of dalapon. For example, 2,4-D or MCPA could be used to replace paraquat if broadleaf weeds predominated.

2. Based on Diuron

As generally practised, blanket applications of diuron are made at intervals of three to five months, and spot-spraying as necessary is carried out with the appropriate herbicides between the diuron applications. The initial diuron application is made at 4 lb of commercial product (Karmex, Diurex) per acre, and subsequent applications at 2 lb per acre. The first application can be made either to freshly weeded ground or to standing weeds. In the latter case it is necessary to include in the spray a suitable non-ionic surfactant at a concentration of 0.5 per cent of the spray volume, or a foliar-acting herbicide such as paraquat or amitrole. The later diuron applications are usually made to substantially weed-free ground so that additions of surfactant or foliar-acting herbicides are unnecessary. However, if a considerable amount of weed is present then a surfactant could be added, or alternatively the diuron could be applied alone and any weeds which were not killed could be spot-sprayed a few weeks after with a foliar-acting herbicide.

The weeds likely to require most attention on diuron-treated areas are couch grass, wandering jew, and the composite, thickhead (*Crassocephalum crepidioides*). Spot-treatments of specific weed species do not raise the difficulties which can occur under a paraquat programme, since there will be no regular paraquat applications to interfere with the action of translocated herbicides.

An alternative method of using diuron to that described above is to apply the first treatment as a blanket application and then all sub-

sequent treatments as spot-sprays of diuron as necessary. For these spot-sprays, as for blanket applications to standing weeds, either a non-ionic surfactant at 0.5 per cent of the spray volume, or paraquat or amitrole is added. A spray mixture of 3 lb Karmex (or Diurex) plus 1 pint of Gramoxone or 3 pints of Weedazol TL Plus with the appropriate amount of surfactant ($\frac{1}{2}$ pint per 45 gallons for Gramoxone or $\frac{1}{3}$ rd pint per 45 gallons for Weedazol TL Plus, i.e., the same amount that would be required if the foliar-acting herbicide was being applied alone), in 45 gallons of spray gives a fairly rapid knockdown and residual control of a wide range of weeds. The combination of diuron with amitrole or paraquat is quicker-acting and usually more effective than the diuron-surfactant mixture.

The spot treatments with the diuron-based spray are required at shorter intervals than the blanket applications, but the total number of treatments applied has been found to be no more than is required in the method which employs spot applications of other herbicides between the blanket applications of diuron. Although spot-spraying diuron reduces the need for spot treatments with other herbicides, in most cases they cannot be completely eliminated. Couch grass and wandering jew, if present, are likely to require additional treatment. The overall cost of this method can be considerably lower, particularly in the first year, than the method employing regular blanket applications, but it does have the disadvantage that excessive amounts of diuron could be applied to localized areas of ground.

3. Based on Other Soil-acting Herbicides

As yet, insufficient experience has been gained with other soil-acting herbicides such as simazine, atrazine, fluometuron ('Cotoran') or metobromuron ('Patoran') to make recommendations concerning their use. In overseas trials, diuron has usually given more consistent results, but in a particular area and weed situation, one or more of these materials may be more suitable than diuron. For example, it has been observed at Aiyura that simazine gives good control of thickhead (*Crassocephalum crepidioides*), which is not controlled by soil applications of diuron, and in a situation where this weed is prominent, simazine may be the

preferred treatment. Against this, however simazine gives no control of a number of weeds, for example, thurston grass and *Amaranthus lividus*, which are controlled by diuron.

The possibility of increasing the spectrum of weeds controlled by using mixtures of soil-acting herbicides is presently being examined.

PROBLEM WEEDS

As indicated above, there are a number of species which are not adequately controlled by one or both of the basic treatments and which therefore require additional treatment.

Paspalum conjugatum (Thurston Grass)

A number of different treatments will control and fairly quickly eliminate this grass. The most appropriate in a given situation will depend on the proportion of this weed in the total weed population, the herbicide being used as the basic treatment, and the importance placed on rapid elimination—which will generally be more costly than slower eradication.

(a) The cheapest method is to use only amitrole. Two applications of between 2 and 4 pints of Weedazol TL Plus per 45 gallons of spray, applied four weeks apart, with a follow-up treatment two to three months later on any patches which are recovering, give excellent results at low cost. While such a treatment is possible where thurston grass is the predominant weed, or where a soil-acting herbicide is being used as the basic treatment, it may not be possible if paraquat is the basic treatment, since it would not be feasible to cease using paraquat during the long period that amitrole takes to kill the grass. One way out of this difficulty, if it is not possible to avoid contacting the thurston grass with paraquat sprays, is to apply amitrole to all the weeds. Although a number of species may not be killed by this treatment, their growth and development will be retarded sufficiently to prevent them spreading while the thurston grass is being eradicated.

(b) However, where paraquat is the basic treatment and thurston grass is not a dominant species in the weed population, it is probably preferable to use amitrole in conjunction with paraquat. This method may take longer to achieve complete eradication and may be more costly but it does bring about a rapid decrease

in the amount of grass. Weedazol TL Plus is spot-sprayed to the thurston grass at a strength of 2 to 4 pints per 45 gallons of spray (depending on the height and density of the grass) and four weeks later the regular Gramoxone application, at 1 pint per 45 gallons, is made to all weeds, including thurston grass. There will be some recovery of thurston grass from this first "split application" treatment, but repeat treatments will eventually give complete eradication.

(c) As mentioned previously, diuron is effective against thurston grass, and where this herbicide is the basic treatment it will give good control, although there will probably be some patches of the grass which persist. These can either be eradicated with amitrole as described in (a) above, and this would be the less costly treatment, or by spot-spraying with diuron. A non-ionic surfactant at 0.5 per cent of the spray volume or amitrole or paraquat should be included with the diuron for spot treatments.

(d) The fourth method of treating thurston grass is with MSMA, but note the previous comment concerning MSMA. Two applications containing 2.25 to 3.75 lb of active ingredient (i.e., 3 to 5 pints of a formulation containing 6 lb active ingredient per gallon) per 45 gallons of spray applied about four weeks apart, with follow-up treatments to regrowth, will give good control. Applying paraquat after MSMA results in less satisfactory control.

Cynodon dactylon (Couch Grass)

Paraquat will "burn-off" the top growth of the grass but regeneration is rapid and even repeated doses fail to control it. Diuron at normal rates is usually ineffective and on diuron-treated areas, the grass can be expected to spread.

The most satisfactory method of treatment is with two applications of dalapon applied four weeks apart. Two applications give better results than one application using the same total amount of herbicide. The amount of herbicide required to give a high percentage kill will vary with the growing conditions of the weed. Applications made when the movement of the sap within the grass is predominantly downwards into the roots will give better

results than when the sap movement is predominantly upwards from the roots, since regrowth is only prevented if the dalapon enters the rhizomes and roots.

Under markedly seasonal conditions, considerable downward movement of sap can be expected towards the end of a period which has been favourable to growth, just prior to the onset of a period which is unfavourable to growth, such as a dry season. At this time the plant is laying down root reserves to carry it over the unfavourable season. In many high-land areas, including Aiyura, the seasonality is not particularly marked or constant, with the "wet season" being broken up by periods of dry weather and the "dry season" not being dry enough to interfere greatly with plant growth. Under these conditions the phasic growth of a perennial grass, as outlined above, may be ill-defined or it may be occurring but be difficult to predict because of the lack of predictability in the onset of dry periods.

In general, then, a dalapon spray containing 5 to 10 lb (of commercial product) per 45 gallons with 0.1 to 0.2 per cent wetting agent, applied twice with four weeks between the treatments, should be used. This range of spray concentration is given on the assumption that the spray is being applied at a rate of about 45 gallons per acre of treated ground. If spot-sprays are being applied at higher volumes, or are likely to be so applied, then the spray concentration should be adjusted so that the upper rate limit does not exceed the equivalent on any patch of grass of 10 lb per acre. If conditions are favourable for the downward translocation of herbicide, then the concentration of 5 lb per 45 gallons should be sufficient to give a high percentage kill. Even at the highest rate complete eradication may not be achieved after one double treatment, although initially all the aboveground growth will appear to be dead. Prompt retreatment of regrowth will result in eventual eradication at the lowest cost.

In an area in which paraquat is being used, double applications of dalapon can be difficult, as mentioned previously. As with amitrole on thurston grass, a split application method can be used in which a spot-spraying of couch grass with dalapon at 5 to 10 lb per 45 gallons precedes by about four weeks the regular over-

all treatments with paraquat. This treatment gives less satisfactory results than the double application of dalapon, and the eradication of the couch grass would be a lengthier process.

As already mentioned, care should be taken to prevent overdoses of dalapon being applied, as damage to the coffee could result from root uptake.

Repeated doses of amitrole will control the grass better than does paraquat alone, but even where several applications have been used, eradication has not been achieved and when treatment ceased the grass recovered. Repeated applications at higher rates (around 8 pints of Weedazol TL Plus per 45 gallons of spray) may be more successful, but would be more expensive than dalapon and would introduce the possibility of affecting the coffee.

A mixture of dalapon and amitrole (a commercial formulation containing these ingredients is marketed as Weedazol Total) is effective, but no more so than dalapon treatments of equal cost.

Commelina diffusa (Wandering Jew)

This weed is likely to become troublesome under a diuron programme. With paraquat, repeated sprayings will usually control it, although additional treatment may be required for very thick infestations, or if relatively low rates of paraquat (less than 1 pint of Gramoxone) are being used, or in exposed areas.

Repeated spot-sprays with 2,4-D amine at 3 to 4 pints per 45 gallons (of formulations containing 5 lb active ingredient per gallon) have been successful in eliminating the weed at Aiyura. However, a recent trial has indicated that MCPA at 4 pints (of Methozone-30) is a more effective and cheaper treatment, although two applications were still not sufficient to completely eradicate a dense infestation. In the same trial, some newer herbicides were superior to MCPA, but their cost seems likely to be considerably higher than that of MCPA.

Crassocephalum crepidioides (Thickhead)

This composite is resistant to soil applications of diuron and usually becomes prominent in an area soon after diuron treatment commences. Foliar applications of diuron with

surfactant, or paraquat, will kill established plants, but will have no residual effect on plants which subsequently appear from seed. The cheapest treatment is spot-spraying Gramoxone at 1 pint per 45 gallons of spray. 2,4-D has some effect on the weed, but although growth may be retarded, recovery often occurs, even from sprays containing 3 pints (of commercial formulation) per 45 gallons. MCPA gives similar results.

Ipomoea batatas (Sweet Potato)

Sweet potato regrowth is resistant to paraquat and only slightly affected by diuron. 2,4-D or MCPA at 2 pints (of commercial formulation) per 45 gallons of spray will kill it.

Lindernia spp.

There are two species of *Lindernia* occasionally present in coffee. They are small prostrate plants which are usually inconspicuous until other weed growth is eradicated. Both species have purplish pigmentation on the upper surface of their leaves and stems. The flowers are purple and white, or purple with a yellow spot. They are resistant to paraquat and possibly also to diuron. However, both species spread relatively slowly and seem unlikely to become a problem. Control is achieved with 2,4-D at 2 pints (of commercial formulation) per 45 gallons of spray.

Polygonum spp.

Polygonum minus and *Polygonum dichotomum* are occasionally seen in plantations, usually in or adjacent to drains. Both are resistant to paraquat. *P. dichotomum* grows fairly prostrately and has firm, dark green leaves and small white and pink flowers in short clusters. It can be controlled with 2,4-D at 2 pints per 45 gallons of spray. *P. minus* grows more upright, has longer, narrower leaves, and small pink or white flowers on flowering branches (racemes). 2,4-D at 2 pints (of commercial formulation) per 45 gallons has not controlled it, but it is likely that higher concentrations would do so.

P. nepalense is a common weed in coffee. It has thin, light green leaves, often with a darker patch near the centre, stems which are usually reddish, and small pink flowers in small clusters. Paraquat is less effective on it than on

most annual weeds, and if it is not being adequately controlled, 2,4-D at 2 pints (of commercial formulation) per 45 gallons can be used.

III. ECONOMICS OF VARIOUS METHODS OF WEED CONTROL

Several trials at Aiyura are examining the economics of various systems of weed control. The two which have been in existence for the longest period are discussed here in some detail.

TRIAL AWC2a

The first, designated AWC2a, commenced in March, 1968. It compares the costs of the following four weed control treatments:—

- (1) Basically paraquat (Gramoxone);
- (2) Basically diuron (Karmex or Diurex);
- (3) Hand-weeded; and
- (4) Hand-weeded during most of the year with diuron used during the peak harvest period.

The trial was laid out over an existing shade-spacing-pruning trial, ACA1, with each weed control treatment being applied to a complete replicate of ACA1. Thus, each herbicide treatment is evaluated under three shade conditions, namely dense Casuarina shade, medium Albizia shade and Unshaded, at each of two sites—the hillside block B15/16 and the "pit-pit" blocks C6-D6. Each shade plot is $\frac{5}{8}$ acre in size. Under each shade the coffee is grown at three spacings (7, 8 and 9 ft triangle) and with two pruning systems (single stem and multiple stem). The weed control costs given for a shade plot are thus an average of the costs in six different growing situations. This is mentioned because in mature coffee, weed growth in different plantings systems varies considerably, as shown in Table 2. Table 3 shows how weed growth is influenced by overhead shade.

Details of the soil types at the two sites are given in Table 4.

The weed problem in the trial area was worse than that existing on most highland plantations, with perennial grasses forming a high proportion of the weed population. On the pit-pit site, the perennial grass problem was accentuated by the heavy, poorly drained soil.

Costs of weed control, both by chemical and manual means, will vary greatly between properties, depending on such factors as rainfall, soil type and weed species. The costs incurred in this trial cannot be directly transposed to different situations elsewhere in the highlands. In fact, for reasons mentioned above, the costs of all treatments in the trial are higher than would be expected on most plantations. However, the relative costs of the different treatments can be usefully compared, and along with results from other current trials, which are discussed later, help to provide a reasonable indication of the likely costs of a particular programme in a given situation.

Table 5 gives the per acre cost of each treatment for the first two years. Details of each treatment follow.

1. *Basically Paraquat*—with no soil-acting residual herbicides

A summary of the applications made under each shade appears in Table 6. The main weeds at which the various additional herbicides used were aimed are indicated, and a breakdown of the total costs due to paraquat and to 'other' herbicides is given.

The weed species are given according to the following code:

A	<i>Paspalum conjugatum</i> (thurston grass)
B	<i>Cyperus brevifolius</i> and <i>C. kyllingia</i>
C	<i>Cynodon dactylon</i> (couch grass)
D	<i>Paspalum orbiculare</i>
E	<i>Paspalum paniculatum</i>
F	<i>Pennisetum purpureum</i> (elephant grass)
G	<i>Pennisetum clandestinum</i> (kikuyu grass)
H	<i>Brachiaria mutica</i> (para grass)
I	<i>Polygonum dichotomum</i>
J	<i>Rumex crispus</i> (dock)
K	<i>Ipomoea batatas</i> (sweet potato)
L	<i>Lindernia</i> spp.
M	<i>Commelina diffusa</i> (wandering jew)
N	<i>Crassocephalum crepidioides</i> (thickhead)
O	<i>Dichrocephala bicolor</i>

For most of the first year the old Gramoxone formulation which contained no added surfactant was used. Agral 60 was added to the spray mix at the manufacturer's recommended concentration of 1.5 pints per 100 gallons of spray. With the new formulation which contains 10 per cent surfactant, 0.5 pints of Agral 60 was added to each 45 gallons of spray. The concentration of Agral 60 used with the other foliar-acting herbicides varied from 0.06 to 0.1 per cent.

Table 2.—Trial AWC2a. Comparison of quantity of weeds growing in the six different spacing-pruning arrangements of each site, prior to the commencement of the control programme

Shade	Site	Weed Weight (lb dry matter per acre) ⁽¹⁾					
		MS 9 x 9	SS 9 x 9	MS 8 x 8	SS 8 x 8	MS 7 x 7	SS 7 x 7 ⁽²⁾
Casuarina ⁽³⁾	Hillside	311	402	50	119	42	102
	Pit-pit	100	202	122	116	62	115
	Mean	206	302	86	118	52	109
Albizia	Hillside	1,737	1,368	1,311	389	256 ⁽⁴⁾	833
	Pit-pit	588	827	1,198	504	257	498
	Mean	1,163	1,098	1,255	447	257	664
Unshaded	Hillside	4,059	3,052	3,512	2,499	2,418	1,187
	Pit-pit	1,282 ⁽⁵⁾	2,505 ⁽⁴⁾	1,923	1,639 ⁽⁴⁾	2,060	396 ⁽⁴⁾
	Mean	3,133	2,817	2,718	2,069	2,264	849

(1) The figures for each site are derived from 16 samples (4 samples from each of 4 shade plots), each sample being from an area of 2 ft².

(2) Pruning system and spacing (in ft) of coffee. The coffee is planted on a triangular spacing. MS=Multiple stem. SS=Single stem.

(3) The weed weights under Casuarina shade include coffee seedlings, which often formed a high proportion of the total weight of samples—100 per cent in a number of instances.

(4) Derived from 12 samples only.

(5) Derived from 8 samples only.

Table 3.—Trial AWC2a. Comparison of quantity of weeds growing, and percentage ground covered by weeds, under different shade conditions, prior to the commencement of the control programme

Shade	Site	Weed Weight ⁽¹⁾ (lb dry matter per acre)					% Cover ⁽¹⁾				
		1	2	3	4	Mean	1	2	3	4	Mean
Casuarina	Hillside	130	88	388	79	171 ⁽²⁾	9	6	17	9	10
	Pit-pit	92	119	83	182	119 ⁽³⁾	6	13	7	13	10
	Mean	....	....	....	....	145	....	....	....	....	10
Albizia	Hillside	1,323	489	1,441	759 ⁽⁴⁾	1,003	50	43	49	55	49
	Pit-pit	975	929	300	375	645	52	48	31	28	40
	Mean	....	....	....	....	824	....	....	....	....	45
Unshaded	Hillside	2,407	2,077	3,952	2,959	2,849	91	76	89	91	87
	Pit-pit	1,483 ⁽⁴⁾	2,131	....	1,322	1,645	77	75	....	73	75
	Mean	....	....	....	....	2,333	....	....	....	....	82

1 Plot to receive paraquat treatment.

2 Plot to receive diuron treatment.

3 Plot to receive hand-weeding treatment.

4 Plot to receive hand-weeding plus diuron treatment.

(1) Derived from 24 samples of 2 ft² in each shade plot.

(2) 38 per cent of this weight was due to coffee seedlings, the percentage ground cover includes coffee seedlings.

(3) 63 per cent of this weight was due to coffee seedlings, the percentage ground cover includes coffee seedlings.

(4) Derived from 20 samples only.

Table 4.—Representative analyses of soils in AWC2a

Site	Soil Type	Percentage Clay (0 to 6 in)	Organic Matter (0 to 6 in)	pH (0 to 6 in)
Hillside	Clay	34.8	14.3	5.1
Pit-pit	Clay	65.9	13.1	5.0

(a) *Unshaded*.—On the hillside plot prior to the first application, *Paspalum conjugatum* (thurston grass) constituted 50 per cent (by weight) of the weeds present, the broadleaf *Drymaria cordata* 12 per cent and *Commelina diffusa* (wandering jew) 10 per cent. On the pit-pit plot, thurston grass accounted for 85 per cent (by weight) of the weeds, *Cynodon dactylon* (couch grass) 5 per cent and *Cyperus brevifolius* 1½ per cent. The heavy weed infestation, dominated by thurston grass, can be seen in Plate I.

After seven applications of paraquat on both plots, it became apparent that paraquat on its own, although achieving a reduction in the amount of thurston grass, particularly on the

hillside plot, was not going to eradicate it. Because of the rapid recovery of the grass after treatment, the intervals between these seven sprayings ranged from three to five weeks. Amitrole was then applied as a split application in conjunction with paraquat, and after a second such double application the grass was largely eradicated. Plate II shows a section of the unshaded pit-pit plot one month after the first amitrole-paraquat split application.

During the second year, the sedge *Cyperus brevifolius*, and to a lesser extent a similar sedge, *C. kyllingia*, and couch grass became serious weeds on the pit-pit site. *C. brevifolius* had initially been present as an insignificant plant a couple of inches high, usually hidden by taller vegetation. With the elimination of other weeds (mainly thurston grass), it became larger (up to 8 in or more high), and spread to form a dense continuous mat of growth, which completely covered about one third of the plot (see Plate III). On the hillside plot, it persisted as a low plant growing in small discrete patches, and was held in reasonable check by paraquat. The sedge has been observed occasionally elsewhere in the highlands, but only growing as small individual

Table 5.—Costs per acre of herbicide treatments in AWC2a

Treatment	Shade	Site	Total Cost (Herbicide, Wetting Agent, Labour)		
			1st Year	2nd Year	Total
Basically paraquat	Casuarina	Hillside	12.23	6.08	18.31
		Pit-pit	9.74	3.25	12.99
	Albizia	Hillside	26.84	10.67	37.51
		Pit-pit	33.22	21.55	54.77
	Unshaded	Hillside	36.72	18.43	55.15
		Pit-pit	39.13	33.11	72.24
Basically diuron	Casuarina	Hillside	20.50	10.96	31.46
		Pit-pit	10.49	7.59	18.08
	Albizia	Hillside	47.58	22.80	70.38
		Pit-pit	50.01	15.98	65.99
	Unshaded	Hillside	61.04	25.98	87.02
		Pit-pit	63.92	23.48	87.40
Hand-weeded plus diuron	Casuarina	Hillside	14.55	13.28	27.83
		Pit-pit	19.47	10.37	29.84
	Albizia	Hillside	35.86	22.80	58.66
		Pit-pit	37.53	20.24	57.77
	Unshaded	Hillside	70.21	35.71	105.92
		Pit-pit	60.00	32.25	92.25
Hand-weeded	Casuarina	Hillside	20.21	11.42	31.63
		Pit-pit	18.61	9.00	27.61
	Albizia	Hillside	49.83	29.16	78.99
		Pit-pit	42.85	28.24	71.09
	Unshaded	Hillside	74.15	42.63	116.78
		Pit-pit	81.50	45.19	126.69

Prices used in compiling costs:

Agral 60 \$6.20 per gallon

Ansar 529 \$8.00 per gallon

Gramevin \$0.55 per lb

Gramoxone \$21.50 per gallon

Karmex 3.25 per lb

Methoxone-30 \$3.40 per gallon

Teepol \$1.18 per gallon

Weedazol TL Plus \$7.50 per gallon

Weedkiller D

(and Amoxone-50) \$5.19 per gallon

Labour 9c per man-hour

plants, and it seems unlikely that it would become a problem on reasonably well-drained soils.

Much of the difference in costs between the two plots can be attributed to this sedge, although couch grass on the pit-pit plot was also a factor, as can be seen by the quantities of dalapon applied (Table 6). Control of the sedge was attempted with amitrole and with MSMA, but at the concentrations used (3 and 5 pints of 60 per cent w/v MSMA formulation per 45 gallons and 4 pints of Weedazol TL Plus per 45 gallons) they were only successful against smaller plants, the bulk of the growth being only temporarily checked. Higher concentrations have subsequently been more successful.

(b) *Albizia* Shade.—At the beginning of the trial, thurston grass constituted 50 per cent (by weight) of the weeds present on the hillside plot, while on the pit-pit plot it formed 67 per cent and couch grass 18 per cent of the weeds present.

The first paraquat treatments removed much more of the thurston grass than had been the case on the unshaded plots, but dense residual clumps remained, and on a poorly shaded section of the pit-pit plot almost no reduction was achieved. The amitrole-paraquat split applications resulted in the virtual eradication of the grass.

In the second year the pit-pit plot required considerable attention for *C. brevifolius* and couch grass, which infested, in particular, a

Table 6.—Summary of the paraquat-based treatment of AWC2a
Quantities of herbicides in lb or pints of commercial product per acre

Herbicide		Unshaded				Albizia				Casuarina			
		Hillside		Pit-pit		Hillside		Pit-pit		Hillside		Pit-pit	
		Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
Paraquat	No. of applications	9	7	9	4	8	7	9	4	6	7	6	4
	Total quantity	9.1	3.5	9.5	2.8	6.6	1.5	8.2	1.8	2.7	1.0	2.3	0.5
	Spray concentration (pints per 45 gal)	0.7-1.6	1.0	0.7-1.8	1.0	0.7-1.7	0.5-1.0	0.7-1.8	1.0	0.7-1.8	0.5-1.0	0.7-1.8	1.0
Amitrole	No. of applications	2	2	2	3	2	2	2	3	2	2	2	2
	Total quantity	2.8	3.4	4.2	7.0	2.1	2.7	3.0	4.6	1.4	0.9	0.7	0.3
	Spray concentration (pints per 45 gal)	2.0-3.4	2.0-8.0	2.0-4.0	2.0-4.0	2.0-3.4	2.0-8.0	2.0-4.0	2.0-4.0	2.0-3.4	2.0-8.0	2.0-4.0	2.0-4.0
Dalapon	Main weeds treated	A	A, B	A, B	A, B	A	B	A	A, B	A	B	A	B
	No. of applications	1	1	1	3	1	1	1	3	1	1	1	3
	Total quantity	1.8	1.9	1.9	7.2	0.85	1.3	1.5	5.0	0.5	1.3	0.2	0.9
	Spray concentration (lb per 45 gal)	6.0	6.0	5.0	5.0-7.5	6.0	6.0	5.0	5.0-7.5	6.0	6.0	5.0	5.0-7.5
	Main weeds treated	C, D	D, E	C, D	C, D	D, F	D, F	C, D	C, D	D	D	C, D	C, D
Dalapon plus amitrole	No. of applications	....	....	....	2	....	....	....	2	....	....	....	....
	Total quantity	....	....	....	3.1d+1.2a	....	....	....	2.2d+0.9a	....	....	....	....
	Spray concentration (lb + pints per 45 gal)	....	....	....	5.0d+2.0a	....	....	....	5.0d+2.0a	....	....	....	....
2,4-D	Main weeds treated	....	....	....	C	....	....	....	C	....	....	....	....
	No. of applications	....	1	1	1	....	....	1	1	....	....	....	....
	Total quantity	....	0.1	0.5	0.6	....	....	0.4	0.1	....	....	....	....
	Spray concentration (pints per 45 gal)	....	2.0	2.0	2.0	....	....	2.0	2.0	....	....	....	....
MSMA	Main weeds treated	....	K	I, J, K	I, J, K, L	....	....	I, J	I, J, L	....	....	....	....
	No. of applications	....	1	....	3	....	1	....	3	....	1	....	2
	Total quantity	....	0.9	....	6.2	....	0.4	....	3.4	....	0.3	....	0.3
	Spray concentration (pints per 45 gal)	....	3.0	....	3.0-5.0	....	3.0	....	3.0-5.0	....	3.0	....	3.0-5.0
	Main weeds treated	....	B, D, E	....	B, D	....	B	....	B, D	....	B	....	B
Cost of paraquat applications (including labour)	\$	31.92	12.17	32.50	9.84	23.41	6.26	28.32	6.53	10.14	3.88	8.72	1.88
Cost of all non-paraquat applications (including labour)	\$	4.80	6.26	6.63	23.27	3.43	4.41	4.90	15.02	2.09	2.20	1.02	1.37
TOTAL COST	\$	36.72	18.43	39.13	33.11	26.84	10.67	33.22	21.55	12.23	6.08	9.74	3.25



Plate I.—A section of the unshaded paraquat plot on the pit-pit site of trial AWC2a at the time of the second application of paraquat. The dominant weed species is thurston grass (*Paspalum conjugatum*)

poorly shaded area, after the original cover of thurston had been removed. However, the sedge remained as small clumps and did not spread to form a continuous cover as it had on the adjacent unshaded plot. The presence of couch grass and sedge was the main reason for the considerable difference in cost between the hillside and pit-pit plots. On the hillside plot, the weeds had been reduced by the end of the first year to a patchy cover of predominantly annuals. This allowed the use of low concentrations of paraquat during much of the second year and a small number of applications with other herbicides.

(c) *Casuarina* Shade.—The weed growth under the dense shade in these plots was very slight. A large proportion of the costs incurred was due to treatments around the perimeter

of the plot. Thus, on large scale plantings under such shade, the weeding costs would be considerably less than is indicated for these $\frac{2}{3}$ acre plots. Weeds were more prevalent in the multiple stem coffee at the widest spacing (9 x 9 ft). Inside the plot, the main weeds, excluding coffee seedlings, were *Crassocephalum crepidioides* (thickhead), *Drymaria cordata* and *Ageratum conyzoides*. On each site in the first year, $1\frac{1}{2}$ pints of the total Gramoxone



Plate II.—View of part of the unshaded paraquat plot on the pit-pit site of Trial AWC2a 38 weeks after the trial commenced. Photo taken one month after the first amitrole-paraquat split application. The clumps of thurston grass (*Paspalum conjugatum*) are still white from the amitrole treatment. The taller, tufted grass which is not showing obvious amitrole symptoms is *Paspalum orbiculare*

used was applied in the first spraying. This blanket application was probably unnecessary but it did remove the very numerous small coffee seedlings.

2. Basically Diuron

Table 7 summarizes the applications made under each shade and indicates the main weeds spot-treated with herbicides other than diuron. The total costs of the spot-sprays and of



Plae III.—Severe infestation of the sedge *Cyperus brevifolius* in a section of the unshaded paraquat plot on the pit-pit site in trial AWC2a. The sedge invaded this area after the thurston grass shown in Plate I had been eradicated

the diuron applications are also given. The wetting agent used in the spot treatments was either Agral 60, usually at a concentration of less than 0.1 per cent, or 'Teepol' at a concentration of 0.1 to 0.2 per cent of the spray volume.

(a) *Unshaded*.—At the commencement of the trial, the main weeds on the hillside plot were thurston grass which made up 31 per cent (by weight) of the weed vegetation, and *Drymaria cordata* which formed 25 per cent. On the pit-pit plot, thurston grass formed 31 per cent, *Cyperus* spp. 25 per cent, couch grass 21 per cent and wandering jew 12 per cent.

All diuron applications were made as blanket treatments, that is, applied to the total ground area. The initial treatment on the two sites differed in that the first application of diuron was applied to standing vegetation (8 to 10 inches high) on the hillside plot, while on the pit-pit plot the knee-high growth was slashed to within a couple of inches of the

ground one week before the first application. On each site the first application was at 5 lb Karmex (i.e., 4 lb diuron) per acre with 1 per cent non-ionic surfactant, the second at 2½ lb Karmex with ½ per cent non-ionic surfactant, and the third at 2½ lb Karmex without surfactant. These applications were made at 0, 28, and 49 weeks on the hillside plot and at 1, 22 and 44 weeks on the pit-pit plot. The ground cover on both plots at the time of the second diuron application was about 30 per cent, while at the third application the ground was predominantly bare.

By the end of the first year, thurston grass had been virtually eradicated and the most prominent weed was *Cyperus brevifolius*, although it did not constitute a serious problem. The sedge is affected by diuron, but larger plants usually recover (at least from lower rates), and there is also reinfestation from the seed of roadside plants.

The elimination of the thurston grass was due almost entirely to the diuron treatments. Amitrole was not used until near the end of the first year (mainly for *C. brevifolius*), and by this time the thurston grass was almost non-existent. The dalapon treatments, if applied to the grass, had only a very slight effect.

In the second year, both plots received two applications of diuron without surfactant, at 2 lb (of Karmex) per acre, plus additional spot-sprays, as indicated in Table 7. The diuron applications were made to predominantly bare ground, in weeks 66 and 85 on the hillside plot, and in weeks 70 and 90 on the pit-pit plot. Throughout the second year, both plots remained substantially weed-free. The main species present at the end of the second year were *Cyperus brevifolius*, *Paspalum orbiculare* and thickhead on the hillside plot, and *C. brevifolius* and *C. kyllingia* on the pit-pit plot.

(b) *Albizia Shade*.—Of the weeds present on the hillside plot at the beginning of the trial, *Drymaria cordata* formed 29 per cent (by weight) and thurston grass 10 per cent. On the pit-pit plot, thurston grass constituted 33 per cent (by weight) of the weeds, *D. cordata* 15 per cent and *Cyperus* spp. 9 per cent.

The applications made to these plots were substantially the same as for the unshaded plots. One difference, however, was that the

Table 7.—Summary of the diuron-based treatment of AWC2a
Quantities of herbicide in lb or pints of commercial product per acre

Herbicide		Unshaded				Albizia				Casuarina			
		Hillside		Pit-pit		Hillside		Pit-pit		Hillside		Pit-pit	
		Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
Diuron	No. of applications	3	2	3	2	3	2	3	2	2	2	1	2
	Total quantity	10.0	4.0	10.0	4.0	9.0	4.0	9.0	4.0	4.7	1.8	1.3	1.8
Dalapon	No. of applications	4	3	4	5	4	3	4	3	3	3	4	5
	Total quantity	14.8	3.5	16.7	8.7	7.6	3.7	7.9	1.2	1.3	1.4	2.8	1.7
	Spray concentration (lb per 45 gal)	5.6-7.5	5.0	7.0-7.5	5.0-15.0	5.6-7.5	5.0	7.0-7.5	5.0-15.0	5.6-7.5	5.0	7.0-7.5	5.0-15.0
2,4-D	Main weeds treated	C, D, G	C, D, G	C, D	C, D	C, D, G	C, D, G	C, D	C, D	D, G	D	C, D	C, D
	No. of applications	4	1	2	1	4	1	2	1	3	1 ¹	2	1
	Total quantity	5.5	0.9	3.1	0.6	4.5	0.7	2.1	0.1	1.9	1.1	2.4	0.1
	Spray concentration (pints per 45 gal)	3.4-4.5	4.0	4.0-4.5	3.0	3.4-4.5	4.0	4.0-4.5	3.0	3.4-4.0	2.0-4.0	4.0-4.5	3.0
MCPA	Main weeds treated	M, N	M	J, K, M, O	M, N	M, N	M	M, O	M, N	M, N	M, N, O	J, M, O	M, N
	No. of applications			....	1			....	1				
	Total quantity			....	0.6			....	0.5				
	Spray concentration (pints per 45 gal)			....	4.0			....	4.0				
Amitrole	Main weeds treated			....	M, O			....	M, N				
	No. of applications	1	2	2	....	1	2	2	....	1	2	2	....
	Total quantity	1.8	3.8	3.6	....	0.4	2.1	1.9	....	0.4	1.3	1.3	....
	Spray concentration (pints per 45 gal)	4.0	4.3-8.0	4.0	....	4.0	4.3-8.0	4.0	....	4.0	4.3-8.0	4.0	....
Paraquat	Main weeds treated	B	B	B	....	B	B	B	....	B	B	B	....
	No. of applications	1	1			1	1			....	1		
	Total quantity	1.5	0.3			0.5	0.2			....	0.2		
	Spray concentration (pints per 45 gal)	1.8	1.0			1.8	1.0			....	1.0		
MSMA	Main weeds treated	M	B			M	B, D			....	N		
	No. of applications	....	2	....	3	....	2	....	2	....	1 ¹	....	2
	Total quantity	....	3.0	....	2.7	....	2.3	....	0.9	....	0.6	....	0.3
	Spray concentration (pints per 45 gal)	....	3.0-4.0	....	3.0-4.0	....	3.0-4.0	....	3.0-4.0	....	2.0	....	3.0-4.0
	Main weeds treated	....	B	....	B, D	....	B	....	B	....	N, O	....	B
Cost of diuron applications (including labour)		\$ 39.98	13.73	39.50	13.51	36.38	13.79	36.19	13.50	17.52	6.22	5.27	6.02
Cost of spot-sprays (in- cluding labour)		\$ 21.06	12.25	17.22	9.97	11.20	9.01	8.96	2.48	2.98	4.74	5.22	1.57
TOTAL COST		\$ 61.04	25.98	63.92 ²	23.48	47.58	22.80	50.01 ³	15.98	20.50	10.96	10.49	7.59

1. This application was a combined treatment of MSMA and 2,4-D.

2. Includes \$4.86 for an initial slashing.

3. Includes \$7.20 for an initial slashing.

second and third diuron applications were at 2 lb (of Karmex) per acre and not $2\frac{1}{2}$ lb. At the second diuron application the weed cover was 10 to 15 per cent, and at the third application it was less than 5 per cent. At the end of the second year the weed cover on both plots was less than 1 per cent. Thickhead was the main weed on the hillside plot and *C. brevifolius* the main weed on the pit-pit plot.

(c) *Casuarina Shade*.—As Table 3 shows, the weed cover within the coffee at the commencement of the trial was low on both sites, although it was somewhat higher around the plot perimeters. The main weeds on the hillside plot were wandering jew and thurston grass, while thickhead, *D. cordata* and *Isachne myosotis* (a small prostrate-growing grass) were the most common weeds on the pit-pit plot.

The weed growth was really too slight to justify the use of an expensive herbicide such as diuron, and apart from an initial blanket application on the hillside plot, all applications of diuron on both plots were made as spot-sprays within the coffee with a blanket spray around the perimeters. Of the total of 4.7 lb Karmex applied to the hillside plot in the first year (see Table 7), 4.0 lb was in the first blanket application. Although there were a considerable number of spot-sprays with other herbicides, which were generally applied at the same time as the other shades were being treated, the amount of weeds present was always small. The average volume of spray required per application (on a per acre basis) in the second year was 8.4 gallons on the hillside plot and 4.6 gallons on the pit-pit plot.

3. Hand-weeded

(a) *Unshaded*.—At the beginning of the trial, which was about 16 weeks after the area had previously been hand-weeded, the main weeds on the hillside plot were thurston grass which formed 37 per cent (by weight) of the weeds present and *Pennisetum clandestinum* (kikuyu) which formed 18 per cent. On the pit-pit plot the main weed was thurston grass, but no figures were obtained because part of the plot was inadvertently weeded about two weeks before the trial was due to commence. The commencement date for the hand-weeded treatment was taken from the date of this

partial weeding and its cost was included in the total cost for this treatment.

In the first year the hillside plot was weeded, with hoes, seven times and the pit-pit plot seven and a half times (the "half" being the accidental partial weeding referred to above). In the second year both plots were weeded six times—four times with hoes and the last two weedings with spades. As much as possible, weeding was done during periods of dry weather in an attempt to obtain a reasonable kill of the perennial grasses. Weeding perennial species at other times is little more than a transplanting operation.

At the end of the second year the main weeds on the hillside plot were thurston grass and kikuyu, and the weed cover 6 weeks after the last weeding was 29 per cent. On the pit-pit plot the main weeds present were thurston grass, couch grass, *Dichrocephala bicolor* (a broadleaf), *C. brevifolius* and wandering jew, and the weed cover nine weeks after the last weeding was 52 per cent.

(b) *Albizia Shade*.—At the start of the trial the main weeds were thurston grass, kikuyu grass and wandering jew on the hillside plot, and *Stellaria media* (chickweed), *Cyperus* spp., thurston grass and *Isachne myosotis* on the pit-pit plot.

Both plots were weeded seven times with hoes in the first year, and four times with hoes and twice with spades in the second year. At the end of the second year the main weeds on the hillside plot were thurston grass, *I. myosotis* and *D. cordata*, and the weed cover 6 weeks after the last weeding was 10 per cent. On the pit-pit plot the main weeds at that time were thurston grass, *I. myosotis* and wandering jew and the weed cover 9 weeks after the last weeding was 14 per cent.

(c) *Casuarina Shade*.—The most common weeds present at the start of the trial were *Paspalum orbiculare*, thickhead and *Digitaria pruriens* on the hillside plot and wandering jew, *Dolichos* sp. and thurston grass on the pit-pit plot. On both sites the weed cover around the perimeter of the plots was considerably more than it was within the plots, where coffee seedlings were more abundant than weeds.

In the first year the hillside plot was weeded (with hoes) five times and the pit-pit plot seven times. In the second year both plots received four weedings with hoes and two with spades.

Decrease in labour requirements.—The decrease in labour requirements for the hand-weeded treatments under all shade situations in the second year (see *Table 5*) was not due to a reduction in the weeds present.

Although the figures for weed cover at the end of the second year are less than those obtained at the commencement of the trial, this can be accounted for by the difference in the time intervals between the assessment and the previous weeding (16 weeks in the case of the first assessment and 6 or 9 weeks in the case of the final assessment). Some of the decrease in labour in the second year can be attributed to the changeover from hoes to spades for the last two weedings, and some to the fact that there was one less weeding in the second year. In the unshaded coffee on both sites, allowance for these two factors still leaves about 20 per cent of the decrease in labour requirements for the second year unaccounted for. Corresponding allowances for the Albizia shade leave 18 per cent and 9 per cent of the decrease not accounted for on the hillside site and pit-pit site respectively. The most likely explanation is that the closer supervision which was given to the labour in the second year resulted in an increase in work output.

This, of course, immediately brings into question the value of the costs given for the hand-weeding treatment (and for the diuron plus hand-weeding treatment). A series of measurements made on a plantation (using plantation labour) on an area of coffee under light Albizia shade, heavily infested with annual weeds (almost no perennial grasses) and on a lighter soil type than Aiyura, gave a labour requirement, using spades, of between 32 and 47 man-hours per acre for one weeding. Considering how much worse the weed situation is at Aiyura, the labour requirements under Albizia shade could be expected to be above the upper limit of that range, while the requirement in unshaded coffee at Aiyura might be one third higher again. In fact, the labour usage in the last two weedings with spades was lower than

this, averaging 32 man hours under Albizia shade and 51 man-hours in the unshaded plots.

In view of the discrepancy in labour requirements between the two years, perhaps a more realistic comparison with the costs of the other weed-control treatments may be obtained by using the plantation figures as guide in forming an estimate of hand-weeding costs in the present trial. If it is assumed that an average of 47 man-hours per acre is required for each weeding under Albizia shade, and 63 man-hours per acre in unshaded coffee, then with seven weedings in the first year and six in the second, the costs over the 2 years (at 9c per man-hour) would be as given in *Table 8*.

A comparison of these estimated costs with the costs of the other treatments as given in *Table 5* shows that the hand-weeding treatment in Albizia and unshaded plots would then be about equal in cost to the paraquat treatment in the first year (and less than the diuron and the unadjusted diuron plus hand-weeding costs), while in the second year it would be more expensive than either the paraquat or diuron treatments.

An alternative method of obtaining an estimate of the labour requirements would be to assume that the labour requirements in the first year were the same as that recorded in the second year. This estimate would give a hand-weeding cost in the first year that was less than the cost of the paraquat treatment under Albizia shade and above the cost of the paraquat treatment in the unshaded plots.

4. *Hand-weeded plus Diuron*

In this treatment diuron is used during the peak harvest period, when labour is likely to be scarce, and hand-weeding is used during the remainder of the year.

Table 9 gives a summary of the operations in this treatment and a breakdown of the costs into those due to hand-weeding and those due to herbicide applications (including labour).

(a) *Unshaded.*—The trial commenced about 16 weeks after the area was last hand-weeded. Thurston grass constituted 40 per cent (by weight) of the weeds present on the hillside plot, and 82 per cent of those on the pit-pit plot. As in the 'hand-weeded only' treatment,

Table 8.—Adjusted costs per acre of the hand-weeded treatment of AWC2a

Shade	First Year			Second Year		
	Adjusted Cost (\$)	% of Actual Cost		Adjusted Cost (\$)	% of Actual Cost	
		Hillside	Pit-pit		Hillside	Pit-pit
Albizia	29.61	59.4	69.1	25.38	87.0	89.9
Unshaded	39.69	53.5	48.7	34.02	79.8	75.3

an endeavour was made to weed when weather conditions were conducive to achieving a reasonable kill of perennial grasses.

On the hillside plot there was a considerable amount of weed growth present at the time of the spray treatment in the first year, so amitrole was added to the diuron to improve the "knockdown" effect. The application rate was 4 lb Karmex plus 3 pints Weedazol TL Plus per acre in 38 gallons. On the pit-pit plot the ground was predominantly clean, so only Karmex was applied at 4 lb per acre. In the second year both plots received Karmex alone at 4 lb per acre.

At the end of the second year the main weeds present on the hillside site were wandering jew and *Paspalum orbiculare* and the weed cover (11 weeks after the last hand-weeding) was 27 per cent. On the pit-pit plot the main weeds present were thurston grass, *Cyperus brevifolius* and wandering jew, the weed cover (13 weeks after the last hand-weeding) being 23 per cent. On both plots there had been a considerable reduction in the total amount and

the proportion of thurston grass—from 40 per cent to 1 per cent of the total weeds on the hillside plot, and from 82 per cent to 60 per cent on the pit-pit plot. The proportion of wandering jew had increased on both plots and on the hillside plot *Paspalum orbiculare* had increased from an initial 8 per cent to 25 per cent of the total weeds.

(b) *Albizia Shade*.—At the beginning of the trial, the main weeds on the hillside plot in order of abundance were *Drymaria cordata*, *Bidens pilosa* (cobble's peg) and thurston grass, while thurston grass, chickweed and *D. cordata* were the most common weeds on the pit-pit plot.

On both plots the herbicide application was at 4 lb Karmex per acre in the first year and 3 lb Karmex per acre in the second year.

During the two-year period there was a large increase in the proportion of *D. cordata* on both plots, a decrease in thurston grass on the hillside plot but not on the pit-pit plot, and an increase in the proportion of *Isachne myosotis* on the hillside plot. The total weed

Table 9.—Summary of treatments and costs for the 'hand-weeded plus diuron' treatment of AWC2a

Shade	Site	First Year				Second Year			
		No. of hand-weedings	No. of herbicide applications	Cost of H.W. (\$)	Cost of herbicide applications (\$)	No. of hand-weedings	No. of herbicide applications	Cost of H.W. (\$)	Cost of herbicide applications (\$)
Casuarina	Hillside	5	0	14.55		5	1	9.30	3.98
	Pit-pit	6	1	18.55	0.92	5	1	7.36	3.01
Albizia	Hillside	6	1	22.63	13.23	5	1	12.59	10.21
	Pit-pit	6	1	24.22	13.31	5	1	10.17	10.07
Unshaded	Hillside	6	1	54.08	16.13	5	1	22.33	13.38
	Pit-pit	6	1	46.52	13.48	5	1	18.94	13.31

cover had decreased from the initial 46 per cent and 21 per cent on the hillside and pit-pit plots respectively to 6 per cent on the hillside plot (determined 11 weeks after the last weeding) and 3 per cent on the pit-pit plot (determined 9 weeks after the last weeding).

(c) *Casuarina* Shade.—As on the other *Casuarina* plots, weed cover was slight within the plot and somewhat greater around the margins. Thickhead, *Drymaria cordata* and *Isachne myosotis* were the most common weeds on the hillside plot and *I. myosotis*, *Dolichos* sp. and thurston grass the most prevalent on the pit-pit plot.

In the first year no herbicide application was made on the hillside plot because throughout the peak harvest period no weed control measures were necessary. The pit-pit plot was only spot-sprayed with Karmex at a concentration of $2\frac{1}{2}$ lb per 45 gallons. The weed growth had been too slight to warrant a blanket application. In the second year the herbicide treatment on both plots was a spot-spraying with Karmex at a concentration of 4 lb per 45 gallons.

Decrease in hand-weeding costs.—There has been a marked decrease in the hand-weeding costs of this treatment in the second year—greater than 50 per cent in most cases. However, as there has been a decrease in the total weed cover, part at least of the decreased hand-weeding costs may be attributable to the diuron applications. It is thus not possible to assume, as could be assumed in the 'hand-weeded only' treatment, that all the difference in labour costs in the 2 years is due to less efficient labour in the first year. Nevertheless, the labour costs in the first year, as shown in Table 9, do seem excessively high.

In the 'hand-weeded only' treatment the labour used in the second year was lower than that used in the first year by amounts varying from 34 per cent on the pit-pit plot under *Albizia* shade to 52 per cent on the pit-pit plot under *Casuarina* shade. If it is assumed that these differences were due to greater labour efficiency in the second year and that the same differences apply to the hand-weeding of the 'hand-weeded plus diuron' treatment, then the labour costs of hand-weeding given for the first year of this treatment should be reduced in each plot by the appropriate proportion, as

indicated by the labour usage in each plot of the 'hand-weeded only' treatment. When this is done, the adjusted costs are given in Table 10.

The adjusted costs of this treatment for the first year are comparable with the adjusted costs of the 'hand-weeded only' treatment over the same period, are lower than those for the diuron-based treatment, and are lower than the costs of the paraquat-based treatment under *Albizia* shade, while remaining higher under no shade. In the second year the costs (actual) of the 'hand-weeded plus diuron' treatment were less than the actual cost of the 'hand-weeded only' treatment and about the same as or slightly better (depending on shade) than the adjusted costs for that treatment. Over this period, however, it was more expensive than both the paraquat and diuron-based treatments, whose costs had decreased considerably in the second year.

Discussion

As Table 5 shows, the paraquat-based treatment overall was the least costly in both years of the trial. However, the hand-weeded treatment was very expensive, even when the adjusted labour figures were used, and it is probable that in situations where perennial grasses are uncommon and hand-weeding is therefore less expensive, paraquat in the first year of its use would be more costly than hand-weeding. Any difference is likely to be small, and after the first year, the paraquat-based treatment could be expected to be cheaper by a considerable margin.

As already mentioned in the section which gave details of the paraquat-based treatment, there was a large difference between the costs of the treatment on the two sites in the second year. This difference illustrates how greatly the weed species present can influence control costs as well as showing the effect the site can have on weed vigour. On the pit-pit site in both *Albizia* and unshaded plots, the problem weeds resulted in the costs of the paraquat-based treatment remaining relatively high in the second year, while the diuron-based treatment dropped so much that on these plots it was less costly than the paraquat-based treatment.

It can be seen by comparing Tables 6 and 7 that the use of diuron need not necessarily result in a reduction in the total number of

Table 10.—Adjusted costs (\$ per acre) for the first year of the 'hand-weeded plus diuron' treatment of AWC2a

Shade	Site	Actual Total Cost	Adjusted Cost of Hand-weeding	Cost of Herbicide Applications	Adjusted Total Cost
Casuarina	Hillside	14.55	8.29	0.0	8.29
	Pit-pit	19.47	8.90	0.88	9.78
Albizia	Hillside	35.86	13.35	13.23	26.58
	Pit-pit	37.53	15.99	13.31	29.30
Unshaded	Hillside	70.21	30.83	16.13	46.96
	Pit-pit	60.00	25.59	13.48	39.07

treatments over that required in a paraquat-based programme. In the first year of the trial, in both Albizia and unshaded plots, the paraquat-based treatment received 12 or 13 separate applications and the diuron-based treatment received 11 or 13 separate applications. In the second year, it was only on the pit-pit site that the diuron-based treatment required appreciably fewer applications than the paraquat-based treatment.

In a situation where weeds that are resistant to diuron are absent or rare, it is possible that the cost of a diuron-based treatment over the first couple of years would more closely approach the cost of a paraquat-based treatment than was the case in this trial. As can be seen from Table 7, if the applications of diuron had been all that was required, the cost of this treatment would have been comparable to the total cost of the paraquat-based treatment. Of course, under equally favourable conditions (i.e., no resistant weeds) the cost of the paraquat treatment would also be lower although the difference in cost between the two treatments would then be less than was the case in AWC2a. In such favourable situations, the diuron-based treatment, although almost certainly more expensive in the first year (and possibly also in later years) than a paraquat-based treatment, may be preferred because of the fewer numbers of applications required. Against this, however, is the fact that the correct use of diuron requires closer supervision than does paraquat.

It is suggested above that paraquat, even in the longer term, is likely to remain the cheaper of the two treatments at present prices. This will be so unless it becomes possible to use less than 4 lb of Karmex per acre per year and

almost no additional herbicides. In the longer term it should be possible to reduce the annual cost of a paraquat-based treatment to less than \$10 per acre even in unshaded conditions. (Note that the cost in the second year of the paraquat-based treatment under Albizia shade is already approaching \$10.) A cost of \$10 is approximately equivalent to 3 lb of Karmex at present prices.

The 'hand-weeded plus diuron' treatment, while offering some cost advantage over the hand-weeded treatment, seems unlikely ever to attain the lower costs of the treatments which depend solely on herbicides, even assuming that rural wages remain constant.* It is likely that in subsequent years the cost of this treatment will not decrease much below the cost incurred in the second year. If paraquat had been used instead of diuron, the total costs in the first year would have been lower, even if, as is likely, two applications were required to maintain weed control for the duration of the peak harvest period. In the second year, however, the costs with paraquat probably would not have decreased because it seems unlikely that one or two paraquat applications per year

*This was written before the publication of the findings of the Rural Wages Board and the granting of the interim increase of 50 cents per week in the minimum rural wages, which took effect from 1st January, 1971.

In compiling the costs of labour used in the treatments, labour was costed at 9 cents per man-hour. The 50 cent increase in the minimum rural wage has raised the cost of labour to 10 cents per man-hour. This increases the cost of the 'hand-weeded only' treatment by 11 per cent, but has considerably less effect on the herbicide treatments. For example, the paraquat-based treatment on the hillside plot (see Table 6) would increase by 71 cents from \$36.72 to \$37.43.

would bring about any permanent decrease in the weed population. The costs would then be at a level approximating to that actually obtained in the second year of the 'hand-weeded plus diuron' treatment.

A method which uses both hand-weeding and herbicides is perhaps a possibility where the difficulty of obtaining casual labour during periods of high labour requirements makes it necessary to maintain a large permanent labour force throughout the year.

Effect of Shade on Weed Control Costs

Table 3 shows the effect of the three shade conditions in the trial AWC2a on weed growth and Table 5 records the considerable effect of shade on weeding costs in AWC2a. As well as the effect of the shade tree on weed growth, the ground shade produced by the coffee itself also influences weed growth. Thus in young coffee or unhealthy coffee which is partly defoliated, weed growth is invariably more vigorous. Spacing and pruning systems, by varying the ground shade, affect weed growth, as shown in Table 2.

In some situations in some years, the extra cost incurred in weeding unshaded coffee may not be covered by the higher yields that unshaded coffee normally produces. However, the long-term average yields at Aiyura show that yields from unshaded coffee are so much higher than from shaded coffee, that the higher weeding costs become unimportant. Over the 11 years 1959-1960 to 1969-1970, the average annual yield of clean coffee from unshaded coffee in trial ACA1 (the area used in the herbicide trial AWC2a) has been 600 lb higher than from coffee under Albizia shade and 500 lb higher than coffee under Casuarina shade. With yield differences of this magnitude there is a substantial net increase in return from unshaded coffee at Aiyura.

Where shade is being thinned or removed, some increase in the costs of weed control can probably be expected. However, if herbicides have been used for a number of years and the weed population has been reduced to a low level, the increase in cost should be relatively minor. Perennial grasses present at the time of shade thinning can be expected to require more attention. Thus it would be preferable to have

as weed-free a condition as possible, and preferably no perennial grasses, at the time of thinning or eliminating shade. But as higher yields can be expected after reducing or removing the shade, delaying this operation until near perfect weed control is obtained may not be profitable.

TRIAL AWC2b

The second costing trial at Aiyura, although not as comprehensive as AWC2a, is of interest because it includes variations in the paraquat and diuron treatments of that trial which have been less expensive, particularly in the first year of use.

The trial (designated AWC2b) is on the pit-pit site immediately adjacent to the pit-pit plots of AWC2a. It compares four herbicide treatments on plots which are again $\frac{2}{3}$ acre in size. The treatments were selected as a result of their effectiveness against thurston grass in a small-plot trial on this grass. The evaluation on the larger scale was to allow comparisons of costs and performance to be made against a wider range of weeds over an extended period. The plots are unshaded and, as in each plot of AWC2a, have coffee growing under six different cultural methods, namely single and multiple stem each at spacings of 7, 8 and 9 ft triangle. The trial is unreplicated, that is, there is only one plot for each treatment. The dominant weed on all four plots at the beginning of the trial was thurston grass.

The four treatments are:—

- (1) *Paraquat and amitrole*, the latter being retained for as long as is considered necessary. Amitrole applications precede paraquat by 4 weeks.
- (2) *MSMA* applied as necessary, usually as a double treatment with the two applications about 4 or 5 weeks apart.
- (3) *Diuron plus amitrole* applied together, the first application as a blanket spray (to existing weeds) and all subsequent applications as spot-sprays when required.
- (4) *Diuron plus paraquat* applied together, the first application as a blanket spray (to existing weeds) and all subsequent applications as spot-sprays when required.

As in AWC2a, it was not feasible to use exclusively only the prescribed treatment, and all plots required supplementary treatment with dalapon (for couch and para grass (*Brachiaria mutica*)) and with 2,4-D (for such weeds as wandering jew and sweet potato).

Table 11 summarizes the herbicide applications and gives the cost of each treatment, adjusted to a per acre basis, for the first 2 years. Additional details of the four treatments are given below.

The dense weed growth on all plots was slashed to ground level about three weeks before the first applications. The trial was considered to begin with the first herbicide applications, so the cost of the slashings is not included in the costs given in Table 11.

1. Paraquat and Amitrole

At the first spraying about 50 per cent of the ground area was covered by weeds, the main species being thurston grass, wandering jew, *Polygonum nepalense*, *Leersia hexandra* (rice grass), *Drymaria cordata*, couch grass and para grass.

The first amitrole application was at 3.75 pints (of Weedazol TL Plus) per 45 gallons of spray (4 pints per acre in 48 gallons) with 0.1 per cent surfactant. Subsequent Weedazol applications were at spray strengths of 4.5, 2, 2, 4, 4, 8 and 8 pints per 45 gallons. The higher concentrations used in the second year were made necessary by *Cyperus brevifolius*, which had become prominent, and not by thurston grass, which by this time had been eliminated. All paraquat applications were with sprays containing 1 pint of Gramoxone plus $\frac{1}{2}$ pint of non-ionic surfactant per 45 gallons. Although there was a total of 12 separate applications in the first year, and 14 in the second year, most were spot-sprays which used relatively small quantities of herbicide, so the total cost was not high. In the first year the volume applied per application averaged 25.5 gallons per acre, and in the second year, 15.8 gallons.

In the second year, two of the dalapon applications to couch grass were made 3 or 4 weeks prior to a paraquat application and not as a double dalapon application. This fitted in more readily with the paraquat applications than the double sprays of dalapon. However, although the dalapon-paraquat treatment

gave a high percentage kill initially, regrowth of couch grass subsequently appeared.

During the second year, *C. brevifolius* became the main weed, although it was mainly confined to one large patch and was not as bad as the infestation previously described on the unshaded pit-pit plot of AWC2a. Two applications of Weedazol TL Plus at 4 pints per 45 gallons were generally ineffective, but two applications at 8 pints per 45 gallons (applied four weeks apart) eradicated the dense area of weed. Some seedling plants have since appeared, but these can be killed with lower rates of Weedazol.

At the end of the second year the plot was substantially clean.

2. MSMA

At the first spraying the weed cover was about 60 per cent, the main weeds being thurston grass, para grass, couch grass, sweet potato, *Rumex crispus* (dock) and *Dichrocephala bicolor*.

Sprays with MSMA were mostly as double treatments applied about four weeks apart. This method of application has given better results, particularly on perennial weeds, than single applications applied at longer intervals. Spray concentrations of Ansar 529 varied between 5 and 2 pints per 45 gallons, with most treatments at 3 or 4 pints. The formulation contains an adequate amount of surfactant and no additional surfactant was used. MSMA gave no control of the couch grass, and para grass, which was more prevalent initially on this plot than on the others, was also not controlled by MSMA. These two grasses necessitated the large number of dalapon applications. The broadleaf weed *Dichrocephala bicolor* was not controlled by MSMA and it spread to become a major weed, before being controlled with 2,4-D. At the end of the second year, the main weeds present were *Dichrocephala bicolor*, *C. brevifolius* and *C. kyllingia* (both sedges present as individual plants, not dense mats) and couch grass. At this time the plot was unacceptably weedy over most of its area.

3. Diuron plus Amitrole

The weed cover at the first spraying was about 20 per cent, the main weeds being thurston, para and couch grasses, wandering

Table 11.—Summary of treatments and costs per acre in AWC2b
Quantities of herbicides in lb or pints of commercial product per acre

Herbicide		Paraquat and Amitrole		MSMA		Diuron + Amitrole		Diuron + Paraquat	
		Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
Amitrole	No. of applications	4	4						
	Total quantity	8.2	9.5						
	Spray concentration (pints per 45 gal)	2.0-4.5	4.0-8.0						
Paraquat	Main weeds treated	A, B	B						
	No. of applications	4	6						
	Total quantity	2.8	2.2						
MSMA	Spray concentration (pints per 45 gal)	1.0	0.67-1.0						
	Main weeds treated								
	No. of applications			8	6				
MSMA + 2,4-D (combined)	Total quantity			18.1	10.5				
	Spray concentration (pints per 45 gal)			1.0-5.0	3.0-4.0				
	Main weeds treated			A, B	A, B				
Diuron + amitrole	No. of applications			....	1				
	Total quantity			....	2.1+2.1				
	Spray concentration (pints per 45 gal)			....	3.0+3.0				
Diuron + paraquat	Main weeds treated			....	A, B, O				
	No. of applications					3	5		
	Total quantity					5.3d+7.1a	3.4d+4.3a		
Dalapon	Spray concentration (lb+pints per 45 gal)					3.1d+4.2a	(3.1d+4.2a)— (2.0d+2.0a)		
	Main weeds treated					A, B	B		
	No. of applications							4	6
2,4-D	Total quantity							7.0d+2.3p	4.0d+1.3p
	Spray concentration (lb+pints per 45 gal)							3.1d+1.0p	(3.1d+1.0p)— (2.0d+0.67p)
	Main weeds treated							A, B	B, N
2,4-D	No. of applications	3	4	8	6	4	3	4	....
	Total quantity	7.8	5.4	24.3	22.8	7.3	2.6	7.8	....
	Spray concentration (lb per 45 gal)	5.0-5.6	5.0-8.0	5.0-5.9	5.0-10.0	5.0-5.6	8.0-10.0	5.0-5.6	....
2,4-D	Main weeds treated	C, H	C, D	C, H	C, H	C, D, H	C, D, H	C, D, H	....
	No. of applications	1	....	2	5	2	....	1	1
	Total quantity	0.7	....	3.8	6.8	1.3	....	1.6	0.1
	Spray concentration (pints per 45 gal)	5.0	....	3.0-6.0	2.0-3.0	2.3-4.5	....	4.5	2.0
	Main weeds treated	J, K	....	J, O	J, M, O	J, K, M,	....	J, K	K
TOTAL COST \$		24.99	21.86	39.28	33.74	33.35	17.99	39.29	18.25

jew and *Polygonum nepalense*. The first blanket application was at the rate of 3 lb Karmex plus 4 pints Weedazol TL Plus per acre (in 43 gallons) with 0.5 per cent non-ionic surfactant. (This high concentration of surfactant was used in the first three applications, but is unnecessary when the spray mixture contains a foliar-acting herbicide, and it was subsequently reduced to 0.1 per cent.) All diuron plus amitrole treatments after the initial one were as spot-sprays. For the first 18 months these sprays contained the same concentration of herbicides as the blanket spray. After that period the spray concentration was reduced to 2 lb Karmex plus 2 pints Weedazol TL Plus per 45 gallons. Two spot-sprays were applied in the first year and six more in the second year. The other herbicides used are given in Table 11.

The plot has remained substantially weed-free from shortly after the first spraying and there has been little difficulty in maintaining it in this condition. At the end of the second year, weeds occupied only about 1 per cent of the ground area. Thurston grass is no longer present and no potentially troublesome weeds have appeared, although small patches of couch have required regular attention. *Cyperus brevifolius* and *C. kyllingia* and thickhead plants continue to appear, but are killed by the diuron-amitrole spray.

4. Diuron plus Paraquat

The weed cover at the first spraying was about 30 per cent and the main weeds were thurston, para and couch grasses. The first application was a blanket spraying at 3 lb Karmex plus 1 pint Gramoxone per acre (in 43 gallons) with 0.5 per cent non-ionic surfactant. [As mentioned in the previous treatment, this high rate of surfactant is unnecessary and it was reduced, firstly to 0.14 per cent and then to 0.1 per cent.] All subsequent applications of the mixture during the first 18 months were as spot-sprays containing the same concentration of herbicides as the initial treatment. After this period the concentration of the spray mixture was reduced to 2 lb Karmex plus 2/3 pint Gramoxone per 45 gallons. Three spot-sprays of the mixture were applied in the first year and six further sprays in the second year.

Weed control has been excellent throughout the two years, and at the end of the period the weed cover was about 1 per cent. Thurston grass has been eradicated but a small amount of couch grass remains. *C. brevifolius*, *C. kyllingia* and thickhead plants which appear are killed by the diuron-paraquat spray. No other potentially troublesome weeds have appeared.

Discussion

In the first 12 months the paraquat-amitrole treatment was the most economical (see Table 11), followed by diuron plus amitrole. Diuron plus paraquat and MSMA were the most expensive. Considering weed control, only the MSMA treatment was not completely satisfactory. It required the highest number of treatments and the plot was weedier at all times than the other three plots. This was partly because MSMA was active against a narrower range of weeds than the other three treatments. However, as mentioned above, the plot initially had more para grass than the other plots and the high costs in the first year can partly be attributed to this weed, although the fact that MSMA did not give even temporary control of couch grass would also have been a factor. The para grass was mostly eradicated by the end of the first year and was not an important weed after that time. The cost of the MSMA-based treatment remained high, however, and as long as *C. brevifolius* and *C. kyllingia* are present, higher concentrations of MSMA (i.e., about 4 pints of Ansar 529 per 45 gallons) will be necessary and this will keep costs relatively high. Spraying with 2, 4-D will continue to be necessary for some broadleaves, in particular *Dichrocephala bicolor*.

Again, as in AWC2a, there was a decrease in costs in the second year. The paraquat-amitrole treatment has remained the cheapest treatment overall for the two-year period, but in the second year, the two diuron-containing treatments were less expensive than the paraquat-amitrole treatment. Both the diuron-containing treatments are giving excellent control and although the diuron-amitrole treatment was cheaper in the first year, there was no difference between them in the second year. Figures given with the details of the treatments above indicated that the initial weed cover on the diuron plus amitrole plot was a little less than on the diuron plus paraquat

Table 12.—Costs per acre for the first two years of herbicide treatments in AWC2a and AWC2b

Trial	Treatment	Cost (\$)	
		Year 1	Year 2
AWC2a	Basically paraquat (on pit-pit site, unshaded)	39.13	33.11
AWC2b	Paraquat and amitrole	24.99	21.86
AWC2a	Basically diuron (on pit-pit site, unshaded)	63.92	23.48
AWC2b	Diuron plus amitrole	33.35	17.99
AWC2b	Diuron plus paraquat	39.29	18.25
AWC2b	MSMA	39.28	33.74

plot. It is possible that the difference in cost between the two treatments in the first year, which is due almost entirely to the extra diuron used on the diuron plus paraquat plot (see Table 13), may have been brought about by the heavier initial weed infestation on the latter plot.

COMPARISON OF RESULTS IN TRIALS AWC2a AND AWC2b

A comparison can be made between the four treatments described above and the herbicide treatments on the unshaded pit-pit plots of AWC2a. The costs of the treatments are collated in Table 12.

The considerable reduction in the cost of the paraquat-amitrole treatment of AWC2b over that of the paraquat treatment of AWC2a can be attributed to three factors. Firstly, the spray treatments in AWC2b commenced on fairly low vegetation—it had been slashed to ground level three weeks before the initial amitrole application—whereas in AWC2a the weed growth had been undisturbed for about 16 weeks, and in places was knee-high. [If the cost of the slashing was included, it would add about \$6 per acre to the first year costs of the AWC2b paraquat-amitrole treatment.] Secondly, the use of the amitrole-paraquat split applications from the beginning resulted in a quick reduction and eventual eradication of the thurston grass. This eliminated the need for frequent and relatively high doses of paraquat which had been needed in the AWC2a treatment. Thirdly, the coffee in some sections of the paraquat treatment of AWC2a was unhealthy and so provided little ground shade. This permitted more vigorous grass growth.

In Table 13, the quantities of individual herbicides used in the diuron treatment of AWC2a are compared with those used in the diuron

plus amitrole and diuron plus paraquat treatments of AWC2b. This breakdown indicates the main source of the difference in costs between the diuron treatments in the two trials. Thus, of the difference in the first year of \$24.63 between the cost of the diuron plus paraquat treatment of AWC2b and the diuron treatment of AWC2a, \$13.38 is due to the difference in the amount of Karmex used (and the surfactant used with the Karmex), and \$4.90 to the difference in the amount of Gramevin used (there was more couch grass on the AWC2a plot). Most of the remaining difference is due to the cost of the initial slashing (\$7), being included in the costs of the

Table 13.—Comparison of amounts of herbicide used in different diuron-based treatments during first 12 months

Herbicide	Treatment		
	Basically Diuron (AWC2a, pit-pit site)	Diuron plus Amitrole (AWC2b)	Diuron plus Paraquat (AWC2b)
Karmex	10.0 lb	5.3 lb	7.0 lb
Weedazol	3.6 pints	7.1 pints	....
Gramoxone	....	....	2.3 pints
Gramevin	16.7 lb	7.3 lb	7.8 lb
Amoxone-50 or	3.1 pints	1.3 pints	1.6 pints
Weedkiller D	....	....	....
Surfactant	8.7 pints	3.6 pints	4.2 pints
No. of treatments	11	9	9

AWC2a treatment and not in those of the AWC2b treatment. Similarly in the diuron plus amitrole treatment, the main source of cost reduction over the cost of the diuron treatment in AWC2a is the reduced amount of Karmex used. While the amount of Karmex used in

the AWC2a treatment could probably have been reduced to 8 lb (applications of 4 + 2 + 2 lb), this could have been expected to increase the requirements for other herbicide treatments, while only partly reducing the difference in costs attributable to Karmex.

In spot-spraying, diuron is only applied where it is needed and thus a considerable saving is made in this expensive material. However, it was rather unexpected that, following the initial blanket application, only two spot-sprays containing diuron were required on the diuron plus amitrole treatment and three spot-sprays on the diuron plus paraquat treatment of AWC2b in the first year. In the second year, six diuron-containing spot-sprays were applied in both treatments.

The method of spot-spraying diuron to emerged weeds, either combined with one of the foliar-acting herbicides used here, or with a non-ionic surfactant, would appear to offer distinct possibilities of reducing the costs of a diuron-based treatment, particularly in the first year of use. However, as this conclusion is based on the data of one unreplicated trial and a not strictly valid comparison with another trial, some caution is necessary in interpreting the results. Further trials have begun comparing the two methods of applying diuron (blanket and spot-sprays).

With the spot-spraying method there is the disadvantage that it is not possible to know how much diuron is being applied over a period to specific small areas. This means that without due care it is possible that in localized areas diuron could accumulate in the soil to levels which are toxic to coffee. Obviously, if over a period a patch of weeds is not being killed by diuron, it would be unwise to continue pouring diuron onto that area. Sufficient attention must therefore be given to the spraying programme to enable the appearance of any such weed patches to be detected early and appropriate action taken.

VARIATIONS IN WEED CONTROL COSTS

As already mentioned, the costs of weed control in the trial AWC2a were fairly high. Those of AWC2b were somewhat lower but they were also obtained from a problem area. Weed control costs for several coffee blocks at Aiyura, some of which have weed populations nearer

the norm for the highlands, are given in *Table 14*, along with a brief description of the blocks and the herbicide treatments. The Table brings out the large variations in costs which can occur. These differences in costs are due both to differences in weed populations and in herbicide treatment.

Block A6 had large areas of thurston grass when herbicide treatment started, mainly in the multiple stem coffee; blocks A15/16 and B14 contained predominantly annual weeds. The difference in control costs between A15/16 and B14 can be attributed to the different herbicide treatments used. If control in B14 had been based on paraquat, the costs could have been expected to be lower than those in the unshaded A15/16 block. That the weed infestation in B14 was less severe than in A15/16 is indicated by the hand-weeding costs of the two blocks in previous years. In block E6, the comparatively low cost was also due to the treatment rather than the weed population. The block initially contained a large amount of thurston grass and was probably more heavily weed-infested than block A6, being somewhat comparable to the Albizia plots on the pit-pit soil of AWC2a.

YIELD INCREASES FROM CLEAN WEEDING

Good weed control can be expected to produce substantially higher yields. This has been shown both at Aiyura and in Kenyan trials. At Aiyura in the cover crop trial ACA3 (Schindler and Fraser 1964), a weed-infested cover crop decreased yields of saleable beans by an average of 300 lb per acre per year compared with the clean-weeded treatment over the first 3½ years of bearing. In Kenya, in a ten-year trial in unshaded coffee, in 41 inch rainfall, thorough weed control gave a mean annual yield increase over minimal weeding (two hand-weedings per year) of 350 lb of clean coffee (Wallis and Blore 1964). Another trial over a four-year period, in unshaded coffee in 67 inch rainfall, gave a mean increase per year of 412 lb of clean coffee per acre (Reynolds 1967). However, trials in two other areas in Kenya with 59 inch and 55 inch mean annual rainfall and over five and four years respectively, did not show significant yield increases from clean-weeding. The coffee in both cases

Table 14.—Variation in costs of chemical weed control at Aiyura

Block	Size	Description of block	Summary of herbicide treatment for first 12 months	Cost per acre in first 12 months (\$)	Cost of hand-weeding (per acre)* (\$)
A6	5 acres	Mature coffee under Albizia shade; half is multiple stem, half single stem, both at 8 x 8 ft spacing; on pit-pit soil	Initially blanket application of diuron plus paraquat, then 2 further blanket applications of diuron, and spot-sprays with paraquat, dalapon and amitrole as necessary	39.77	40
A15/16	5 acres	Mature single stem coffee on 9 x 9 ft spacing; unshaded; on shallow hillside soil	Paraquat (9 applications, from 1 to 2/3 pint Gramoxone per 45 gallons) plus 2 applications of dalapon	17.97	40
B14	5 acres	Mature multiple stem coffee at various spacings (5 x 5 ft to 9 x 7 ft) under dense Albizia shade; hillside soil	3 blanket applications of diuron (3, 2, and 2 lb Karmex per acre) plus spot-sprays with paraquat as necessary	30.73	22½
E6	1.5 acres	Mature multiple stem coffee, spaced at 9 x 9 ft; Albizia shade; pit-pit soil	9 applications of amitrole at 4.7 to 1.5 pints (Weedazol TL Plus) per 45 gallons	13.91	

* Means of costs for the 3 previous 12-month periods.

was growing under shade and this was thought to be the possible reason for the lack of response (Wallis and Blore 1964).

Theoretically it might be expected that, even where previous weed control by hand-weeding has been good, the introduction of herbicides with the accompanying end to the disturbance of feeder roots, would result in higher yields. However, yield increases due to this factor may not eventuate owing to other balancing factors. If (as in most cases), the use of herbicides leads to greatly improved weed control, then, as indicated by the evidence quoted above, increases in yield should result. To date, it has not been possible to show any yield increases from improved weed control in the trial AWC2a, and the large variations in yield which occur between replicates both in the same year and from year to year may mean that any differences will not be detected. In Kenya, over the first 4 years of a long-term weed control trial there has been no significant difference in yield between herbicide-treated plots and mechanically or hand-weeded plots (Mitchell 1967). It would seem that the main tangible benefit likely to result from the use of herbicides in coffee is a decrease in weeding costs.

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