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HEXAFLURATE: A NEW HERBICIDE FOR SELECTIVE CONTROL OF HARRISIA CACTUS

by G. J. HARVEY, M.Agr.Sc.

SUMMARY

Hexaflurate (potassium hexafluoroarsenate) is a new herbicide currently being evaluated for control of harrisia cactus (*Eriocereus martinii* (Lab.) Ricc.). Technical data on hexaflurate are presented.

Hexaflurate is both highly selective and residual, providing excellent control of harrisia at 4 kg ha^{-1}. The mode of action of hexaflurate is described. At 4 kg ha^{-1}, the only other plant, apart from other Cactaceae (or cacti), known to be affected is currant bush (*Carissa ovata*) which suffers temporary leaf injury. Higher rates of hexaflurate provide excellent control of harrisia, but cause increasing, if temporary, injury to other plants.

The contribution to natural soil arsenic levels resulting from hexaflurate application is discussed, and it is concluded that hexaflurate residues do not constitute an environmental hazard.

I. INTRODUCTION

Harrisia cactus (*Eriocereus martinii* (Lab.) Ricc.) is a serious weed of 68 000 ha of prime grazing land in the Collinsville–Nebo region, north Queensland. Other infestations have been reported from Charters Towers, Mount Morgan, Rockhampton, Rannes, Ipswich, Gatton, Greenmount, Glenmorgan, Goondiwindi, Tara, Mitchell, Charleville and Cunnamulla in Queensland (Mann 1970) and from Sydney and West Wyalong in New South Wales (V. H. Gray, personal communication 1974).

The closely related *Eriocereus tortuosus* Forbes occurs at Western Creek in Queensland (Mann 1970) and Scone in New South Wales (V. H. Gray, personal communication 1974).

Since the 1950s, 44 different organic and inorganic herbicides, alone or in combination, have been tested for control of harrisia (Queensland Department of Lands reports, unpublished). These include 2,4-D (2,4-dichlorophenoxyacetic acid), 2,4,5-T (2,4,5-trichlorophenoxyacetic acid), dichlorprop (($\pm$)2-(2,4-dichlorophenoxy) propionic acid), fenoprop (($\pm$)2-(2,4,5-trichlorophenoxy) propionic acid), dicamba (3,6-dichloro-2-methoxybenzoic acid) and picloram (4-amino-3,5,6-trichloropicolinic acid) as a variety of salt and ester formulations.

Of all the herbicides tested, dichlorprop and fenoprop are the most effective, each being equally effective either as the potassium salt or the butyl/isobutyl ester when applied as 1% a.i. solutions or emulsions, respectively, in water. Application of such concentrated sprays results in damage to the pasture grasses, mainly Rhodes grass (*Chloris gayana*) and buffel grass (*Cenchrus ciliaris*), and native herbs, although the extent and duration of this injury has never been determined.

Similar results have been obtained in the United States against various *Opuntia* species. For example, Wicks, Fenster and Burnside (1969) studied 13 herbicides for control of plains prickly-pear (*O. polyacantha* Haw.) in Nebraska. Of these, 2,4,5-T, fenoprop, picloram, and dicamba gave the best control (dichlorprop was not included in the herbicides tested). Fenoprop and picloram were superior to dicamba and 2,4,5-T; picloram and dicamba injured the native grasses.

The Cactaceae are noted for their regenerative capacity and herbicide treated populations return to pretreatment levels within a few years if the herbicide application is not repeated. Harrisia regrows readily from unkilled stem or tuber segments, and even a 15 cm section of exposed root has been observed to produce a new plant. Thus repeated applications of dichlorprop and fenoprop have to be made to control harrisia.

Since 1968, trials have been conducted with a new inorganic herbicide, hexaflurate (potassium hexafluoroarsenate). Results indicate that hexaflurate provides both highly specific and residual control of harrisia cactus.

II. MATERIALS AND METHODS

Hexaflurate is an off-white, crystalline solid with no odour, is non-volatile, and is readily soluble in water (21% at 25°C), slightly soluble in methanol (4·4% at 25°C), and insoluble in oil and other nonpolar solvents.

Toxicity: $LD_{50} = 1 \cdot 2 \pm 0 \cdot 1 g\ kg^{-1}$ (acute oral toxicity study—rats), which may be compared with acetyl salicylic acid (aspirin), $LD_{50} = 1 \cdot 75\ g\ kg^{-1}$, and 2,4-D, $LD_{50} = 375\ mg\ kg^{-1}$.

Following earlier trials in which hexaflurate indicated great potential as a selective suppressant of cacti, a trial was set out near Collinsville in October 1971 to compare the effectiveness of hexaflurate at the rates of 2·2, 4·5, 9 and 18 kg ha^{-1} for the control of harrisia cactus. The area chosen had been cleared and ploughed some years previously, and supported a moderate (approximately 20 000 plants ha^{-1}) but fairly uniform cactus population and a dense stand of Rhodes grass.

Hexaflurate was applied by boom spray in 160 litres ha^{-1} of water to plots approximately 0·2 ha in area. Treatments were assigned at random and each treatment was replicated three times.

Plant densities have been calculated annually from quadrat counts at random points within each plot. Data are analysed by pooling data for each treatment and comparing treatments using a 't'-test based on the difference in proportion of quadrats in which no plants are found.

Observations will be continued until it becomes apparent that hexaflurate is no longer effectively controlling harrisia.

III. RESULTS AND DISCUSSION

The reduction in harrisia numbers per hectare is shown in figure 1. This reduction was relatively slow, taking approximately 24 months to reach a minimum and was proportional to the amount of hexaflurate applied (see table 1). Control at $2 \cdot 2$ kg ha^{-1} was still reasonable in 1974, but surviving plants treated at this rate were beginning to show signs of recovery from hexaflurate toxicity in 1975 and control at this date was not satisfactory. Plants in plots treated with $4 \cdot 5$ kg ha^{-1} or more continue to show signs of hexaflurate toxicity and control of harrisia is excellent at all these rates.

TABLE 1

RELATIONSHIP BETWEEN DENSITY OF HARRISIA CACTUS AND HEXAFLURATE APPLICATION RATE (1975 DATA)

Treatment Number	Hexaflurate kg ha^{-1}	Proportion of quadrats in which no harrisia occurs, %	Average number of harrisia plants per 100 quadrats
	(0)	(43)	(263)
1	2·2	63	105
2	4·5	79	36
3	9	89	24
4	18	94	8

Treatments 1 and 2 differ significantly from each other at the 99% level of confidence; treatments 2 and 3 differ significantly at the 95% level of confidence; treatments 3 and 4 do not differ significantly at the 95% level of confidence.

The outstanding feature of these results is the excellent residual control of harrisia afforded by one application of hexaflurate. Three factors contribute to this residual control—

1. The high specific toxicity of hexaflurate to harrisia cactus and other Cactaceae.
2. The AsF_6^- ion is very stable to hydrolysis (Kolditz 1967) and consequently hexaflurate is very stable in the soil.
3. All Cactaceae, including harrisia, have an extensive but shallow feeding-root system; hexaflurate is apparently retained within this feeding-root zone as was found for arsenic pentoxide (Cuddihy and Cheyne 1974).

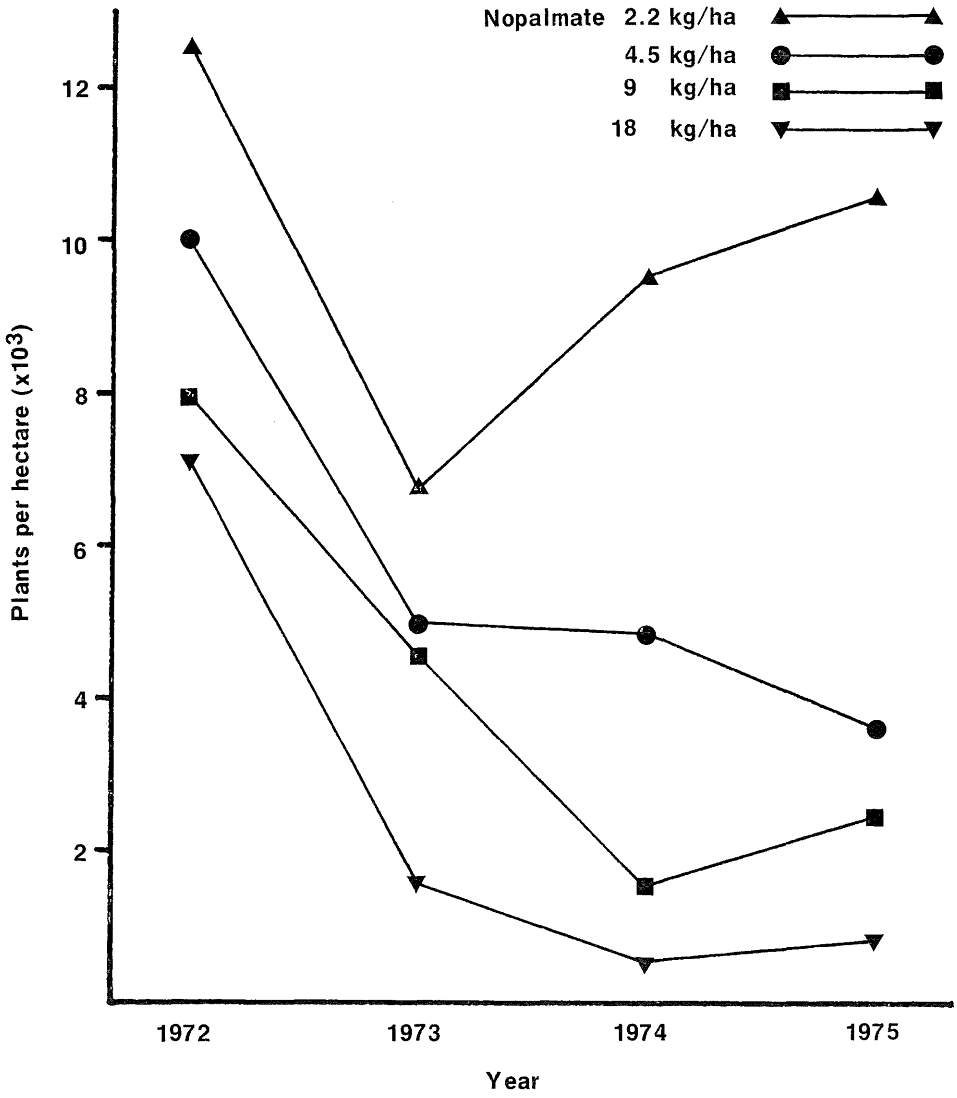
From the data presented above, and from other trials not reported here, the conclusion has been drawn that 4 kg ha^{-1} hexaflurate is a sufficient rate for control of harrisia cactus.

Mode of action of hexaflurate

Glasshouse trials on harrisia and prickly-pear (*O. inermis*) showed that hexaflurate absorption by stems or phylloclades is minimal, and herbicidal activity of hexaflurate depends on root absorption from treated soils. This is the expected result for an inorganic salt.

Hexaflurate toxicity is distinctive and easily recognized. The first signs are an orange discoloration of the vascular tissue throughout the plant, and cessation of growth in the stem apexes. The apexes turn brown or black and the stems die back progressively from the apex, areoles first, becoming shrivelled or dehydrated in appearance as they do so. The feeding roots and tubers soon die,

Figure 1
Decline in the number of Harrisia cactus (Eriocereus martinii) plants per hectare 9 to 45 months after one application of Nopalmate in October 1971.



causing any unkilled portions of stem to lose effective contact with the ground. As they are thus unable to absorb hexaflurate from the soil, these unkilled portions of stem may persist for some time, even years. (Since such portions of stem are potentially capable of producing a new plant, they are counted as plants and included as such in the results presented in table 1 and figure 1).

If hexaflurate is applied at a sublethal rate (2·2 kg ha^{-1} in the trial reported here) or if plants are slow to die, a number of other effects may be observed. One outstanding symptom of hexaflurate toxicity is the almost total inhibition of flowering in affected plants; if a flower is produced, the resulting fruit is small and often fails to mature; if maturity is reached, the number of seeds produced is much reduced.

In the above experiment, two small fruits about half normal size (5 cm diameter) were produced in the first 12 months, both on plots receiving 2·2 kg ha^{-1} hexaflurate. These fruits contained 20 to 30 seeds each, as opposed to 400 to 1 000 seeds in a normal fruit. No subsequent fruit production has been observed in any plot.

Flower and fruit production in harrisia apparently depends on starch reserves in the tubers. Ploughing or any other disturbance of the plant which depletes these reserves reduces the number of flowers or fruit produced (Harvey, unpublished data; Anderson 1971). Low application rates of hexaflurate severely affect root and tuber systems even when the plant as a whole is not killed, and probably also reduce flowering by reducing starch reserves.

Growth of new stems is also inhibited. Several new stems may be produced on a treated plant, but they usually fail to grow to more than 5 cm in length before growth ceases. Such stems are globose, lack the ribbed appearance of normal stems, the internodes are much compressed, and no spines or hairs are produced at the areoles. The apex and areoles die, and the plant then produces a new shoot. This process continues until the plant dies or hexaflurate ceases to be effective. Plants receiving 2·2 kg ha^{-1} in the above experiment are now producing normal regrowth.

Viability of untreated harrisia cactus seed is initially greater than 90%, but this falls rapidly to less than 10% after 1 year and 1 to 2% after 2 years. By suppressing regrowth and flowering, hexaflurate not only controls harrisia cactus in those areas to which it has been applied, but also prevents spread of the plant to other areas. Hexaflurate should thus allow one of the major aims of the harrisia cactus control programme to be achieved: restriction of the plant to those areas in which it already occurs.

Effects on other vegetation

In an earlier trial, hexaflurate at 18 and 36 kg ha^{-1} severely retarded grass and herbage growth. This effect is long-lasting (2 to 3 years) but not permanent. At 36 kg ha^{-1}, hexaflurate causes death of the apical portions of brigalow (*Acacia harpophylla*) phyllodes, but this effect lasts only a few months. At rates less than 9 kg ha^{-1}, hexaflurate produces no observable effect on brigalow. Identical symptoms to those on brigalow also occur on currant bush (*Carissa ovata*) at 4 kg ha^{-1} hexaflurate, but again this effect lasts only for a few months.

No brigalow or currant bush plants are known to have been killed by hexaflurate even at 36 kg ha^{-1}.

Observations on prickly-pear (*Opuntia inermis*) and velvety tree-pear (*O. tomentosa*) plants growing in harrisia plots show that 4 kg ha^{-1} hexaflurate is also sufficient for control of these pest pears.

Hexaflurate at 4 kg ha^{-1} is highly selective, killing or suppressing only Cactaceae and producing no discernible lasting effects on other vegetation.

Environmental safety

Data presented in this paper show that application of hexaflurate at 9 kg ha^{-1} presents no cause for concern regarding the AsF_6^- ion itself. The only danger to the environment from use of hexaflurate would result from the eventual breakdown of the AsF_6^- ion to toxic arsenic oxides.

If we assume a bulk density for a heavy clay soil of the Collinsville type of 1 100 to 1 300 kg m^{-3}, and further assume that all hexaflurate is retained in the top 15 cm of soil and none is lost by leaching or plant uptake, then the theoretical contribution of arsenic to the soil is as shown in table 2.

TABLE 2

THEORETICAL RESIDUES OF HEXAFLURATE ($KAsF_6$) AND ARSENIC IN A HECTARE x 15 CM OF SOIL RESULTING FROM HEXAFLURATE APPLICATION TO CONTROL HARRISIA CACTUS

Hexaflurate kg ha^{-1}	Hexaflurate μg g^{-1}	Arsenic μg g^{-1}
9	4·63 to 5·54	1·52 to 1·79
4·5	2·31 to 2·77	0·76 to 0·90
2·2	1·16 to 1·38	0·38 to 0·45

Natural arsenic levels in soil may be of the order of several hundred μg g^{-1} (Fergus 1955), far in excess of the contributions to arsenic levels shown in table 2. Thus the contribution of arsenic from hexaflurate may be considered inconsequential. Analyses for arsenic from trial plots show 1 to 3 μg g^{-1} As from control plots as well as from hexaflurate–treated plots, and support the conclusion that use of hexaflurate results in a negligible residue of arsenic.

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The author is an agronomist with the Sir Alan Fletcher Research Station, Queensland Department of Lands, stationed at Sherwood, Q. 4075.

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