Herbicide treatment with a Handy® sprayer.
Photo J. Martin

# Paraquat, diuron and atrazine for the renewal of chemical weed control in northern Cameroon

**In 1995, cotton growers in Cameroon treated nearly 60 000 ha of cotton and cereal cropland with herbicides, four to five times more than in the 1980s. Three products have been found to be efficient in controlling weeds, thus facilitating crop establishment and initial growth: paraquat, a non-selective herbicide that has been widely used since 1987, along with diuron and atrazine, two generic molecules recommended (since 1992) for pre-emergence treatment of cotton and maize.**


During the cropping season, farmers in cotton-growing regions devote most of their time to weed control. In rainy years, weeds are definitely the most important constraint on farms – delaying agricultural work and limiting the effectiveness of inputs. When weeding is postponed, cottonseed yield losses due to weed competition are around 20 kg/ha/day after the optimum weeding date, which is generally 10-15 days after the sowing date under rural draught farming conditions. Weeding becomes more laborious and takes longer beyond this ideal date. The regeneration potential of some weeds increases considerably (*via* cuttings or transplantation) and the earliest species fruit. In addition to these problems of early weed competition for light, water and minerals, late competition (mainly for water) can be a limiting factor, e.g. obstructing harvesting (climbing weeds) or contaminating the harvested crops (weed plant debris and seeds). Finally, weed cover can shelter crop pests (insects, diseases) or enemies of man and domestic animals (snakes).

In northern Cameroon, farmers perform most maintenance tasks manually (weeding, hoeing) or mechanically (tilling, earthing-up). However, they are generally unable to maintain weed cover at acceptable levels throughout their cropfields. Chemical weed control can thus be beneficial in two major ways:
– better labour management (both on and off the farm) during intensive work periods involving tilling, sowing and the first weeding;
– limitation of early weed competition and easier subsequent maintenance.

In addition to chemical weed control, the Société de développement du coton du Cameroun (SODECOTON) recommends conducting mechanical interrow weeding under draught farming conditions. The company thus offers farmers weeding tools that are adapted to their equipment and financial resources.

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# Expansion of chemical weed control in cotton-growing regions

In 1976, Cameroon was the first cotton-producing country in French-speaking Africa to use herbicides for weed control in cotton and food cropfields, i.e. maize, groundnut, sorghum and rainfed rice (Tables 1 and 2). SODECOTON recommended using pre-emergence herbicides to enhance crop intensification in the southern part of the cotton belt. This in-migration region has a high agricultural potential, with annual rainfall levels of over 1 000 mm, but it is still underpopulated and there are not many draught animals. Hand sprayers are used for ultra low volume treatments (10-25 l/ha of spray mixture) – they are easy to handle and reduce water supply problems.

The Cameroonian Institut de la recherche agronomique (IRA) regularly tested herbicides used to control weeds in cotton cropfields, but they had no data or reference products concerning food cropfields. Herbicides widely used by SODECOTON were commercial formulations, mainly binary mixtures, proposed at relatively high doses (3-4 l/ha of commercial product).

Table 1. Herbicides used for pre-emergence treatments of cropfields in northern Cameroon.

| Herbicide | Mode of action | Active ingredient dose (g/ha) | Advantage | Treatment stage |
|---|---|---|---|---|
| **diuron** cotton | root penetration | 720 | good efficacy - on superficially rooting plants, beware of the phytotoxicity risks | pre-emergence of weeds |
| **atrazine** (maize) | root and leaf penetration | 800 | good efficacy on superficially-rooting plants, selective for maize and sorghum | pre-emergence of weeds |
| **paraquat** | contact | 200 to 400 | rapid effect easy to use | post-emergence of weeds, splitting recommended |
| **glyphosate** | non-selective systemic herbicide | 1 440 | useful in integrated control of perennials | post-emergence of weeds, slow action (2-4 weeks) |
| **glufosinate** | non systemic contact action slower than with paraquat | 200 or 400 | effective against Poaceae species and dicots | pre-sowing, pre-tillage |

Table 2. Binary mixtures used in pre-emergence treatments, formulated and marketed by several companies.

| Crop | Active ingredient or combination | Active ingredient dose (g/ha) |
|---|---|---|
| **Cotton** | flumeturon + prometryn | 750 + 750 |
| | dipropetryn + metolachlor | 720 + 480 |
| | terbutryn + metolachlor | 500 + 1 000 |
| | dipropetryn | 750 |
| | metolachlor | 1 080 |
| **Maize** | atrazine + alachlor | 1 000 + 1 000 |
| | atrazine + metolachlor | 750 + 750 |

During the 1980s, after the initial rapid expansion, the herbicide-treated area remained stable at 40-60% of the overall area under crops: 10 000-13 000 ha of cotton cropfields (i.e. 40 to 60% of the surface) treated per year (10-15% of the area sown), and 2 000-3 000 ha of intensively-grown maize cropfields. A few hundred hectares of rainfed rice, groundnut and sorghum cropland were weeded chemically. Pre-emergence herbicides were partially subsidized in the first few years, but later became too expensive for farmers to purchase. In 1990, the average cost of a pre-emergence treatment against weeds in a cotton cropfield was the equivalent of two-thirds of the cost of a pesticide protection programme or of 100 kg of mineral fertilizer.

## Important weed control innovations

In 1987, SODECOTON introduced paraquat, a non-selective contact herbicide, since pre-emergence treatments are useless for controlling weeds in recolonised fields. Farmers were quick to adopt this new highly efficient, rapid-acting and relatively inexpensive product. In 1992, based on the work of IRA, SODECOTON began promoting low-dose treatments with two generic molecules, diuron to control weeds in cotton cropfields and atrazine in maize fields. These herbicides replaced former binary formulations, and the performance:cost ratio is almost threefold higher. Paraquat and pre-emergence herbicides were shown to be quite complementary. Under these suitable technical and economic conditions, and particularly since training, logistics and credit were provided by SODECOTON, renewed the interest in chemical weed control.

## Expansion of herbicide-treated areas

1992 marked a reversal in the herbicide treatment trend concerning cotton and maize cropland. In 4 years,

Manual inter-row weeding after weeding with an ass-drawn plough.
Photo J. Martin

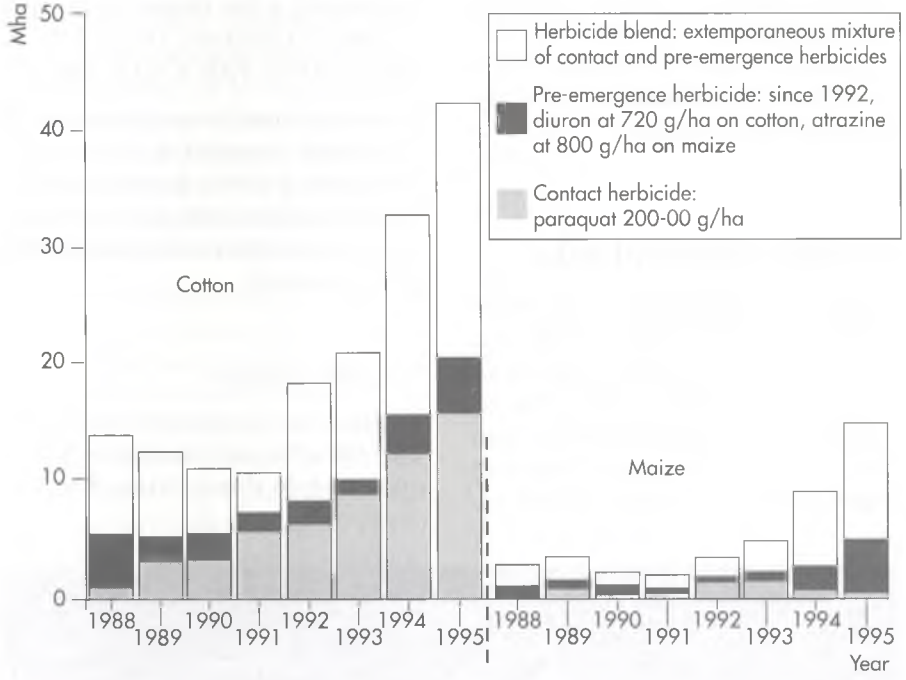


Figure 1. Cotton and maize cropland treated with herbicides in northern Cameroon (source: SODECOTON).

there was a 4-fold increase in the area under chemical weed control, while the area treated with pre-emergence herbicides increased 6-fold over the same period (Figure 1).

In 1995, chemical treatments were carried out to control weeds on around 60 000 ha of cropland, i.e. 42 000 ha of cotton and 16 000 ha of maize, along with 2 000 ha of sorghum and groundnut. Between 1991 and 1995, there was a marked increase in the surface area treated relative to that sown: 12-28% for cotton and 40-90% for intensively cropped maize. Atrazine treatments were also started in fields of "traditionally-grown" maize (without fertilizer): 3 700 ha in 2 years, or 13% of the area. There was also a modest, but definitely significant increase in the use of atrazine to control weeds in sorghum cropfields and diuron in groundnut fields (1% of the overall area).

## The use of paraquat, diuron and atrazine

Paraquat can be used alone or in extemporaneous mixtures with pre-emergence herbicides. Since 1987, there has been a steady increase in the use of paraquat alone to control weeds in cotton cropfields (around + 40%/year, up to nearly 16 000 ha in 1995). However, there has been a reduction in its use in maize fields (less than 500 ha in 1995). This reduction could be explained by the spectacular increase in treatments with atrazine alone, i.e. almost 5 000 ha in 1995, or + 250%/year since 1992. There was a more moderate increase in treatments with diuron alone in cotton cropfields (+ 40%/year). Since 1992, combined treatments (paraquat + pre-emergence herbicides) have increased substantially in cotton and maize cropfields, i.e. nearly 22 000 ha and 10 000 ha in 1995, or + 135% and 220%/year, respectively.

Geographically, herbicide use has expanded considerably from the southern region (Touboro and, to a lesser extent, Garoua regions) to the centre of the cotton-growing region (Guider region, with around 4 300 ha treated, including more than 900 ha with food crops), and up to the northern part of the cotton-growing region (more than 2 600 ha treated in 1995, including almost 500 ha with food crops).

The cotton-growing area has generally increased due to the devaluation of the CFA franc, thus affecting all cotton-producing countries of the franc zone. This change forced Cameroonian farmers to use herbicides to a greater extent in their cotton and food cropfields (DUGUE & DOUNIAS, 1995).

# Paraquat treatments

Paraquat treatments were introduced in 1987, at a time when gramoxone was the only formulation (200 g/l)

Excellent efficacy of herbicides in a cotton field 20 days post-treatment. In the centre, the two untreated rows show a predominantly Poaceae plant population.
Photo J. Martin

meeting the Food and Agriculture Organization/World Health Organization (FAO/WHO) safety standards. This monopoly ended recently.

Paraquat is a non-selective contact herbicide that is extensively used by farmers in northern Cameroon to facilitate the establishment of rainfed crops, and to reinforce the action of pre-emergence herbicides in reinfested fields. It is highly useful when the rainy season is early, or sowing is extended or late.

Treatment conditions rapidly became diversified, based on experience acquired by farmers and SODECOTON supervisory staff:
– treatments with double (or even triple) doses relative to the initial 200 g/ha dose, to deal with high weed conditions;
– treatments with paraquat alone, without being mixed with a pre-emergence herbicide;
– pre-tillage treatments, to obtain weed-free fields, with a more sustained effect than with post-tillage treatments. Pre-tillage treatments are sometimes advanced by several days in order to reduce the herbicide dose.

It is important to note that paraquat enabled the development of a new crop establishment technique, i.e. direct-sowing without tilling on weed mulch. In such conditions, paraquat is often used in extemporaneous mixtures with a pre-emergence herbicide, thus reinforcing its action and ensuring a more sustainable clearing effect. This new technique was applied on 15 000 ha of cotton cropfields in 1995, and has been fully adopted in the southern part of the cotton-growing region.

## Limiting treatment risks

Paraquat, although not very hazardous in normal usage conditions, is highly toxic when swallowed accidentally (WHO, 1994). Nevertheless, in hot climates, there is more risk of intoxication through dermal absorption or inhalation. Users are less aware of these risks and have no protective gear and clothing (glasses, masks, boots, gloves, etc.), which are difficult to obtain and to wear under tropical conditions.

### Risks of oral intoxication

Reference toxicological levels offer only a starting point for assessing risks associated with the handling and spraying of commercial formulations (decanting and proportioning), since the toxicity of a molecule depends on the concentration. Paraquat, at 20% concentration (commercial formulation), has been classified as highly hazardous to dogs (BCPC, 1987) and man, i.e. swallowing a few drops can be fatal to small children (SEVERIN & TISSUT, 1991; PAN & CTA, 1993).

However, there is very little risk of accidental ingestion, e.g. by confusion with a drink, because of the highly repulsive effects of formulations that comply with FAO/WHO safety standards.

### Suitable dilutions

Paraquat spray mixtures diluted to 2% (400 g/ha) are moderately hazardous, while those diluted to 1%

Insufficient weed control efficacy 30 days post-treatment in a field overrun with *C. benghalensis*. Manual weeding combined with herbicide treatment was too late. In the absence of herbicide, the cotton plants have practically disappeared under *C. benghalensis* cover.
Photo J. Martin

Ox-drawn tillage after paraquat treatment.
Photo P. Marnotte

(200 g/ha) have almost no toxic impact. 1% paraquat spray mixtures have the same risk level as products classified as not dangerous, e.g. glyphosate and diuron. Users must therefore be careful to keep containers of paraquat (concentrated or diluted) away from children.

Long-term toxicity criteria should be taken into account with respect to agricultural workers on industrial plantations. Moreover, these criteria should be considered in terms of northern Cameroonian conditions, where farmers carry out three to four half-day herbicide treatments yearly (10 at most). Under these conditions, the properties of paraquat have a relatively minor impact.

### Treatment techniques

For manual ultra low volume (ULV) treatments, spray mixture concentrations are high and the spray cloud generated through disk rotation can drift considerably. The risks depend on the spraying technique and constraints. Handy® sprayers are used for herbicide treatments in northern Cameroon and other French-speaking countries of Africa. The herbicide spray mixture is gravity-fed onto a rotating disk driven by a battery-powered electric motor, thus forming a low circular spray cloud of about 1 m diameter. One inter-row is treated per run, spraying behind the operator, at a flow rate of about 20 l/ha of spray mixture. There is very little lateral and vertical drift under these conditions.

### Reducing the spray mixture concentrations

To improve safety, the proposed measures involve reductions in the herbicide dose and operator exposure time. It would be unsuitable to reduce the spray mixture concentration by increasing the volume, as this would increase the problem of getting water supplies at the side of the field and, in addition, farmers are used to the convenience of simply filling the container with 5 l of spray mixture to treat quarter-hectare plots in a single operation. On the other hand, the dose can be reduced, while maintaining or increasing the herbicide efficacy, by conducting treatments under optimal weather conditions or by splitting the treatments.

## Splitting doses and optimal treatment conditions

### Splitting doses

The paraquat doses used in northern Cameroon (200-400 g/ha) are low compared with those commonly used worldwide (600-800 g/ha). The "high" dose (400 g/ha) can be recommended when the weed cover is dense or there are tufts of weeds partially buried by tilling. The "low" dose (200 g/ha) is recommended to avoid treatments at concentrations above 1%.

To obtain the same efficacy, optimal conditions are required for treatments and the high dose can be split so as to conduct two treatments, which are more effective than a single treatment at 400 g/ha. The second treatment reaches the lower parts of the weeds, which become more accessible after the initial treatment. In addition, any strips missed in the first run can thus be covered.

### Optimal treatment conditions

Treatments done under the full sun can wilt and completely dry out young annual plants within in a few hours. However, there are only partial and temporary effects on dense plant stands composed of mature annual or perennial plants, as regrowth can begin from the untouched lower plant parts or from underground reserves.

The treatment efficacy, even at high doses, is limited by the fact that paraquat reacts quickly under high light conditions. A treatment carried out in the evening or in overcast weather conditions will have a slower but greater effect, i.e. penetration is improved through a cuticle that is more permeable due higher humidity, and the herbicide is diffused better under low light conditions. The cells are then destroyed when the light returns.

### Addition of wetting agents

Additives can be extemporaneously mixed with the herbicide formulation in some cases (GAUVRIT, 1995). Ultra low volume paraquat treatments at 400 g/ha are not very efficient against infestations of *Tridax procumbens,* which has very downy leaves. The addition of tensioactive wetting agents can enhance spreading of the herbicide film over the leaf surface and between the leaf hairs to the cuticle.

### Consequences of splitting treatments

Splitting treatments increases battery consumption and the demand for sprayers that SODECOTON supplies to farmers. This also increases the workload at a point when the cropping calendar is quite full. However, the additional treatment time is minimized when there is a sufficient stock of sprayers, i.e. 1 h to treat a standard quarter-hectare plot, and there is a long potential treatment period. Pre-emergence treatments can be carried out within the 4-day period after sowing, and often even later. This treatment modification is thus quite easy to apply, especially since some farmers already follow a programme that includes pre-tilling and post-sowing treatments. Sometimes the pre-tilling treatment can be advanced several days to reduce the herbicide quantity, increase efficacy and obtain weed-free fields.

### Recommendations for spray mixture preparation

To reduce user exposure to concentrated paraquat, the spray mixture should be prepared in the herbicide shed, where safety gear is available (soap, funnel, etc.), along with water in case of accidents or splashing. A deposit can form in preprepared mixtures and then redissolve when the container is shaken during transport and treatment. Empty herbicide containers should be burned or buried after use, but in practice they are often recovered and sometimes sold. Such containers should be rinsed at least three times, as recommended in northern Cameroon.

# Features of other non-selective herbicides

## Glufosinate

Glufosinate, a contact herbicide, can replace paraquat in post-sowing treatments. 15 days post-treatment, it is as effective as the same dose of paraquat against Poaceae and more effective against dicots (LE BOURGEOIS *et al.*, 1992). However, different treatment conditions are necessary because of its slower action. This is especially important for pre-tillage treatments, as they must allow for a 1-2 week delay in the herbicide action. It could be classified among moderately hazardous products, although it is 4- to 8-fold less toxic by ingestion than paraquat. The main factor that limits extension of this product is its high cost.

## Glyphosate

Systemic non-selective herbicides such as glyphosate have almost no shock effect.

Glyphosate treatment conditions differ from those of contact herbicides: they are more restrictive and require a new weed control approach involving a special cropping calendar with treatment times that have to be respected.

This herbicide is of interest for targeted control of perennial weeds. Moreover, the price of this compound has dropped steadily since the expiration of its patent in 1991 (FEUILLETTE *et al.*, 1994; MARNOTTE, 1994). In 1995, glyphosate began being used widely in the cotton-growing region of northern Cameroon, with treatments at 1 440 g/ha recommended against *Imperata cylindrica*.

## Conclusion

There is presently no cost-effective and non-toxic herbicide available to replace paraquat which would be adapted to pre-emergence weed control in cotton-growing regions of northern Cameroon.

# Diuron and atrazine

In 1989, IRA and CIRAD, in collaboration with several pesticide manufacturers, renewed testing of herbicides that could be used in cotton and food cropfields, along with non-selective herbicides. In 1990 and 1991, multi-site trials demonstrated the efficacy of two generic molecules, i.e. diuron in cotton cropfields and atrazine in maize fields, when treatments were conducted at relatively low doses as compared to those used with binary mixtures supplied by the manufacturers. The results helped define suitable doses, the spectrum of activity, phytotoxicity risks, impact on subsequent crops, and treatment conditions adapted to the farming environment. The tests were carried out on split plots: treated and non-treated. In 1992, following these tests, SODECOTON recommended treatments with diuron at a dose of 720 g/ha and with atrazine at 800 g/ha.

## General characteristics

These two molecules have many common points. They were discovered in the 1950s and developed in the 1960s, and were among the first selective pre-emergence herbicides available with persistent activity. Maize-selective atrazine favoured the worldwide expansion of this crop. Diuron was used for initial weed control treatments in tropical plantations, as well as in cotton cropfields, particularly in USA.

They have quite high chemical stability, with a few weeks to months persistence in the upper soil layers. Overall, they have the same herbicide performance, i.e. they have high efficacy against weeds with superficial root systems, destroying (from the cotyledon leaf stage) weeds with small seeds that germinate close to the soil surface.

These molecules are degraded by physico-chemical and microbiological processes, in relation to the biological soil activity and the affinity of various types of microorganisms (SEVERIN & TISSUT, 1991). Diuron belongs to the substituted urea family and atrazine to the chlorotriazine family. Diuron and atrazine, like

Draught tillage.

Ass-drawn weeding operation.

Light tractor tillage, ploughing in of *Imperata cylindrica*.

Ox-drawn earthing-up.

Hoe weeding

Grass stand scorched by paraquat.

Photos J. Martin

most herbicides used in pre-emergence treatments, are relatively non-toxic to man and warm-blooded animals.

These two herbicides are used worldwide in integrated pest management programmes, alone or in combination or alternation with other active ingredients.

## Weed control with atrazine

Atrazine is absorbed through the roots and leaves and has a broad spectrum of activity in pre-emergence treatments (at less than 1 000 g/ha), especially against Poaceae, annual Cyperaceae and Commelinaceae species (MARTIN & GERARDEAUX, 1994). This product can be used in post-emergence weed treatments, with high efficacy against broad-leaved species (often dominant after tillage), but with poor efficacy against annual grasses, that are abundant on new plots. It can also be used in direct-sowing conditions without tillage.

### Treatments adapted to maize and sorghum crops

Maize and sorghum very efficiently metabolize and detoxify atrazine (GAILLARDON, 1991). This herbicide can therefore be used in post-emergence treatments on fields cropped with these two cereals without any special precautions.

Atrazine does not have phytotoxic side-effects on subsequent crops (cotton or legumes). These risks have not yet been fully assessed on catch crops (cowpea, cover crops), although they seem low when the catch crop is sown 45 days after the pre-emergence treatment.

In 1992, atrazine began being used widely for pre-emergence treatments in sorghum cropfields, and this technique in now fully adopted. Improved red sorghum (*Sorghum caudatum* "Djigari") crops, sown without tillage once the first rains occur, are soon overrun with weeds.

High efficacy of atrazine in a maize cropfield.
Photo J. Martin

Poaceae species are generally abundant or dominant. Pre-emergence treatments promote good initial plant growth and replace the first weeding, which is generally a long operation.

Sorghum is cropped on around 400 000 ha of land in northern Cameroon, including 40 000 ha planted with improved varieties, which are of considerable interest in terms of weed control.

### Efficacy of atrazine against *Commelina benghalensis*

Atrazine is of major interest because of its efficacy against *C. benghalensis* (MARTIN & GERARDEAUX, 1994). This weed becomes dominant after a few years of cropping, when it is difficult to control because of regrowth. It is highly competitive with crops, especially in the wetter southern parts of the cotton-growing region. It germinates massively after any extent of surface tillage, and quickly affects cotton and maize cropping areas where these crops are sown after rapid draught tillage (low coverage with little clearing). On sandy soils with a low exchange capacity, which is a very common situation in the cotton-growing regions of Cameroon and western Africa, post-sowing treatments of maize cropfields with a low atrazine dose (800 g/ha) generally keeps the cropfield weed-free for more than a month. The young weeds still present can then be quickly and efficiently buried by an earthing-up operation - along with a second urea application, when this is scheduled in intensive cropping situations.

The excellent efficacy of atrazine against *C. benghalensis* is certainly responsible for the increased use of chemical weed control in fields of maize, which is almost always sown

Post-sowing treatment after tillage with a Handy® sprayer.
Treatment with a pre-emergence herbicide and paraquat.
Photo J. Martin

After weeding an intercropped field, the plants are piled up to hinder regrowth.
Photo J. Martin

in tilled fields. Moreover, atrazine is sometimes persistent until harvest under experimental conditions, when weed control is very carefully performed – with cleaner tillage and very regular spraying. According to farmers and extension agents, there is lower weed infestation with cotton when it is planted after atrazine-treated maize, particularly when the field is infested with *C. benghalensis*.

## Diuron treatments of cotton cropfields

In cotton cropfields, the persistent activity of diuron (at 700-800 g/ha) is the same as that of widely used pre-emergence herbicides. However, its persistence is twofold less than that of atrazine, at a dose of 800-1 000 g/ha in pre-emergence treatments.

### Limit weed competition with cotton

After shallow tillage, weeds grow rapidly and regularly – before or at the same time as the cotton plants – especially if it rains between tillage and sowing. Generally rapid and shallow draught ploughing leads to rapid growth of weed cover (LE BOURGEOIS & MARNOTTE, 1994). Cotton plantlets are challenged after a few days when cotton fields are infested with *C. benghalensis*. Pre-emergence treatments delay the emergence of *C. benghalensis* by 15-20 days and promote the initial growth of the crop. Thereafter, the advantage given to developing cotton plants is quickly nullified, as the density and growth rate of the *C. benghalensis* population are often markedly superior to those of the crop. Weeding is thus recommended before the 30$^{th}$ day post-sowing, from the *C. benghalensis* 3-4 leaf stage if possible, in order to limit regrowth *via* natural cuttings. Early earthing-up should be done to hinder *C. benghalensis* from re-emerging.

There has been a marked increase in the use of diruon for weed control in cotton cropfields, despite its fairly short persistence. It is also starting to be used in groundnut cropfields, with nearly 600 ha treated.

### Diuron selectivity for cotton

There are phytotoxicity risks of diuron to cotton as this herbicide has position selectivity. Phytoxicity symptoms are often observed. They are limited to the cotyledons (white spots or plaques), sometimes reaching the first or second true leaf (relatively discoloured intervein spaces), without harming subsequent development to a major extent. The herbicide concentration must be zero or very low in growth zone of the first roots, around 5 cm below the surface.

Severe phytotoxicity can occur in many cases:
– on very poor or eroded soil, where herbicide migration is rapid, root growth is poor;
– on shallow-sown plots or unclosed seed holes;
– after heavy rains, *via* rapid herbicide migration;
– due to accidental overdoses or splitting of treatments.

The success of weed control depends on regular sowing in closed seed holes, while complying to recommended doses.

Groundnut and cowpea crops, which benefit from more careful sowing than cotton (1 seed per well-closed seed hole), can thus be treated with diuron. However, on poor or eroded soils, the diuron dose should be reduced by 25-50% or the treatment, which becomes dangerous and not very efficient, could even be cancelled altogether.

## Complementarity of diuron or atrazine with paraquat for controlling perennial weeds

In northern Cameroon, as in most cotton-growing regions, there are large infestations of some perennial weed species, against which diuron and atrazine are considered ineffective: tuber-bearing Cyperaceae (*Cyperus rotundus* and *C. esculentus*) or rhizome-bearing Poaceae

*(Imperata cylindrica)*. Moreover, paraquat has only a temporary and partial effect on perennials and well-developed annuals.

When these weeds do not cover the soil, combined diuron + paraquat treatments in cotton cropfields, or atrazine + paraquat in maize fields, show an interesting synergistic efficacy, and the effect of paraquat is boosted.

Some growers claim that diuron treatments facilitate weeding of fields infested with *I. cylindrica*. Progressive absorption of small quantities of herbicide slows plant growth and weakens its root system. The slight but prolonged effect of this root-penetrating photosynthesis inhibiting herbicide can add to the shock effect of paraquat, particularly when the weed roots are mostly superficial, which is often the case with tufts of weeds disturbed by tillage but not ploughed under.

## Treatment programmes against *Rottboellia cochinchinensis*

Diuron and atrazine are ineffective against *R. cochinchinensis*. Presently proposed solutions involve treatments of pendimethalin combined with diuron or systemic anti-Gramineae products.

### Resistance and vigour of *R. cochinchinensis*

This annual large-seed Poaceae species, with rapid initial growth, can efficiently compete with crops, particularly on rich well-watered soils. Its seed can germinate very deeply, thus providing it with a good resistance to herbicide treatments.

### Variable susceptibility to pendimethalin

*R. cochinchinensis* is susceptible to pendimethalin at a dose of 1 000 g/ha in pre-emergence treatments (LE BOURGEOIS *et al.*, 1992). However, the results of experiments conducted since 1992 have highlighted considerable variability in the efficacy of pendimethalin against *R. cochinchinensis*. This could be attributed to weather conditions during treatments (promoting volatility and photodegradation losses), to soil porosity (influencing vapour dispersal in the soil) and to the depth at which the seeds are buried, since they can only germinate in the top 8 cm soil horizon (LE BOURGEOIS & MERLIER, 1995).

In 1995, pendimethalin (at 1 000 g/ha) combined with diuron (at 720 g/ha) was recommended for controlling *R. cochinchinensis* in cotton cropfields.

The use of this product is limited, in spite of good results, by its relatively high price. Although pendimethalin is not very hazardous, it has a poor reputation because it can deeply dye clothes and skin yellow. There are other chemical solutions, such as post-emergence treatments of cotton fields with slow-acting, systemic graminicides, which are very selective for dicots, but are still too expensive.

## New chemical weed control possibilities

Since 1992, SODECOTON has extended the use of diuron (at 720 g/ha) and atrazine (at 800 g/ha), replacing the binary formulations used in pre-emergence treatments. The reasons behind the current increase in chemical weed control are technical, economic and linked with organization, in addition to the fact that it can promote an increase in cotton cropland.

Table 3. Variation in the cost of supplying farmers or farmers' organizations with established or recently recommended herbicides from SODECOTON in northern Cameroon (source: SODECOTON, agricultural production directorate).

| Crop | Herbicide treatment | Active ingredient dose g/ha | 1991 | 1992 | 1993 | 1994 | 1995 |
|---|---|---|---|---|---|---|---|
| **Price of pre-emergence treatment CFA franc/ha** | | | | | | | |
| Cotton | binary 400 SC(1) | 1 200 | 10 000 | 4 000 | | | |
| Cotton | diuron 800 WP(1) | 720 | | 4 000 | 4 000 | 5 200 | 5 600 |
| Maize | binary 400 SC | 1 600 | 10 000 | 6 000 | | | |
| Maize | atrazine 500 WP | 800 | | 6 000 | 4 000 | 5 200 | 5 600 |
| Cotton | pendimethalin 500 SC | 1 000 | | | | 16 000 | |
| Cotton | chlortoluron 500 SC | 1 000 | | | | | 5 600 |
| **Price of non-selective herbicide treatment CFA franc/l** | | | | | | | |
| | paraquat 200 SL | 200-600 | 2 000 | 2 000 | 2 100 | 3 000 | 3 700 |
| | glyphosate 360 SL | 1 080 | | | | 5 000 | 4 500 |

(1): SC = suspension concentrate, WP = wettable powder.

## Cost-effective pre-emergence treatments

The use of diuron and atrazine has lowered the average cost of pre-emergence treatments by threefold (Table 3). There are three components involved in this reduction: price, dose and formulation.

Since the patents for these molecules expired, they have become generic herbicides used worldwide. They are produced and marketed by many competing companies. Conversely, previously recommended binary formulations contain active ingredients that are more expensive and less widespread.

Currently recommended active ingredient doses are about twofold lower since binary formulations have been abandoned. The herbicide combinations previously recommended for maize all contained atrazine at similar doses. The reduction in the herbicide dose can be especially attributed to the absence of a second active ingredient, belonging to the chloro-acetamide family (metolachlor or alachlor).

Diuron was not included in previously-recommended herbicide formulations for cotton.

The high active ingredient concentration in wettable powders reduces transport costs and these formulations have a long shelflife of many years, thus minimizing losses.

## Adaptation of formulations and packaging

Herbicide spray preparations from wettable powders (WP) of diuron and atrazine are highly practical, especially concerning single dose packets for quarter-hectare treatments. This type of packaging is not as expensive as containers required for suspension concentrate (SC) formulations. Powder formulations have a long shelflife, while suspension concentrates often form relatively unmixable sediments in the containers.

## Sufficient organization

Extension of any herbicide product involves training and monitoring activities, as well as adapted management of supplies and credit. Hundreds of demonstration plots, with cotton and food crops, have been set up yearly since 1992 throughout cotton-growing regions. Technical datasheets designed for extension agents have been updated. IRA researchers conduct sessions intended for SODECOTON trainers. Follow-up is provided by SODECOTON staff, who are experienced and highly present in the field during crop establishment. The herbicide supply costs include battery consumption and depreciation of SODECOTON spraying equipment. Herbicides for cotton and food crops are supplied on credit and paid for when the cotton is sold. The "input" credits are granted to organizations of around 10 farmers with joint responsibility, thus ensuring repayment. Herbicides, batteries, sprayers and gear are supplied to village stores between cropping seasons.

## Economic impact of weed control

The costs of the different herbicide products and expenses associated with their use have been assessed: labour savings for weeding, crop production increases, treatment costs, and supplementary labour costs due to increased yields.

An optimal maintenance programme involves two weedings and an earthing-up before the weed cover develops beyond the economic damage threshold, e.g. on days 14, 28 and 42 after sowing (GABOREL, 1989). In practice, maintenance

## The economic impact of chemical weed control in 1995

It was estimated that chemical weed control in cotton cropfields enables a labour gain of 12 days/ha. The herbicide can reduce period of excessive weed competition by 10 days for cotton, i.e. equal to 15 kg/day of seed cotton. The estimated crop-yield gain following herbicide treatment is 150 kg/ha for cotton. The financial assessment was carried out as follows (Table 4):

– one day's income is 500 CFA francs, i.e. 6 000 CFA francs for 12 days of work;
– the price of seed cotton in 1995 was 160 CFA francs/kg;
– the costs associated with cotton harvesting (picking and marketing) were 30 CFA francs/kg;
– the cost of herbicide treatments with an extemporaneous mixture of a pre-emergence herbicide + paraquat at low dose was 5 600 + 3 700 = 9 300 CFA francs/ha.

Total savings obtained through chemical weed control were evaluated at more than 16 000 CFA francs/ha for cotton. These economic benefits are incurred with increased crop production, estimated at 6 300 t of seed cotton for the entire cotton-growing region, and 7 000 t of maize seed.

Table 4. Estimated seed cotton and maize production gains (CFA francs) following herbicide treatments.

| Budgetary terms | Cotton | Maize |
|---|---|---|
| Savings on weeding | + 6 000 FCFA | + 9 000 FCFA (18 days) |
| Value of supplementary production | + 24 000 FCFA | + 20 000 FCFA (50 FCFA per kg) |
| Cost of harvesting supplementary production | - 4 500 FCFA | - 1 500 FCFA (5 FCFA per kg) |
| Cost of herbicide treatment | - 9 300 FCFA | - 9 300 FCFA |
| Total | + 16 200 FCFA | + 18 200 FCFA |

work is always carried out later than the optimal weed treatment dates (DUGUE & DOUNIAS, 1995), thus substantially increasing the duration and laboriousness of weeding operations (GABOREL, 1989), reducing the efficacy of earthing-up and leading to crop-production losses due to weed competition. Under field conditions, one herbicide treatment reduces the weeding time and the period when weed cover is invasive, which enables labour savings and yield gains.

In Benin, in a region of similar ecological conditions, 175 tests were carried out in collaboration with local farmers (GABOREL & FADOEGNON, 1991). The results were as follows:

– the use of herbicides led to a yield increase of 240-600 kg/ha of seed cotton and 550-650 kg/ha of seed maize;

– labour time was reduced by 17-19 days/ha for both crops. These gains are the equivalent of weeding one highly weed-infested hectare of cropland or two lightly infested hectares.

## The future of chemical weed control in cotton-growing regions of Africa

The herbicide treatment experience acquired in northern Cameroon, using paraquat, atrazine and diuron, will be useful for other African countries. Indeed, chemical control could complement current (mainly manual) weed control techniques. All treatment possibilities have not yet been fully explored, e.g. interactions between paraquat and pre-emergence herbicides, apart from the complementarity noted above. Pre-emergence herbicide doses could be reduced by 25-50% for poor soils with a low exchange capacity, while being increased for soils with high clay content, organic matter or organic mulch levels. In maize cropfields, atrazine treatments can be split into two treatments, or the post-sowing treatment could even be cancelled. Split treatments are more difficult to carry out in cotton cropfields.

New solutions are being investigated in order to diversify the range of products available and weed control programmes. Treatment recommendations concerning glyphosate, pendimethalin and chlortoluron (a substituted urea herbicide) should be drawn up. In trials currently under way, treatments with chlortoluron (at 1 000 g/ha) were found to be as efficient as those with diuron (at 720 g/ha).

## Increased logistics and training needs

An increased range of herbicides and weed control combinations implies complex supply organization and reduced training needs. Regular efficient organization, involving extension and follow-up, logistics and credit, is an essential prerequisite for rational weed control.

The control strip method — with two or three lines left untreated for a few metres — provides a good weed control demonstration. This technique can enhance and accelerate training, especially if undertaken by many neighbouring users: highlighting variability in the effects of treatment and their causes through discussions between neighbours, or with the help of a trainer, and gaining knowledge on the diversity of effects of different products under various treatment conditions.

# Conclusion

A "list of essential commonplace herbicides" would be highly useful for savanna farmers, such as that recommended by WHO for health purposes and applied to many African countries. Nevertheless, training, follow-up, herbicide supply and credit (and repayment schedules) still have to be organized. In addition to having an overall understanding of weeds that infest cropfields (LE BOURGEOIS, 1993; GRARD *et al.*, 1995), full and accurate knowledge of available herbicides is required for the purposes of rational control.

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# *Abstract... Résumé... Resumen*

J. MARTIN, L. GAUDARD — **Paraquat, diuron and atrazine for the renewal of chemical weed control in northern Cameroon.**

In Northern Cameroon, based on the recommendations of SODECOTON and tests carried out by IRA in collaboration with CIRAD, paraquat has been used widely since 1987, and diuron and atrazine since 1992. Paraquat shows rapid and highly effective activity. To limit the toxicity effects and optimize this treatment, it is recommended to split the treatments into 200 g/ha doses, with treatments preferably in the evening or under cloudy conditions. Treatments conditions are varied (pre-ploughing treatment, high-dose treatment in case of high weed populations, etc.). The recommendations must be followed for the spraying preparation. Glyphosate and glufosinate can be used in pre-sowing treatments, but their mode of application is more restrictive. In cotton-growing regions, weed control recommendations also include the use of diuron at 720 g/ha in cotton cropfields and atrazine at 800 g/ha for maize. Atrazine is a very interesting herbicide for the control of *C. benghalensis* in maize fields and for pre-emergence treatments in sorghum fields. Diuron is less effective on *C. benghalensis* but its use is recommended in cotton fields. In addition, diuron and atrazine are associated with paraquat for the control of perennial weeds. The pre-emergence treatments recommended in this cotton-growing region were shown to be cost-effective thanks to the gains obtained in working time and production. Logistics and training support are provided by SODECOTON.

Keywords: maize, cotton, sorghum, weed, herbicide, diuron, atrazine, paraquat, dose, toxicity, Cameroon.

J. MARTIN, L. GAUDARD — **Paraquat, diuron et atrazine pour renouveler le désherbage chimique au Nord-Cameroun.**

Au Nord-Cameroun, le paraquat est vulgarisé depuis 1987 et le diuron et l'atrazine depuis 1992, à la suite des recommandations de la SODECOTON et des tests réalisés par l'IRA en collaboration avec le CIRAD. Le paraquat montre une efficacité importante et rapide. Pour limiter les risques de toxicité et optimiser ce traitement, il est conseillé de fractionner les doses en applications de 200 grammes par hectare, à réaliser de préférence le soir ou par temps couvert. Les conditions d'emploi sont diversifiées (traitement de pré-labour, traitement à forte dose en cas de végétation importante d'adventices). Les recommandations doivent être suivies pour la préparation des bouillies. Le glyphosate et le glufosinate sont utilisables en traitement de pré-semis, mais leur mode d'application est plus contraignant. Dans la zone cotonnière, les conseils de désherbage comprennent aussi l'emploi du diuron à 720 grammes par hectare sur cotonnier et l'atrazine à 800 grammes par hectare sur maïs. L'atrazine est un herbicide très intéressant pour lutter contre *C. benghalensis* dans les cultures de maïs et en traitement de pré-levée des sorghos. L'effet du diuron sur *C. benghalensis* est moindre, son emploi est recommandé en culture cotonnière. En outre, le diuron et l'atrazine peuvent être associés au paraquat pour lutter contre les vivaces. Les traitements de pré-levée préconisés dans cette région cotonnière se révèlent rentables grâce aux gains de temps de travail et de production obtenus. Un appui de logistique et de formation est assuré par la SODECOTON.

Mots-clés : maïs, cotonnier, sorgho, mauvaise herbe, herbicide, diuron, atrazine, paraquat, dose, toxicité, Cameroun.

J. MARTIN, L. GAUDARD —**Paraquat, diurón y atrazina para renovar la escardadura química en el norte de Camerún.**

En el norte de Camerún, el paraquat está vulgarizado desde 1987 y el diurón y la atrazina desde 1992, consecutivamente a las recomendaciones de SODECOTON y a las pruebas realizadas por el IRA en colaboración con el CIRAD. El paraquat ofrece una eficacia elevada y rápida. Para limitar los riesgos de toxicidad y optimizar este tratamiento, se aconseja fraccionar las dosis en aplicaciones de 200 gramos por hectárea, realizadas preferentemente al caer la tarde o en tiempo cubierto. Las condiciones de empleo son diversificadas (tratamiento previo a la labranza, tratamiento a dosis fuerte en caso de gran vegetación de adventicias). Deben seguirse las recomendaciones para la preparación de los caldos. El glifosato y el glufosinato son utilizables en tratamiento previo a la siembra, pero su modo de aplicación es más restrictivo. En la zona algodonera, los consejos de escardadura incluyen también el empleo de diurón a 720 gramos por hectárea en el algodón y la atrazina a 800 gramos por hectárea en el maíz. La atrazina es un herbicida muy interesante para luchar contra *C. benghalensis* en los cultivos de maíz y en tratamiento previo al brote de los sorgos. El efecto de diurón en *C. benghalensis* es menor, recomendándose su empleo en cultivo algodonero. Además, el diurón y la atrazina pueden asociarse al paraquat para luchar contra las viváceas. Los tratamientos previos al brote de los sorgos en esta región algodonera resultan rentables gracias a los ahorros de tiempo de trabajo y producción obtenidos. SODECOTON aporta un apoyo de logística y formación.

Palabras clave: maíz, algodón, sorgo, maleza, herbicida, diurón, atrazina, paraquat, dosis, toxicidad, Camerún.