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Effectiveness of glyphosate herbicide in a juvenile oil palm plantation in Côte d'Ivoire

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Effectiveness, glyphosate, herbicide, oil palm tree, paraquat

1 SUMMARY

To diversify herbicides used in oil palm tree farms, an experiment was conducted in CNRA (Centre National de Recherché Agronomique) in La Me research station located in the southern rain forest of Cote d'Ivoire. It was to assess the effectiveness of three application rates (2, 3 and 4 l/ha) of Roundphos compared to the usual optimal rate (3 l/ha) of Roundup and Callaxone Super. The results show that 3 l/ha of Roundphos and the widely used herbicide (Roundup) applied at the same rate have similar effectiveness. Except for the first date of observations, i.e. 15 days after treatment (DAT), the effectiveness of Calloxone Super remained under the 80 % threshold limit with a lower residual effect. The higher rate of Roundphos (4 l/ha) was significantly more effective than the best control herbicide only at 45 DAT. Therefore, 3 l/ha of Roundphos is optimal with an effectiveness above the threshold limit up to 60 DAT. No symptom of phytotoxicity was observed on young trees during this assay.

2 INTRODUCTION

Chemical weed control was recognized to be an economical practice in industrial plantations of oil palm trees (Hornus, 1990; Hornus et *al*., 1990a) and it can reduce reliance on manpower for hand weeding which can delay operations in time of scarcity, and increase weed infestation in the plantation. Moreover, manual weeding which is often practiced in oil palm tree plantations is more expensive than chemical weeding (Hamel, 1986). Therefore, chemical weeding is a suitable alternative for oil palm production, especially in the humid forest of West Africa.

Various studies done previously on chemical weed control in oil palm tree plantations focused mainly on testing the effectiveness and selectivity of common herbicides, e.g. 2,4_D, Paraquat and Glufosinate(Quencez & Dufour, 1982a,b; Hornus, 1983; Hamel, 1986; Boum & Hornus, 1987;) and their economic viability (Hornus *et al*., 1990b).

Although common bioactive molecules suitably protect oil palm trees against weed invasion (Quencez & Dufour, 1982a), their continued use has induced resistance in some weed species (Marnotte, 2000). This resistance is affecting herbicide effectiveness and thus increasing weed abundance in oil palm tree plantations in the forest zone of Côte d'Ivoire.

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Therefore, alternative molecules that can be efficient against weeds are required. However, excepted for paraquat, there is limited knowledge of herbicide molecule effectiveness on weed competition in oil palm tree plantation, especially in Côte d'Ivoire.

The current study was initiated to identify additional effective molecules of herbicides that can be used as alternatives for weed control in oil palm plantations at the juvenile stage to avoid resistance in weed species.

3 MATERIALS AND METHODS

3.1 Study site: LA ME is located 5 ° 26 ' N, 3 ° 50 ' E; 23 m above sea level, in the rain forest zone, about 30 kilometers northeast of Abidjan city. The climate is Equatorial transition (Péné & Assa, 2003) characterized by two rain seasons (April-July and October-November) alternating with two dry seasons (December-March and August-September). The annual average rainfall is about 1500 mm with a daily average temperature of approximately 21 °C and the annual average insolation reaching 1660 h. The representative soil is tertiary sand under a forest dominated by *Africanus turraeanthus* and *Heisteria parvifolia.*

3.2 Plant material: Weed test was implemented in a juvenile oil palm tree plantation, made up of two hybrids ' Tenera ' categories C 1001F (DA115DAF x LM2TAF) and C 2501 (DA5D x DA3D) x LM2TAF. Weed population was dominated by *Chromolaena odorata, Desmodium adscendens, Emilia praetermissa, Heterotis rotundifolia*, *Mariscus cylindristachyus, Nephrolepis biserrata, Oplismenus burmannii, Panicum laxum* and *Phaulopsis falcisepala* (Traoré *et al.* 2005).

3.3 Chemical products: Commercial product tested was Roundphos 360 SL, a glyphosate molecule with formula $H_2O_3P\text{-}CH_2\text{-}NH\text{-}CH_2\text{-}COOH$. It is a systemic phosphonomethylamine acid (Akobundu, 1987) with an exclusive foliar absorption. Glyphosate acts by inhibition of the 5-enolpyruvylshikimate-3-phosphate, which operates mainly in the biosynthesis of phenylalanine, tyrosine and tryptophan. Its action is against protein synthesis in cells, which affects plant growth. The effectiveness of this herbicide was compared to two other commercial products (table 1), Roundup 360 SL, which is glyphosate-based and Calloxone Super SL, which is paraquat based ($C_{12}H_{14}N_2$). Paraquat belongs to the bipyridyle family and the group of the quaternary ammonium compounds. This is a contact product acting by inhibition of respiration and photosynthesis, destroying the plants foliar system.

Table 1: Herbicide evaluated for effect against weeds in oil palm plantations in Côte d'Ivoire.

Herbicide trade name	active molecule	Formulation	Rate applied	Distributor	Target weeds	Application	Quantity (l/ha)
Roundphos 360 SL	Glyphosate 360 g/l (Total weed-killer systemic)	Soluble concentrate (SL)	2, 3 and 4 l/ha	Agrokom	annual or perennial weeds	Post emergence	**300**
Roundup 360 SL	Glyphosate 360 g/l (Total weed-killer systemic)	Soluble concentrate (SL)	3 l/ha	STEPC	annual or perennial weeds	Post emergence	**300**
Calloxone super SL	Paraquat 200 g/l (contact weed-killer)	Soluble concentrate (SL)	3 l/ha	Callivoire	annual or perennial weeds	Post-emergence	300

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3.4 Experimental design: The study was conducted during the rainy season, from September to mid December 2004. A complete randomized blocks design for a single factor was studied with 5 levels: (3 rates of Roundphos 360 SL (2, 3, 4l/ha =T1, T2 and T3); 3l/ha of Roundup 360 SL (T4) and 3l/ha of Calloxone super SL (T5) and 4 repetitions. A non-weeded control was included (Te). Adjacent control plots separated treatment plots. Herbicides were applied on 23 September 2004.

Each elementary plot was composed 4 palm trees with 1.5 m x 2m dimension, with two consecutive lines of plants , on 20 m long rows , with a net area equal to 60 m². Each adjacent control had 30 m ² and 2 palm trees.

3.5 Observations: Observation was made to assess the abundance of grass in each parcel treated compared to the non-treated adjacent parcel. Parameters used were coverage of the soil and the identification of resistant species and new generations of weed.

Effectiveness of herbicide treatment was assessed comparing treated plot to the adjacent control according to scale (table 3) of the European Weeds Research Council (EWRC) (Marnotte & Téhia, 1992; Mathieu & Marnotte, 2000). The optimum herbicide efficiency threshold is 80 % on this scale. Practically, the mesh of the grid containing non-senescent weeds was counted at the following interval: 15, 30, 45, 60, 75 and 90 days after treatment (DAT).

Effectiveness of each treatment is obtained by the relationship below:

$$\textbf{Eff} = 100\ \% - \textbf{Tc obs}$$

100 % Is the adjacent control plot abundance grass rates

Tc obs' Is the observed abundant grass rate of Basic plots treated to the date of the observations.

In each elementary plot, the grid was put 8 times on each date of observation. The average value of the coverage rate observed is the rate of abundance of grass in the basic plot.

Table 3: Scale of evaluation of herbicide treatments' effectiveness according to the European Weeds Research Council (EWRC) (Marnotte & Téhia, 1992).

Note	Coverage rate (%)	Effectiveness rate (%)	Interpretation
1	99	1	No effectiveness
2	93	7	Very low effectiveness
3	85	15	Little marked effectiveness
4	70	30	Poor effectiveness
5	50	50	Weediness 50 % decrease
6	30	70	Moderate effectiveness
7	15	85	Acceptable effectiveness
8	7	93	Good effectiveness
9	0	100	Perfect effectiveness

Plant toxicity was assessed by comparison of the vegetative state of palm trees in the treated and non-treated plots. Data were analyzed using «SPSS 10 for Window».

4 RESULTS

Effectiveness herbicide treatments: Highly significant differences (p= 0.01) were observed between some treatments during the 6 consecutive observations (at 15, 30, 45, 60, 75 and 90 DAT). Roundphos at rates of 2, 3 and 4 l/ha had equal or higher effectiveness than Calloxone (T5) and Roundup (T4) treatments applied at the rate of 3 l/ha (table 4, figure 1). Except on the first date of observation (15 DAT), Calloxone had the lowest efficiency and it was distinguished by its low residual effect compared to the others. Its effectiveness varied from 88 % at 15 DAT to 58 % at 30 DAT (figure 2). Two other glyphosate herbicides, applied at the rate of 3 l/ha (T2 and T4), have a quasi-similar persistence with effectiveness averaging between 92 % at 15 DAT to 81 % at 60 DAT. The highest rate of Roundphos (4 l/ha) was only significantly more efficient than the Roundup (3 l/ha) at 45 DAT. At the six observations dates, Roundphos applied at rate T2 (3 l/ha), which is

equivalent to the standard control (Roundup applied at the same rate of 3 l/ha) had optimal efficiency above the threshold of 80 % up to 60 DAT.
No symptom of phytotoxicity of different herbicide treatments was observed on young palm trees.

Some weeds such as *Alternanthera sessilis, Spermacoce latifolia*, *Asystasia gangetica* and *Commelina forskalaeii* were resistant to various treatments. In addition, from 75 DAT new generations of weeds occurred such as *Digitaria horizontalis*, *Ipomoea involucrata* and *Boerhavia diffusa.*

Table 4: Average effectiveness of herbicide treatments on weeds in oil palm plantations over a 90 day period

Treatment	Effectiveness surveys dates					
	15 DAT	**30 DAT**	**45 DAT**	**60 DAT**	**75 DAT**	**90 DAT**
T1	91.2 AB	85.7 (b)	75.7 (b)	73.7 b	61.0 (b)	57.5 b
T2	92.2 b	89.0 (b)	84.7 c	81.7 bc	64.0 (b)	62.0 bc
T3	**96.2 c**	**94.7 (b)**	**92.0 (d)**	**91.5 (c)**	**79.5 (c)**	**74.0 (d)**
T4	93.5 bc	90.7 b	85.7 (c)	82.0 bc	69.7 bc	66.5 cd
T5	**88.5 a**	**58.7 a**	**21.2 a**	**18.5 a**	**16.5 a**	**15.7 a**
Average	92.3	83.8	71.9	69.5	58.1	55.4
CV (%)	1.2	3.8	1.8	4.7	5.4	4.3
Treatment effect	s. 1 %	s. 1 %	s. 1 %	s. 1 %	s. 1 %	s. 1 %
Block effect	NS	NS	NS	NS	NS	NS

DAT = D**ays after treatment; Treatment T1 = 2 l/ha Roundphos; T2 = 3 l/ha Roundphos; T3 =4 l/ha Roundphos; T4=3 l/ha Roundup; T5= 3 l/ha Calloxone Super**
Means followed by the same alphabetical letter along the same column are not significantly different according to Duncan's test at 5% threshold level; s.1% indicates significance at 1 % level; ns: not significant at 5 % threshold; CV = coefficient of variation.

Figure 1: Effect of the optimal rate of Roundphos (3 l/ha) on the weeds compared to that of standard controls at 15 days after treatment. T2 = Roundphos at 3 l/ha ; T4 = Roundup at 3 l/ha ; T5 = Calloxone at 3 l/ha.

5 DISCUSSION

Effectiveness of herbicides and their residual effect depends on the physical and chemical composition of the soil to which they are submitted (Hornus, 1990). The molecules are absorbed by the clay slips or colloids of organic matter and the absorption by clay is known to be temporal, with release occurring progressively in the soil solution (Séverin & Tisssut, 1991), thereby increasing their persistence. In contrast, the persistence of substances is low in soil that is richer in organic matter due to degradation during microbial activity (Akobundu, 1987). In sandy soil, the full availability of the compounds is associated with more effectiveness of the herbicide (Marnotte, 2000). However, in the present study which was characterized by sandy soil, no phytotoxicity was observed. This was probably due to the leaching effect of induced by the heavy rainfall (500 mm) experienced during the experiments.

During the experiment, the mean temperature recorded was 27°C; which can accelerate herbicide effectiveness especially with paraquat. Moreover, its foliar penetration is increased when the air relative humidity is high; the penetration of the molecule may be 3 to 5 times greater at 95 % air relative humidity than at 65 % (Séverin & Tisssut, 1991). In contrast, during drought periods the activity of herbicides is more limited.

Gauvrit (1996) reported that paraquat is more active if applied during low brightness (very cloudy, evening or night) than high brightness (mid-late morning). In the latter case, the important flow of photosynthesis electrons induces greater production of superoxide ions that can provoke plant tissues destruction which limit herbicide movement in the plant. Otherwise, in the evening or early in the morning under limited sunlight, there is reduced superoxide ions production, which decreases plant tissues destruction and subsequently an enhancement herbicide distribution in the plant (Séverin & Tisssut, 1991).

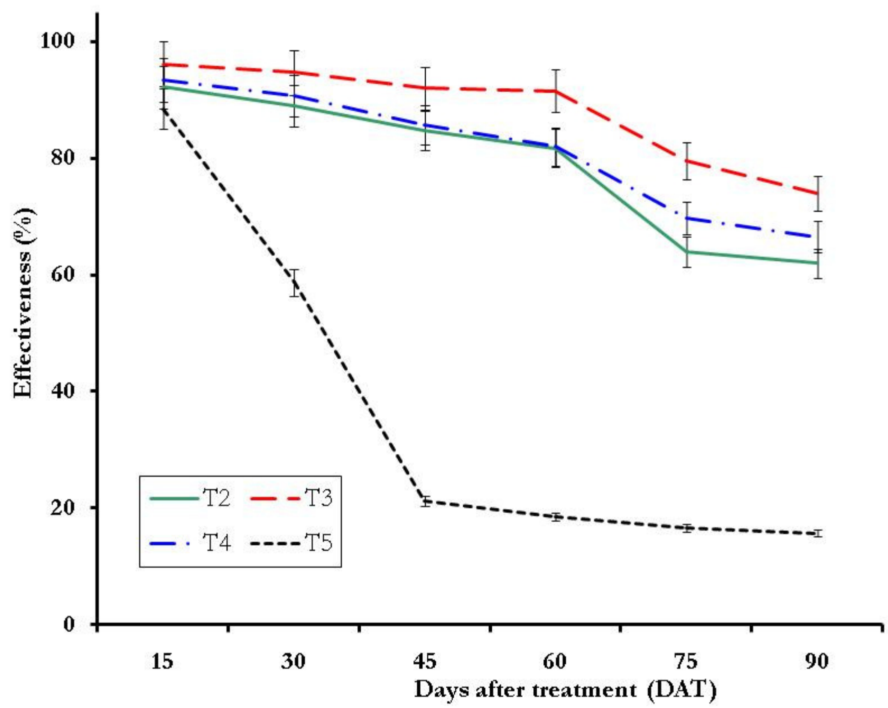

Figure 2: Effectiveness of herbicide treatments on weeds in oil palm plantation assessed over 90 days. T2 = Roundphos 3 l/ha ; T3 = Roundphos 4 l/ha ; T4 = Roundup 3 l/ha ; T5 = Calloxone 3 l/ha.

The activity of glyphosate is lower if treated plants have experienced water deficiency in soil before its application (Barralis *et al.*, 1990). This has been confirmed by many other observations for different weed species as reported by Gauvrit (1996). Indeed some authors explain this phenomenon by a decrease of the penetration of glyphosate in stressed plant following an increase of cuticular waxes (Quencez & Dufour, 1982a, 1982b; Hornus, 1983). Other factors also play important roles, in particular the intensity of photosynthesis and plant growth (Hamel, 1986; Boum & Hornus, 1987) The movement of glyphosate in plants, through the ostioles, is facilitated by the conditions which

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increase photosynthesis and the migration of the assimilates. These two processes are reduced in conditions of water stress.

When the relative humidity of the air is high, glyphosate penetrates quickly into the plants; due to faster cuticular transfer of the water soluble herbicides. The hydration of the cuticle, which would create an "aqueous way", may be responsible for the rapid transfer. The high solubility of glyphosate in water (salt of isopropylamine) makes this herbicide highly sensitive to being scrub off by rain (Caseley, 1989). The effect of air temperature is not always clear, though several experiments indicate it affects foliar penetration of glyphosate (Coupland, 1984).

This experiment took place during the short rainy season and the day of treatment was characterized by low brightness (cloudy sky). In fact, approximately 500 mm of rain was recorded during the 4 months of experimentation, from September to December. This resulted in an excess (+ 270 mm) from September to November and a deficit (-110 mm) in December (figure 3). The water deficit in December was mitigated by water reserves built up in the preceding month. This rainfall ensured sufficient development of weeds, so the effectiveness of herbicides was not particularly influenced by climatic conditions in this study.

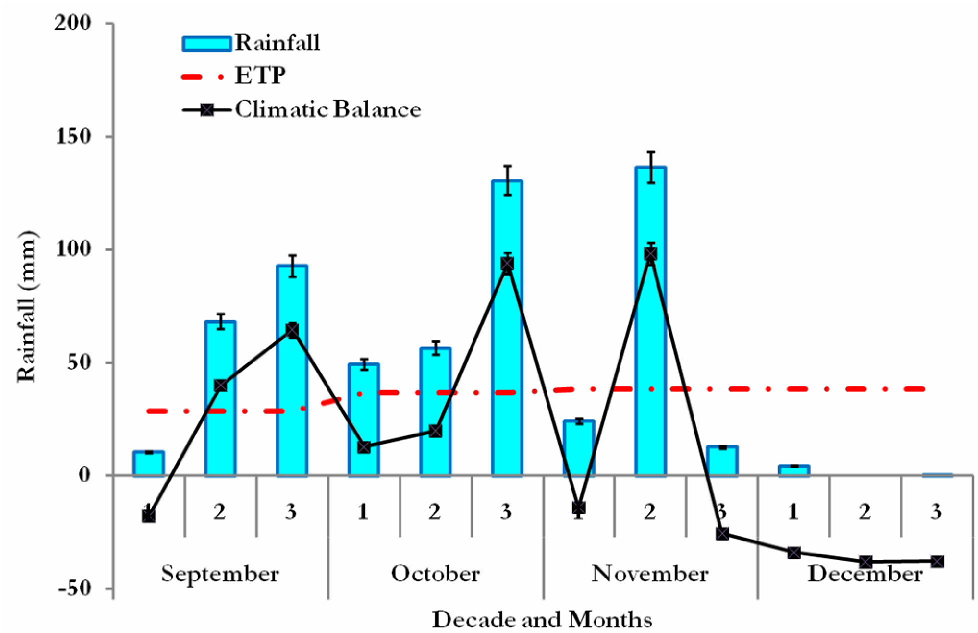

Figure 3: Rainfall and climate balance sheet water in experimentation from September to December 2004, at La ME.
ETP =Evapotranspiration ; Climatic Balance= Rainfall - ETP

5.1 Weed resistance to herbicides: The dominant weed species at La ME station were *Chromolaena odorata, Desmodium adscendens, Emilia praetermissa, Heterotis rotundifolia , Mariscus cylindristachyus, Nephrolepis biserrata, Oplismenus burmannii, Panicum laxum, Phaulopsis falcisepala* (Traoré *et al.,* 2005). All these were effectively controlled by herbicide treatment. *Alternanthera sessilis, Spermacoce latifolia, Asystasia gangetica* and *Commelina forskalaei* proved resistant and regenerated after a short period of senescence. This observation corroborates the work done by Quencez and Dufour (1982a). The resistance observed limits the number of herbicides available for controlling these weeds. Indeed, that inevitably led to selection of flora which is often reduced in monospecific population, constituting of individuals on whom the active molecules in the herbicides are not effective (Marnotte, 2000). This identified flora can be controlled only if one modifies the techniques of weeding or at least if one diversifies the products used by choosing other chemical families, which will have other sites of action.

The resistant species present had two characteristics (Gasquez, 1991); they are not part of the spectrum of effectiveness of the product employed and their selection by the treatment is quite predictable. In some cases, they are normally susceptible weed populations, but it could happen that some individuals escape the treatment or that the prescribed rate is not applied. These plants that are not destroyed develop and multiply, thus creating a new population which is described as resistant.

The tolerant species can become highly dominating since they have a great evolutionary capacity s. This evolutionary potential can be related either to the selection of an already existing mechanism (increased metabolism or detoxification of the herbicide) or with the appearance of mutation (appearance of a non-existent metabolism or modification of the site of action of the active compound).Thus, when a herbicide penetrates into a plant, it encounters an enzymatic reaction which can variably interfere with the activity of the new molecule (Le Baron & Gressel, 1982). The weed species with resistance to glyphosate infest now 3.251 farms in the United States; being equivalent to 2.37 million hectares in 19 States (Weed Science, 2007). Multiple combinations of eight different species have developed resistance: *Amaranthus palmeri, Amaranthus rudis, Ambrosia trifida, Ambrosia artemisiifolia, Conyza bonariensis, Conyza canadensis, Lolium multiflorum* and *Lolium rigidum* (Weed Science, 2007). Five other species of weed developed resistance to glyphosate in other countries. Of the 58 cases of resistance to glyphosate identified in the world during the last decade, 31 were reported in the United States, where 30 appeared between 2001 and 2007.

5.2 Residual effect of herbicides in the soil:

An inefficiency of tested herbicides after 10 weeks was observed during the study. This is a consequence of a short residual effect of these herbicides in the soil especially glyphosate and the paraquat as previously observed by Quencez and Dufour (1982a). Indeed, glyphosate, after ionization in the soil is more negatively charged and cannot in theory fix itself directly on colloids that are also negatively charged. It is thus retained by oxides and hydroxides of iron and aluminum. As for the paraquat, which is positively charged, it very strongly binds to colloids so much so that desorption will hardly occur (Séverin & Tissut, 1991). The effectiveness of these active compounds is a function of leaf area and the activity of the molecules. Thus, fully developed leaves absorb them and convey them much better than senescent ones (Quencez & Dufour, 1982a).

In conclusion, the results obtained in this study on La Mé on sandy soils in the humid forest zone need to be confirmed by repeating the trials elsewhere for wider application.

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