

Weed Management Challenges in Fairtrade Banana Farm Systems in the Windward Islands of the Caribbean

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1. Introduction

The banana (*Musa* sp.) is the foundation of the agricultural and rural-based community life of the Windward Islands where about 8000 farmers are involved in its production. Banana is primarily grown on small farms in hilly areas averaging two hectares in size, usually owned by local family farmers and exported mainly to Britain and Europe. These farmers have limited financial resources, farm part-time and grow other crops and/or livestock in their system of farming. With the loss of preferential European market arrangements and higher production costs than Latin America, many banana growers have turned to alternative marketing arrangements such as Fairtrade to maintain their profitability.

Fairtrade is an organized social movement and market-based approach that aims to assist small-scale and other disadvantaged producers in developing countries to improve their quality of life through better trading conditions and sustainability (Moberg, 2005). The movement advocates the payment of a higher price to producers as well as social and environmental standard (Moberg, 2005). These disadvantaged producers receive a price premium of about 12 % and a social premium that is returned to support community projects such as street lights, bus shelters, community centres, school equipment and building, and scholarships (Moberg, 2009; Rodriguez, 2008). Fairtrade also stipulates the need for more sustainable production systems, which use fewer or no chemicals, and, in particular, restricts the use of herbicides (Moberg, 2005).

It is estimated that weed control accounts for approximately 50% of the total cost of banana production (Hammerton, 1981). There is no detailed information available about the amount of crop yield losses due to weeds in the Windward Islands. However, certain weeds associated with banana are known to harbour pests, which cause major losses in production. Among them, *Commelina diffusa* Burm. F (watergrass), which harbours the root-burrowing (*Radophilus similis*) (Queneherve et al., 2006), reniform (*Rotylenchulus reniformis*) and the banana lesion (*Pratylenchus goodeyi*) (Robinson et al., 1997) nematodes. It also harbours the

soil borne fungus, *Fusarium oxysporum* (Waite & Dunlap, 1953) which causes Fusarium wilt. These nematodes all contribute to a significant reduction in banana production, particularly *R. similis* which may reduce yields by more than 50 % and decrease the productive life of banana fields by feeding on the secondary and tertiary roots of banana feeder roots and at high populations, cause severe necrosis and toppling of plants (Queneherve et al., 2006; Isaac et al., 2007a).

Bourdôt et al. (1998) noted that weed science should focus on those species that are causing, or are likely to cause, significant damage and loss of income in a particular industry or region. Myint (1994) described *C. diffusa* as a herbaceous, shade tolerant, tufted, rhizomatous perennial weed which is often spreading with stems growing up to 100 cm tall, creeping and rooting at the nodes. Fournet (1991) and Myint (1994) indicated that the weed is propagated mainly by seed, stem cuttings and rooting from nodes. Plants may also arise asexually when buds grow into autonomous, adventitiously erect leafy shoots, which later become separated from each other and grow into erect shoots directly without undergoing a period of inactivity (Duke, 1985). It is this type of reproductive capability and its long persistence in cultivation that Holm et al. (1977) attributes to one of the difficulties in controlling this weed.

Commelina diffusa has proliferated as the dominant weed in banana fields throughout the Windward Islands of the Caribbean because of several factors: i) *Commelina diffusa* was once encouraged as a groundcover to minimize soil erosion (Edmunds, 1971; Simmonds, 1959) and is recommended for use as a ground cover in plantation crops (Bradshaw & Lanini, 1995); ii) growers have for decades relied extensively on the use of herbicides such as 2,4-D, paraquat and glyphosate (Feakin, 1971; Hammerton, 1981), which non-selectively removed vegetation creating disturbances within the ecosystem and causing suspected herbicide-resistant biotypes of *Commelina* species; iii) banana growers recent adoption of the Fairtrade system, which restricts the use of herbicides, causing the spread of *Commelina* species to reach an all time high in the Windward Islands. Farmers sole use of cutlass and/or rotary trimmers as the only alternative strategy have further intensified the problem by spreading plant propagules (Isaac et al., 2007a; 2007b); iv) More importantly, these islands, which are characterized by hilly landscapes in a multitude of valleys have ideal moist conditions for the proliferation of *Commelina* species; and v) Crop rotations and recommended tillage practices have not been done on these banana fields for many years which have resulted in the stabilization of *Commelina* species populations.

Generally, the presence of weed populations in banana fields is the result of ecological reactions to previous management practices, soil characteristics of the site, and the climatic and weather conditions (Froud-Williams et al., 1983; Milberg et al., 2000). In addition, cultural, chemical and mechanical weed control activities can have a strong influence on weed populations. Knowledge of weed community structure therefore, is an important component of the development of an effective weed management programme.

There is a paucity of information on the management of weeds, including *C. diffusa*, by other means than herbicides. Banana growers in the Windward Islands urgently need to find alternatives to herbicides in order to sustain their export capacity and remain Fairtrade compliant.

This chapter gives an overview of weed management in Fairtrade banana systems in the Windward Islands of the Caribbean and addresses the myriad challenges faced by small

producers in tropical climates as they seek to move to pesticide free production (PFP) systems. It also focuses on experiments carried out over 4 years in the Windward Islands and highlights the challenges faced with managing *C. diffusa*.

2. Methods of weed control in banana plantations

No single method of control has been identified for the effective management of *C. diffusa* in plantation crops such as banana (Terry, 1996). Wilson's review on the control of these *Commelina* species was directed towards finding suitable chemicals for their control in the early stages of growth, summarizing results of trials from different parts of the world. However, he suggested that since dense mats of plant material make chemical weed control of older plants difficult, and recommended removal by hand as the only effective control at the mature stage (Wilson, 1981).

Hand removal increases cost of production, which for small farm systems operated by resource poor farmers, is hardly appropriate. Consequently, chemical control is still generally considered the only practical means of controlling large infestations of *Commelina* species (Ferrell et al., 2006; Webster et al., 2005; Webster et al., 2006). The management challenge associated with *C. diffusa* is intricately linked to its ability for regeneration after attempted management even by cultural, mechanical or chemical control. Further, current concerns worldwide about the environmental impacts of pesticide use in agriculture require the adoption of alternative cropping systems that are less pesticide based. An Integrated Management Strategy has been recommended as the best control of this weed species. Webster et al. (2006) suggested a multi-component approach, which included an effective herbicide for successful management.

The several components of such a multi-component approach include chemical, mechanical and biological strategies as well as the use of living and non-living mulches. These are now discussed.

2.1 Chemical weed control

Herbicides are not usually effective against *C. diffusa*. CABI (2002) indicated that control using herbicides is variable depending on the herbicide, accuracy of leaf coverage and environmental conditions. Spraying with a selective or non-selective herbicide may work but repeated treatments are required for preventing regrowth. Plants should not be under moisture stress when sprayed. Surfactants will improve penetration into the waxy-coated leaves. *Commelina elegans* has shown resistance to growth-regulator type herbicides (Ivens, 1967). The first resistance verified was registered in 1957, when *Commelina diffusa* biotypes were identified in the United States (Hilton, 1957; Weed Science, 2005).

Wilson (1981) indicated that many standard herbicides have relatively low activity on species of *Commelina*. These include 2,4-D, propanil, butachlor, trifluralin and pendimethalin. Treatment with 2,4-D or MCPA at the pre-emergent stage has been shown to be ineffective and although a reasonable kill of very young seedlings can be obtained with post-emergent spraying the plants develop a rapid resistance with age (Ivens, 1967). Research has shown that particular biotypes resistant to 2,4-D may be cross resistant to other Group O / 4 herbicides (Weed Science, 2005) which are mainly growth regulator herbicides.

It has been found that one biotype of *Commelina diffusa* could withstand five times the dosage of a susceptible biotype (WeedScience.org, 2005).

Resistance to residual herbicides has also been reported and relatively high doses of simazine and diuron appear to be necessary to achieve control (Ivens, 1967).

In the Windward Islands of the Caribbean, farmers started using paraquat around 1989 and noticed that it was ineffective. Gradually they started using Gramocil (paraquat + diuron) at high doses and this too was not effective and resistance in *Commelina* spp. began to show (Paddy Thomas, Personal Communication June 2002). Reglone (diquat + agral), Roundup (Glyphosate) and Talent (paraquat + asulam) have also been used with little success for the control of *C. diffusa* in the Windward Islands (Paddy Thomas, Personal Communication, April, 2002).

Studies were conducted on the efficacy of Basta (glufosinate ammonium) for weed control in coffee plantations and it was found that it did not effectively control *Commelina* spp. at a rate of 0.3-0.6 kg a.i. / ha. However, Paracol (paraquat + diuron) and Gardoprim (terbuthylazine) suppressed this perennial weed better (Oppong et al., 1998). Flex (fomesafen) and Cobra (lactofen) were shown to be two products with good potential for control of this broadleaf weed (Carmona, 1991).

2.2 Mechanical control

Mechanical weed control using tillage is not widely practised in these banana systems in the Windward Island where the terrain is undulating and sloping. Simmonds (1959) notes that tillage tends to damage the root systems of the banana plant and in general should be avoided. Terry (1996) indicated that alternatives to tillage are desirable. Kasasian and Seeyave (1968) cautioned that the most common method of weed control, slashing, will not be good enough to secure optimum yields because as Feakin (1971) pointed out, this practice may damage the banana stems and suckers if done carelessly. A real risk in small farm systems where temporary or casual labour is employed to slash weeds and payment is for work done in a day, usually much less care is taken by these workers than if the owner is doing the weed control. Feakin (1971) noted that a typical practice is to slash weeds 3-4 times a year, leaving a weed mulch on the surface to help avoid soil erosion to delay fresh weed growth. However, Terry (1996) indicated that this cannot prevent weed competition and eliminate weeds as it will encourage weeds with a prostrate habit such as *Cynodon dactylon* or *C. diffusa*.

Commelina diffusa is particularly difficult to control by tillage practices, partly because broken pieces of the stem readily establish roots and underground stems with pale, reduced leaves and flowers are often produced (Ivens, 1967). The plant is easy to rake, roll or hand pull and very small infestations can be dug out. Bagging and baking in the sun is also an effective destruction strategy. However, follow-up work is essential as any small fragment of the stem remaining will regrow and need to be removed and destroyed off - site. The use of the mechanical string trimmer has become popular in recent years because of the amount of acreage that could be covered compared to manual methods in the same time. Labour costs are reduced. However, this practice has contributed to the spread of stem cuttings in addition to damaging the banana root system as much of that system lies within the top 15 cm of the soil (SVG farmers, Personal Communication 2004).

2.3 Living and non-living mulches for weed control

Agricultural environments in banana farms in the Windward Islands are characterised by high rainfall which makes it difficult to maintain soil organic matter and to retain residue on the soil surface on steep slopes where the crop is planted. Since soil is exposed to high levels of erosion from heavy rainfall after the removal of weeds, living mulches such as cover crops can play an important role in erosion reduction. It is critically important that the areas around each banana plant should be kept free of weedy vegetation particularly in the early stages of growth and development. A potential solution to overcoming weed infestations is by intercropping the banana with a fast, low-growing shade tolerant cover crop. This can be done by intercropping with melons, *Mucuna pruriens* (negra and ceniza), tropical alfalfa, *Cajanus cajan*, mung bean (*Vigna radiata*), cowpea (*V. unguiculata*), *Crotalaria juncea*, *Indigofera endecaphylla*, *Phaseolus trinervius*, Carioca beans and sweet potato. All of these have rapid canopy coverage which can suppress the establishment of weeds.

Studies in the Windward Islands by Rao & Edmunds (1980a-d) indicated that intercropping banana with cowpeas, corn, sweet potatoes and peanut could significantly suppress weed infestations. There was an increase in banana yield when intercropped with corn compared to pure stands in trials conducted and this was probably due to adequate fertilization of both crops.

Non-living mulches also offer another viable option for weed control in banana plantations. Mulching with rice straw, cut bush, grass, water hyacinth or even the dead or senescent banana leaves, pruned suckers and old stems can significantly suppress weed growth. Non-living mulches provide benefits which include retention of soil moisture, prevention of leaching, improved soil structure, disease and pest control, improved crop quality and weed control (Grundy & Bond, 2007). Synthetic mulches such as black plastic mulch also provide good weed control as it stifles weed seedling growth and development when light penetration is blocked. Research has shown that clear plastic mulch, which is used in soil solarization, a hydrothermal process of heating moist soil, can successfully disinfect soil pests and control weeds (Benjamin & Rubin, 1982; Ragone & Wilson, 1988; Abu-Irmaileh, 1991; Elmore & Heefketh, 1983). Soil solarization by covering with plastic sheeting for 6 weeks in the warmer months will weaken the plant. After removing the plastic any regrowth can be dug out or sprayed. However, this method will not be effective in full shade. Solarization can be used alone or in combination with other chemicals or biological agents as the framework for an Integrated Pest Management (IPM) programme for soil-borne pests in open fields. Mudalagiriappa et al. (2001), recommended an integrated weed management approach using soil solarization with transparent polyethylene (TP) at 0.050 mm + *Gliricidia* (*Gliricidia sepium*) as reducing the weed count of *Commelina benghalensis* and other weeds by 77 and 74 % over the control at 90 days after sowing (DAS) and at harvest, respectively in a groundnut (*Arachis hypogaea*) -French bean (*Phaseolus vulgaris*) intercropping trial. They also found that yield and yield components were highest in the crop residue + soil solarization treatments. The highest yields of 20.8 t/ha (for groundnut) and 7.7 t/ha (for French bean) were obtained with *Pongamia* (*Pongamia pinnata*) + TP at 0.05 mm.

2.4 Biological control

There have not been many reports on biological control of *Commelina* species. *Commelina diffusa* is commonly grazed by small ruminants, pigs and cows. Holm et al. (1977) reported

that because this species is very fleshy and has high moisture content, it is difficult to use as fodder for domestic stock. However, recent research has indicated that *C. diffusa* compared well with many commonly used fodder crops and could contribute as a protein source for ruminants on smallholder farms (Lanyasunya et al., 2006). There have also been reports of foraging of this weed by chickens (*Gallus domesticus*) (Anton Bowman, Personal Communication, August, 2005). Growers in Georgia will autumn graze beef cattle in fields infested with *C. benghalensis* following agronomic crop harvest (Theodore Webster, Personal Communication, November, 2006). As a forage crop, *C. benghalensis* was rated as 102 relative forage quality (RFQ) [10.5% crude protein (CP), 61% total digestible nitrogen (TDN)], comparable to bermudagrass (*Cynodon* species) 116 RFQ (12.1% CP, 59% TDN) and perennial peanut (*Arachis glabrata* Benth.) 133 RFQ (15.1% CP, 66% TDN) (Theodore Webster, Personal Communication, November, 2006).

There are no reports of promising insect candidates for biological control of *Commelina* spp. in the USA (Standish, 2001). In Korea and China, Zhang et al. (1996), reported *Lema concinnipennis* and *Lema scutellaris* (Coleoptera: Chrysomelidae), two leaf-feeding species, on *C. benghalensis*. Another leaf-feeding species, *Noelema sexpunctata* (Coleoptera: Chrysomelidae), occurred on *C. benghalensis* in the USA (Morton & Vencl, 1998).

In Central Virginia, USA, *Pycnodees medius* (Hemiptera: Miridae) was found to cause tissue necrosis on Asiatic dayflower (Johnson, 1997). Hill & Oberholzer (2000) also recorded feeding and nymphal development (up to 3rd and 4th instar) of *Cornop aquaticum* (grasshopper) on *Commelina africana* L., and *Murdannia africana* (Vahl.). They observed that *Rhaphidopalpa africana* beetles fed more on *Commelina* species than on other weeds.

There are records of agromyzid leaf miners which may be promising sources of candidate biological control agents (Smith, 1990). *Liriomyza commelinae* (Diptera: Agromyzidae), a leaf-miner, was reported on *C. diffusa* in Jamaica (Smith, 1990). *C. diffusa* is the main food plant of *L. commelinae*, however, the leaf-miner is susceptible to predation by the formicid *Crematogaster brevispinosa* as well as competition by and exposure to the sun (high temperatures) which causes high mortality (Smith, 1990).

There are prospects for the management of alien invasive weeds in Latin America using co-evolved fungal pathogens of selected species from the genus *Commelina* (Ellison & Barreto, 2004). Pathogens recorded in the native range of *Commelina* species include: *Cercospora benghalensis* Chidd., *Cylindrosporium kilimandscharium* Allesch. (Hyphomycete), *Kordyana celebensis* Gaum, (Exobasidiales: Brachybasidiaceae), *Phakopsora tecta* H.S. Jacks and Holw (Uredinales: Phakopsoraceae), *Septoria commelinae* Canonaco (Coelomycete), *Uromyces commelinae* Cooke (Uredinales: Pucciniaceae) (Ellison & Barreto, 2004). These mycobiota would appear to be good potential agents for classical biological control (CBC) (Ellison & Barreto, 2004). Although some of the most promising (e.g. the rusts *Phakopsora tecta* and *Uromyces commelinae*) are already present in the New World, they are restricted to certain regions and could be redistributed (Ellison & Barreto, 2004). It should be noted that the release of a phytopathogen in a new area could result in disastrous effects for the ecosystem, if it is not done under very strict control. The uredinal state of a rust was found widespread on spreading dayflower in Hawaii (Gardener, 1981) sometimes causing death of parts above ground. Studies aimed at identifying mycoherbicidal biocontrol agents have been conducted in Brazil on three endemic pathogens of tropical spiderwort which were: a bacterium (*Erwinia* sp.) and two fungi (*Corynespora cassicola* and *Cercospora* sp.) (Lustosa & Barreto, 2001).

The use of biological control measures for weed control and more specifically for *C. diffusa* in banana has been largely unexplored in the Caribbean.

3. Alternative strategies for weed control

Alternative weed management strategies were compared in established banana fields under irrigated and non-irrigated regimes in the rainy and dry season, 2003 to 2004. The performance of these weed management strategies were compared to a reference standard system using herbicides. The treatments consisted of:

- Two herbicide treatments: (i) glufosinate-ammonium and (ii) fomesafen which were applied at early post-emergence (at the weed 3-5 leaf stage). These herbicides were applied with a backpack sprayer which delivered 269 L ha⁻¹ at kPa pressure using a fan-nozzle (TJ-8002).
- Three non-living mulch treatments: (i) banana mulch (traditional practice) applied at a depth of 5-6 cm using fully green and senescing leaves, (ii) coffee hulls applied at a depth of 3-5 cm and (iii) clear plastic mulch using high - density, transparent polyethylene tarp at 0.5 mils (50 gauge) thick for a 6-week period.
- Three live mulch treatments: (i) *Arachis pintoi* Krapov & W.C. Greg. (wild peanuts) planted by seed and stem cuttings drilled into the soil in rows 16 cm apart with 5 seeds per hole; (ii) *Mucuna pruriens* (L) DC (velvet beans) drilled into the soil in rows 30 cm apart with 3 seeds per hole; (iii) *Desmodium heterocarpon* var *ovalifolium* (L) DC (CIAT 13651) broadcast at a rate of 5 kg/ha.
- Two organic treatments: (i) Corn gluten meal, a pre - emergent weed blocker and a slow release fertiliser (9-1-0), which controls emerging weeds and provides nutrients to the crop, applied at a rate of 10 kg/ha and (ii) Concentrated vinegar and acetic acid, a post-emergent contact herbicide, sprayed directly to weeds at the 3-5 leaf stage.
- Two control treatments: (i) Hand weeded control which was hand weeded once every 4 weeks and (ii) an unweeded control which was left unweeded from week 1 to week 16. The experimental design was a randomised complete block design with two replicates at each site. Treatments were arranged under banana planted 4.5 m x 4.5 m.

All treatments reduced *Commelina diffusa* and other weeds compared to the unweeded control (UWC) up to 49 days after treatment (DAT). At 21 DAT, the herbicide and non-living mulch treatments were as effective at suppressing weed growth as the hand weeded control (HWC) and at 35 and 49 DAT were actually more effective. Of the other treatments, only the *D. heterocarpon* (DH) live mulch gave such good weed control, being similar to the HWC at 35 and 49 DAT, although not quite as effective as the non-living mulches or fomesafen. All three non-living mulches gave excellent suppression of weed growth for 49 DAT, even better than the HWC by 35 DAT. The weed control efficiency (WCE) of the two dead mulches, banana mulch and coffee hulls, at 49 DAT was around 95 %.

Of the 3 cover crop treatments, *D. heterocarpon* suppressed the highest number of weeds at all 3 dates after application. The two organic treatments which included the vinegar and acetic acid and corn gluten meal were not as effective as other treatments in suppressing weed populations. Weed density under the corn gluten meal treatment increased from 53 to 62 % from 35 to 49 DAT, respectively, which was similar to the increase in the unweeded

control from 55 to 66 % in the same DAT. Weed control scores at 63 DAT also showed similar trends to the weed density at 49 DAT (Figure 1).

The two dead mulches (banana mulch, 96 %, and coffee hulls, 95 %) showed excellent weed control. Weed control efficiency was also high (from 87 % to 72 %) in *D. heterocarpon*, followed by fomesafen, glufosinate-ammonium and clear plastic mulch. The hand-weeded treatment at 67 % was similar to the latter two treatments. *Arachis pinto*i, concentrated vinegar, *M. pruriens* and corn gluten meal were less efficient (52 % to 43 %) in controlling weeds, but still better than the unweeded control at 27 %.

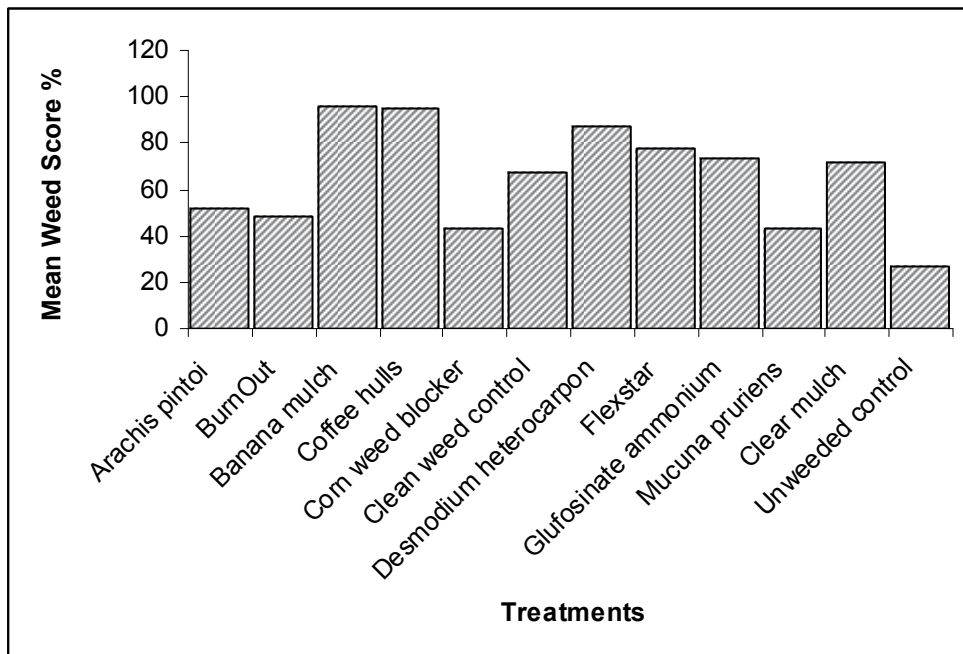


Fig. 1. Effect of treatments on mean weed control efficiency (WCE) at 63 DAT.

The non-living mulches, banana mulch and coffee hulls, as well as the clear plastic mulch, were the best weed management alternatives as they gave the highest levels of control. Coffee hulls significantly suppressed weed seed germination and seedling growth. This may have been due to the exclusion of light or from exudates released from the decaying plant material. It is possible that WCE of the decomposing coffee hulls is not only due to the amount of material applied on the soil surface but also to exudates released from the decaying material. Relating this to the caffeine found in coffee, Rizvi et. al. (1980) described caffeine as a natural herbicide selectively inhibiting germinating seed of *Amaranthus spinosus* L. After the clear plastic mulch was removed at 42 DAT, the stressed and etiolated weeds, which had germinated under the plastic recovered, causing an increase in weed density. Marengo & Lustosa (2000) reported an increase in seed germination of *C. benghalensis* L. when clear plastic was removed in a trial using clear plastic mulch for soil solarization in Brazil. The cost of clear plastic will be an issue for small resource poor farmers. In addition,

to maintain the 5-6 cm thickness of the banana mulch, leaves had to be frequently replaced. The practicality of this is a concern on a commercial scale, as there are unlikely to be sufficient leaves available, as discussed by Cintra & Borges (1988) in studies conducted in Brazil. The availability of sufficient quantities of coffee hulls would be a similar concern.

Of the living mulches however, *D. heterocarpum* gave better coverage and was therefore more competitive than *Arachis pinto*i and *Mucuna pruriens*. The rapid establishment of *D. heterocarpum* quickly suppressed emerging weeds which is contrary to findings by Bradshaw & Lanini (1995) who noted that this cover crop required more than 2 months for establishment and control of weeds in Nicaraguan coffee. *Arachis pinto*i fell prey to predatory *Rattus novegicus* (rats) and *Gallus domesticus* (domestic chickens). Weed density in this treatment was high for most of the monitoring period; it was not until 12 weeks that any significant weed suppression occurred. Although *M. pruriens* vigorously established itself, weed density was also high for this treatment as most of its growth was in climbing the banana plant as reported by Buckles et al. (1998). The vines had to be removed often from banana and their effectiveness in suppressing weeds was low. Additionally, the vines began senescing after producing pods allowing further weed establishment. Buckles et al. (1998) noted that for effective weed control with *M. pruriens* fields should be planted over a 3-year period as exudates from senescing leaves have a herbicidal effect.

As a follow-up, a Participatory Approach which involved farmers in the design, conduct and evaluation of three potential cover crops (*Mucuna pruriens*, *Desmodium heterocarpum* var *ovalifolium* and *Arachis pinto*i) was conducted (Ganpat et al., 2009). Thirty six (36) participating farmers applied treatments using the paired-treatment design with three replicates. Weed data were collected weekly and farmers subjected data to the Overlap test (Ooi et al., 1999) to evaluate differences in treatments, which revealed that *Desmodium heterocarpum* was the most effective of the cover crops. Further analysis (F-test) confirmed that the most promising cover crop was *D. heterocarpum* as weed levels were significantly lower under this treatment ($p < 0.05$). Farmers and Researchers agreed that *D. heterocarpum* var *ovalifolium* could significantly reduce weed levels and provide a sustainable non-chemical approach to improved weed management of *C. diffusa* in banana fields.

4. Conclusions

The *Commelina* species are very persistent, noxious weeds which must be managed using an integrated approach. Weed management strategies that are narrowly focused will ultimately cause shifts in weed populations to species that no longer respond to the strategy resulting in adapted species, tolerant species or herbicide resistant biotypes as cautioned by Owen (2000). *Commelina* species in cropping systems falls into this category and this has been the case with *C. diffusa* in banana systems in the Windward Islands of the Caribbean. The integrated approach should utilize alternative strategies such as cover crops in addition to cultural and mechanical control and with a minimum and judicious use of herbicides. Such combinations should provide significant management levels of *Commelina* species for both conventional as well as organic growers using a PFP approach.

The integrated approach must begin very early as once an infestation is really entrenched it presents several difficulties because of the pernicious growth habit of this weed. As Webster et al. (2006) suggested for the successful management of *C. benghalensis*, a multi-component

approach including an effective herbicide that provides soil residual activity is required. Studies on the management of *Commelina* species have focused primarily on effective herbicides and herbicide mixtures for their control despite hard evidence of the development of herbicide resistant biotypes. Additionally the adoption within recent years of genetically modified (GM) crops particularly herbicide – resistant crops presents serious issues involving their negative ecological impact as already there are reports of *Commelina* species prominence in some agroecosystems due to simple and significant selection pressure brought to bear by these herbicide – resistant crops and the concomitant use of the herbicide (Owen & Zelaya, 2004).

Perhaps the best way to control *Commelina* species for small holders in developing countries would be by implementing an integrated approach that embraces a variety of options which should be attuned to the individual farmer's agronomic and socio – economic conditions (soil type, climate, costs, local practices and preferences). The extent of his financial resources and whether he is a part-time or full-time farmer and is involved in mixed farming systems also needs to be considered. For example in banana growing areas in the Windward Islands, the growth of the weed can be suppressed by a single application of a herbicide or weed whacking very early before extensive spread of the weed followed by planting a competitive cover crop like *Desmodium heterocarpon* that would not only prevent re-invasion but improve soil fertility.

In the Windward Islands more than 70 % of the banana farmers still adhere to their traditional practices of chemical use. Adoption of Fairtrade practices is growing, yet many farmers still remain unconvinced of the benefits of integrated crop management to reduce or eliminate the use of certain pesticides. In the absence of herbicides, infestations of weeds such as the most prevalent, *Commelina* spp. have only served to dissuade farmers from adopting a more organic approach. Although the social and economic advantages have been elucidated by Fairtrade based on acceptance of produce into international markets with conformity to certain standards, further research into alternative agricultural practices is needed. Studies on the biology, ecology and dynamics of *Commelina diffusa* and strategies for their management in banana fields are therefore justified as they will provide valuable information for incorporation into an integrated weed management system for banana growers. Moreover, modern communication strategies have to be used to extend these findings if farmers are to be fully convinced. Appropriate research and Extension hold a key to meeting the challenges associated with weed management in Fairtrade banana systems in the Windward Islands of the Caribbean.

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6. References

- Abu-Irmaileh, B.E. (1991). Weed control in vegetables by soil solarization, In: *FAO Plant Production and Protection Paper*, pp. 155-165, ISBN 92-5-103057-X, Amman, Jordan

- Benjamin, A., & Rubin, B. (1982). Soil solarization as a means of weed control. *Phytoparasitica*, Vol.10, pp. 4,280, ISSN 1876-7184
- Bourdôt, G.W., Hurrell, G.A. & Saville, D.J. (1998). Weed flora of cereal crops in Canterbury, New Zealand. *New Zealand Journal of Crop and Horticultural Science*, Vol.26, pp. 233-247, ISSN 1175-8783
- Bradshaw, L. & Lanini, W.T. (1995). Use of perennial cover crops to suppress weeds in Nicaraguan coffee orchard. *International Journal of Pest Management*, Vol.41 No.4, pp. 185-194, ISSN 1366-5863
- Buckles, D., Triomphe, B. & Sain, G. (1998). Cover crops in hillside agriculture: Farmer Innovation with Mucuna. Mexico City, Mexico: International Development Research Centre (IDRC), Ottawa, Canada and International Maize and Wheat Improvement Centre (CIMMYT), ISBN 0-88936-841-4 p. 218
- CAB International (CABI). (2002). *Crop Protection Compendium, 2006 edition*. Wallingford, UK: CABI, Accessed: March 14, 2006, Available from
<<http://www.cabi.org/compendia/cpc/index.htm>>
- Carmona, A. (1991). Flex (fomafafen) and cobra (lactofen): Two products with potential for broadleaf weed control for leguminous covers in oil palm plantations. *ASD Oil Palm Papers*, Vol.4, pp. 1-5, ISSN 1019-1100
- Cintra, F.L.D., & Borges, A.L. (1988). Use of a legume and a mulch in banana production systems. *Fruits* Vol.43, No.4, pp. 211-217, ISSN 0248-1294
- Duke, S.O. (1985). *Weed Physiology Vol. 1: Reproduction and Ecophysiology*, CRC Press, Boca Raton, Florida, ISBN 10: 0-8493-6313-6; ISBN 13: 978-0849363139
- Edmunds, J.E. (1971). Association of *Rotylenchulus reniformis* with 'Robusta' banana and *Commelina* sp. Roots in the Windward Island. *Tropical Agriculture*, Vol.48, No.1, pp. 55-61, ISSN 0041-3216
- Ellison, C.A., & Barreto, R.W. (2004). Prospects for the management of invasive alien weeds using co-evolved fungal pathogens: a Latin American Perspective. *Biological Invasions*, Vol.6, No.1, pp. 23-45, ISSN 1573-1464
- Elmore, C., & Heefketh, K.A. (1983). Soil solarization an integrated approach to weed control, *Proceedings of the 35th Annual California Weed Conference*, pp. 143, Davis, California
- Feakin, S.D. (1971). *Pest Control in Bananas*. PANS Manual No.1. Centre for Overseas Pest Research. 2d ed. College House, UK, PANS
- Ferrell, J.A., MacDonald, G.E. & Brecke, B.J. (2006). *Tropical spiderwort (Commelina benghalensis L.), identification and control*. University of Florida Institue of Food and Agricultural Science SS-AGR-223, Accessed October 22, 2006, Available from:<<http://edis.ifas.ufl.edu/AG230.htm>>
- Fournet, J., & Hammerton, J.L. (1991). *Weeds of the Lesser Antilles*. Paris France: Institute of National Research Agronomy (INRA), ISBN 2-7380-02090-9; ISSN 1150-3912
- Froud-Williams, R.J., Drennen, D.S.H. & Chancellor, R.J. (1983). Influence of cultivation regime on weed floras of arable cropping systems, *Journal of Applied Ecology*, Vol.20, pp. 187-197, ISSN 1365-2664
- Ganpat, W.G., Isaac, W.P., Brathwaite, R.A.I., & Bekele, I. (2009). Farmers' Attitude towards a Participatory Research and Development method used to evaluate weed management strategies in Bananas. *Journal of Agricultural Education and Extension*, Vol.15, No.3, pp. 235-244, ISSN 1389-224X

- Gardener, D. E. (1981). Rust on *Commelina diffusa* in Hawaii. *Plant Diseases*, Vol.65, Vol.8, pp. 690-691 ISSN 0191-2917
- Grundy, A.C. & Bond, B. (2007). Use of Non-living Mulches for Weed Control, In: *Non-Chemical Weed Management: Principles, Concepts and Technology*, Upadhyaya, M.K. and Blackshaw, R.E. (eds.), pp. 135-154, CAB International, ISBN 978-1-84593-290-9
- Hammerton J.L. (1981). Weed Problems and Weed Control in the Commonwealth Caribbean, *Tropical Pest Management*, Vol. 27, No.3, pp. 379-387, ISSN 0143-6147
- Hill, M.P., & Oberholzer, I.G. (2000). Host specificity of grasshopper, *Cornops aquaticum*, a natural enemy of water hyacinth, *Proceedings of the X International Symposium on Biological Control of Weeds*, PP. 349-356 4-14 July, 1999, N.R. Spencer (ed.), Montana State University, Bozeman, Montana, USA, July 4-14, 1999
- Hilton, H.W. (1957). *Herbicide Tolerant Strains of Weeds*, Hawaiian Sugar Planters Association Annual Report. Honolulu, Hawaii, pp. 69-72
- Holm, L.G., Pluknett, D.L., Pancho, J.V. & Herberger, J.P. (1977). *The World's Worst Weeds: Distribution and Biology*, The University Press, Honolulu, Hawaii
- Isaac, W.A.P., Brathwaite, R.A.I., Cohen, J.E. & Bekele, I. (2007a). Effects of alternative weed management strategies on *Commelina diffusa* Burm. Infestations in Fairtrade banana (*Musa* spp.) in St. Vincent and the Grenadines, *Crop Protection*, Vol.26, pp.1219-1225, ISSN 0261-2194
- Isaac, W.A.P., Brathwaite, R.A.I., Ganpat, W.G. and Bekele, I. (2007b). The impact of selected cover crops on soil fertility, weed and nematode suppression through Farmer Participatory Research by FairTrade banana growers in St. Vincent and the Grenadines, *World Journal of Agricultural Sciences* Vol.3, No.1, pp.1-9, ISSN 1817-3047
- Ivens, G.W. (1967). *East African Weeds and Their Control*, Oxford University Press, ISBN 0196440173, 9780196440170, Nairobi, Kenya
- Johnson, S.R. (1997). *Commelina communis* (Commelinaceae) as host to *Pycnoderes medius* Knight (Hemiptera: Miridae) in central Virginia, USA, *The Entomologist* Vol.116, pp. 205-206, ISSN 0013-8878
- Kasasian, L., & Seeyave, J. (1968). Chemical weed control in bananas – a summary of eight years' experiments in the West Indies, *Proceedings of the 9th British Weed Control Conference*, pp. 768-773, ISBN 10: 0901436119; ISBN 13: 9780901436115, Brighton, England, November 18-21, 1968
- Lanyasunya, T.P., Wang Rong, H., Abdulrazak, S.A. & Mukisira, E.A. (2006). The potential of the weed, *Commelina diffusa* L., as a fodder crop for ruminants, *South African Journal of Animal Science*, Vol.36, No.1, pp. 28-32, ISSN 0375-1589
- Lustosa, D. C., & Barreto, R.W. (2001). Primeiro relato de *Cercospora commelinicola* Chupp em *Commelina benghalensis* L. no Brasil, *34 Congresso Brasileiro de Fitopatologia, 2001, São Pedro. Fitopatologia Brasileira*, Vol.26, pp.364-364, ISSN 0100-4158
- Marengo, R.A., & Castro-Lustosa, D. (2000). Soil solarization for weed control in carrot. *Pesquisa Agropecuaria Brasília*, Vol.35, No.10, pp. 2025-2032, ISSN 0100-203X
- Milberg, P., Anderson, L. & Thompson, K. (2000). Large-seeded species are less dependent on light for germination than small seeded ones, *Seed Science Research*, Vol.10, pp. 99-104, ISSN 0960-2585

- Moberg, M. (2005). Fair Trade and Eastern Caribbean Banana Farmers: Rhetoric and Reality in the Anti-Globalization Movement. *Human Organization*, Vol.64, pp.4-15, ISSN 0018-7259
- Moberg, M. (2009). *Slipping Away: Banana Politics and Fair Trade in the Eastern Caribbean*, Berghen Books, ISBN 1845451457, New York, USA
- Morton, T.C., & Vencel, F.V. (1998). Larval beetles form a defence from recycled host-plant chemicals discharged as faecal waste, *Journal of Chemical Ecology*, Vol.24, pp.765-785, ISSN 0098-0331
- Mudalagiriappa, Nanjappa, H.V. & Ramachandrappa, B.K. (2001). Integrated weed management in groundnut-French bean cropping system. *Karnataka Journal of Agricultural Sciences*, Vol. 14, No.2, pp. 286-289, ISSN 0972-1061
- Myint, A. 1994. *Common weeds of Guyana*, National Agricultural Research Institute, ISBN 976-8099-01-1
- Ooi, P.A.C., van den Berg, H., Hakin, A.L., Ariawan, H. & Cahyana, W. (1999). Farmer Field Research. Jakarta: The FAO Programme for Community IPM in Asia. 8
- Oppong, F.K., Osei-Bonsu, K., Amoah, F.M. & Opoku-Ameyaw, K. (1998). Evaluation of Basta (gluphosinate ammonium) for weed control in Coffee, *Journal of the Ghana Science Association* Vol.1, No.1, pp.60-68, ISSN 0855-3823
- Owen, M.D.K. (2000). The value of alternative strategies for weed management, (abstract) *Proceedings of the III international Weed Science Congress, Foz do Iguassu, Brazil*, pp.50 International Weed Science Society, Oregon, June 6-11, 2000
- Owen, M.D.K., & Zelaya, I.A. (2004). Herbicide – resistant crops and weed resistance to herbicides, *Paper presented at the Symposium 'Herbicide – resistant crops from biotechnology: current and future status' held by the Agrochemicals Division of the American Chemical Society at the 227th National Meeting, Anaheim, California, March 29 -30, 2004*
- Queneherve, P., Chabrier, C., Auwerkerken, A., Topart, P., Martiny, B. & Martie-Luce, S. (2006). Status of weeds as reservoirs of plant parasitic nematodes in banana fields in Martinique, *Crop Protection* Vol.25, pp. 860-867, 0261-2194
- Ragone, D., & Wilson, J.E. (1988). Control of weeds, nematodes and soil born pathogens by soil solarization, The University of Hawaii, Honolulu, *Alafua Agricultural Bulletin* Vol.13, pp. 13-20, ISSN 1015-8499
- Rao, M., & Edmunds, J.E. (1980a). Intercropping bananas with corn. *Windward Islands Banana Growers Association (WINBAN) Research and Development Division Advisory Bulletin* 14
- Rao, M., & Edmunds, J.E. (1980b). Intercropping bananas with cowpeas. *Windward Islands Banana Growers Association (WINBAN) Research and Development Division Advisory Bulletin* 15
- Rao, M., & Edmunds, J.E. (1980c). Intercropping bananas with peanuts. *Windward Islands Banana Growers Association (WINBAN) Research and Development Division Advisory Bulletin* 16
- Rao, M., & Edmunds, J.E. (1980d). Intercropping bananas with sweet potatoes. *Windward Islands Banana Growers Association (WINBAN) Research and Development Division Advisory Bulletin* 17
- Robinson, A.F., Inserra, R.N., Caswell-Chen, E.P., Vovlas, N. & Troccoli, A. (1997). *Rotylenchulus* species: identification, distribution, host ranges and crop plant resistance, *Nematopica*, Vol.15, pp.165 – 170, ISSN 0099-5444

- Rodriguez, K. (2008). Fairtrade, Dominica's shining light, Accessed January 16, 2011, Available from
 <http://dominica.tamu.edu/student%20projects/Dominica%20Projects%20pdf%20copy/Rodriguez_Kristen.pdf>
- Rizvi, S.J.H., Jaiswal, V., Muierji, D. & Mathur, S.N. (1980). 1,3,7- trimethylxanthine--a new natural herbicide: its mode of action, *Plant Physiology*, Vol.65, No.6, pp. 99, ISSN 0032-0889
- Simmonds, N.W. (1959). *Bananas*, Longmans, ISBN 0 582 06355 6, London, U.K.
- Smith, D. (1990). Impact of natural enemies on the leaf mining fly *Liriomyza commelinace* (abstract), *Proceedings of the Interamerican Society for Tropical Horticulture*, 1990, Vol. 34, pp. 101-104, ISSN 0254-2528
- Standish, R.J. (2001). *Prospects for biological control of Tradescantia fluminensis Vell. (Commelinaceae)*. New Zealand Department of Conservation: Doc Science Internal Series 9, ISSN 1175-6519; ISBN 0-478-22156-8
- Terry, P.J. (1996). Weed Management in Bananas and Plantains. *Weed Management for Developing Countries*, edited by R. Labrada, J.C. Caseley and C. Parker, pp. 311-315. FAO Plant Production and Protection Paper 120, ISBN 92-5-105019-8, ISSN 0259-2517
- Waite, B.H., & Dunlap, V.C. (1953). Preliminary host range studies with *Fusarium oxysporum* f. *Cubense*, *Plant Disease Reporter*, Vol.37, pp. 79-80, ISSN 0032-0811
- Webster, T.M., Burton, M.G., Culpepper, A.S., York, A.C. & Prostko, E.P. (2005). Tropical Spiderwort (*Commelina benghalensis*): A tropical invader threatens agroecosystems of the Southern United States, *Weed Technology*, Vol. 19, No. 3, pp. 501-508, ISSN 1939-7291
- Webster, T.M., Burton, M.G., Culpepper, A.S., Flanders, J.T., Grey, T.L. & York, A.C. (2006). Tropical Spiderwort (*Commelina benghalensis* L.) Control and Emergence Patterns in Preemergence Herbicide Systems, *Journal of Cotton Science*, Vol. 10, pp. 68 -75, ISSN 1524-3303
- WeedScience.org, (2005). *Group O/4 resistant spreading dayflower (Commelina diffusa)*, USA: Hawaii, Accessed: February 15, 2006, Available from:
 <<http://www.weedscience.org/Case/Case.asp?ResistID=394.htm>>
- Wilson, A.K. (1981). Commelinaceae - a review of the distribution, biology and control of the important weeds belonging to this family, *Tropical Pest Management*, Vol. 27, No. 3, pp. 405-418, ISSN 0143-6147
- Zhang, XiuRong, Ma Shu, Ying, Dai BingLi, Zhang, X.R., Ma, S.Y. & Dai, B.L. (1996). Monophagy of *Lema scutellaris* on *Commelina communis*, *Acta Entomologica Sinica*, Vol. 39, pp. 281-285, ISSN 0454-6296