Chapter 21

Managing Commelina Species: Prospects and Limitations

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1. Introduction

Commelina species, notably *C. communis* L, *C. diffusa* Burm, *C. elegans* Kunth. and *C. benghalensis* L. as well as their biotypes, are perennial herbs of Neotropical origin which now have a pantropical distribution. Members of this family (Commelindeae: Commelinaceae) are common throughout the Caribbean, North and Latin America, Africa, Asia, the Middle East and parts of Oceania [18, 27, 28, 63, 64]. There are 500 - 600 species reported in the family Commelinaceae [50]. Recent data indicates that the Commelinaceae family contains 23 genera and at least 225 species native to or naturalized in the New World and 23 genera and about 200 species in the Neotropics [41] and also website reports of 50 genera and 700 species [16, 31]. There are 170 species of Commelina in the warmer regions of the world and 50 species of Murdannia occurring in the tropics and warm temperate regions worldwide with Tropical Asia having the greatest diversity [17].

Wilson [84] presented a comprehensive review on Commelina species and its management with emphasis on chemical weed control in 1981. Since Wilson's review much has been written about the weedy members of this family, notably Commelina species [84]. Indeed, the CAB ABSTRACTS Database contains well over 1200 references on Commelinaceae from 1981 to the present. *Commelina benghalensis* in particular has been the most reported species with several reports of research conducted on its control in southern states of the United States of America (USA) including Alabama, Florida, Georgia, Louisiana and North Carolina [18, 74, 75, 78-81]. Many of these studies should be consulted for basic details of the biology and ecology. The National American Plant Protection Organization (NAPPO) offers a comprehensive global distribution list of this weed species [47].

The current review is an attempt to provide an update on the status of the weedy Commelina species in agricultural production systems. This review is based on world literature over the last 45 years and considers major Commelina species found in the tropics and warm temperate regions in relation to their status, distribution, biology and spread and management.

2. Weed Status

Commelina benghalensis (Tropical spiderwort or Benghal dayflower) has become increasingly important, gaining pest significance in agronomic production systems in the southeastern coastal plain of the United States of America (USA) in crops such as cotton (*Gossypium* spp.) and peanut (*Arachis hypogea*) [70, 71] and in the North China Plain in crops such as potato (*Solanum tuberosum*) and summer corn (*Zea mays*) [37, 71, 72, Li et al. unpublished data 2007). It is commonly associated with wet locations. This weed was in fact listed as a Federal Noxious weed in Florida and Georgia where it is the most troublesome weed in cotton and a pest in peanut, corn (*Zea mays*), soybean (*Glycine max*), nursery stock and orchards [81]. This species which was first observed in USA in 1928 [18] gained noxious weed status in 1983 [81]. Between 1998 to 2001 and then to 2004 this weed which was ranked among the top 39 most troublesome weeds across all crops by Georgia extension agents (in 1998) moved to the 9th most troublesome (in 2001) to the most troublesome cotton weed in Georgia (in 2003) [77] and Florida (2004) and the 3rd most troublesome weed of peanut in several south Georgia counties [54, 80]. In Georgia alone the weed is estimated to infest more than 80,000 ha [80-82] with a confirmed presence in 29 Georgia counties [54]. It is also observed throughout the panhandle and central Florida and listed by the United States Department of Agriculture (USDA) as appearing in more than 12 Florida counties [82].

Commelina communis has become one of the three most troublesome weeds in soybean fields in the Northeast China, and has caused significant reduction in production and quality of soybean [42]. Commelina species, namely *C. diffusa* and *elegans,* were reported as the 3rd most troublesome weed in the Caribbean where they are a serious problem of banana and other crops in the Windward Islands of Dominica, Grenada, St. Lucia and St. Vincent and the Grenadines [24]. Presently, Commelina species, commonly called watergrass, caner grass, pond grass, spiderwort, spreading dayflower, wandering Jew or French weed in these Islands, are by far the most serious in these countries. *Commelina diffusa* was once encouraged as a ground cover to reduce soil erosion [13] and has been identified as the host of the reniformis nematode *Rotylenchulus reniformis* [57], the banana lesion nematode *Pratylenchus goodeyi* [87] and recent data have confirmed its association with the burrowing nematode *Radopholus similis* [55]. These nematodes all contribute to significant reductions in banana production particularly *R. similis*, which may reduce banana production by more than 50 % and decrease the production duration of banana fields [55].

3. Biology and spread

Commelina species are C-3, monocotyledonous plants and therefore have a high efficiency of CO_2 uptake at low irradiance [34]; therefore, they tolerate shade very well and could become persistent. They are both annuals and perennials and therefore dominate the fallow vegetation because they are most competitive due to their growth and regeneration characteristics [72].

The plant is propagated mainly by seeds, stem cuttings and rooting from nodes and pieces [19, 46, 74, 75]. Plants may arise asexually when buds grow into autonomous, adventitiously erect leafy shoots, which later become separated from each other [12]. Occasionally the buds may sprout and grow into erect shoots directly without undergoing a period of inactivity [12]. The plant produces roots readily at the nodes of the creeping stems and will do so especially when broken or cut [27, 28]. Farmers in the Windward Islands report that Commelina species may be intensified when cut with a weed whacker as stolons spread more extensively.

The stems of Commelina species have a high moisture content and once it is well rooted the plant can survive for long periods without moisture [84]. This fact is evident in young banana plantations in the Windward Islands where stems become dried and shrivelled due to the direct contact with solar radiation particularly in the dry season. However, at the onset of rains and when the canopy of the banana closes, stems regain moisture, re-establish and rapidly begin to spread by runners which root at the nodes.

The mature aerial seeds of *C. benghalensis* are produced within 14 to 22 days after flower opening [74] and in some instances, e.g., the rice paddies of the Philippines, can produce in excess of 1,600 seeds/plant [53] or even 12,000 seeds/m^2 [74], whereas seeds grown from underground seeds are capable of producing 8,000 seeds/m^2 [74]. In cultivated areas the plant is spread by irrigation water and waterways. Animals may also spread the seeds.

Commelina species has gained noxious weed status in the Windward Islands because of several factors. Firstly, the fact that the weed was encouraged as a groundcover was compounded by inappropriate agricultural practices, notably irrational herbicide use which farmers have relied on for decades. The non-judicious use of herbicides has created imbalances and disturbances within the ecosystem in these Islands causing resistant biotypes. Secondly, the move within recent years by banana growers to adopt a Fairtrade system which uses no herbicides has catapulted the spread to an all-time high in the Windward Islands. Farmers have been forced to rely on the use of the cutlass or weed whacker as the only alternative strategies which have further intensified the problem by spreading plant propagules [30]. Most importantly these Islands which are characterized by hilly landscapes have ideal moist conditions for the proliferation of Commelina species. Finally, many of the banana plantations have been farmed for several years with virtually no crop rotations or tillage practices and this has further contributed to the stabilization of Commelina species populations.

In the USA, its sudden emergence as a noxious weed is attributed to crop production practices which are well suited for prolific weed growth such as minimum – tillage production (which is undertaken in conjunction with the use of glyphosate – resistant crops) and extreme tolerance to glyphosate [79-81]. The weed appears to be well-suited for high input agricultural production where high levels of fertilizers, irrigation and herbicides are used [79, 80]. The spread of *C. benghalensis* is attributed, in part, to the adoption of weed management programmes that lack the use of residual herbicides along with the adoption of reduced-tillage production practices [54]. Additionally, after introduction, invasive species often go long periods of time (lag period) during which the pest increases in distribution or density without being noticed as an obvious pest [54].

4. Economic impact in crop production

Three species of the Commelinaceae family are considered to be major problem weeds in cropping systems where they have become persistent and difficult to manage [27]. *Commelina benghalensis* is the most important of the three and it occurs as a weed in 25 different crops in 28 countries [27]. This weed has gained high importance in peanut and cotton in the southern United States [78, 79]. *Commelina diffusa* occurs as a weed in 17 crops in 26 countries and *Murdannia nudiflora* occurs as a weed in 16 crops in 23 countries [27].

Commelina diffusa thrives on cultivated soils of cocoa (*Theobroma cacao*), citrus, root crops such as dasheen (*Colocasia esculenta*) that tolerate water, and it is also a major weed in sugarcane (*Saccharum officinarum*), upland rice (*Oryza sativa*), soybean (*Glycine max*), cassava (*Manihot esculenta*), corn (*Zea mays*), banana and plantain (*Musa* spp.) [27]. *Commelina benghalensis* has been reported as a principal weed in upland rice in India and the Philippines, tea (*Camellia sinensis*) in India, coffee (*Coffee arabica*) in Tanzania and Kenya, soybean in the Philippines and cotton and maize in Kenya [27, 47]. This species is common in rice in Sri Lanka, sugarcane in India, the Philippines and Mozambique, cassava in Taiwan and maize in Zimbabwe [9]. *Commelina benghalensis* was reported as a weed of jute (*Corchorus olitorius*), sisal (*Agave sisalana*), beans (*Phaseolus* spp.), pastures, sweet potatoes (*Ipomoea batatas*), vineyards and barley (*Hordeum vulgare*) and other cereals in many countries [7].

Because of Commelina's vigorous growth habit, which allows the plant to form dense pure stands, they may compete easily with low growing crops such as vegetables, pulses and cereals as well as pasture grasses and legumes by smothering them [27]. Because Commelina species is a broadleaved weed it is generally not considered highly competitive for nutrients however this fact is not well researched and its allelopathic potential also needs to be ascertained. Invasive species such as *C. benghalensis* had higher plant growth rate at high nutrient availability and across water availability compared to a related non – invasive, but alien, congener, *C. bracteosa* Hassk. [6]. Interestingly, severe stunting has been reported in *C. diffusa* caused by high nitrogen [59] and altered growth and physiological characteristics for different *C. erecta* clones with increased phosphorus supply [71]. Results from systematic studies on the influence of *C. benghalensis* populations on crop yield are limited [54]. Increased reduction in above-ground and root dry matter as well as a 100% reduction in the number of leaves in lettuce (*Lactuca sativa*) plants were recorded with 1% and 3% hydro – alcoholic extracts of *C.benghalensis* suggesting its allelopathic potential [68].

Studies on the critical periods of interference in Commelina species are limited. Generally crops are affected most severely during the first 2 – 5 weeds of crop growth although mature plants can also be affected [7]. *Commelina benghalensis* in particular may affect crop growth and yield but this varies with environmental conditions [47]. Research aimed at evaluating the periods of interference of *C. benghalensis* in the initial growth of coffee seedlings reported prevention

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periods of 15 to 88 and 22 to 38 days after coffee seedling sowing under winter and summer conditions, respectively [11]. In cotton it was found that yield loss from *C. benghalensis* can be minimized by planting cotton early in the growing season, prior to substantial emergence of the weed [81].

5. Pests and diseases associated with commelina species

Commelina diffusa is an alternate host plant for the nematodes *Rotylenchulus reniformis*, *Helicotylenchus* spp., *Pratylenchus* spp., *Meloidogyne* sp. and *Radopholus similis* in banana [13, 27, 29, 44, 55, 57, 60, 87] and coffee [58]. The plant is also a collateral host of *Helicotylenchus dihystera* infecting guava fields [35]. *Commelina benghalensis* has also been identified as an alternate host of the southern root-knot nematode (*Meloidogyne incognita*) [55]. The southern root-knot nematode is widely distributed across cotton regions in Georgia [54]. Snails and slugs feed on *C. diffusa* plants and these affect crops such as pineapple and soybean [84].

Five viruses have been found naturally infecting species of Commelinaceae. Aneilema a potyvirus has also been found infecting 15 species of the Commelinaceae family including 4 of Commelina. There have been reports of *Commelina diffusa* potyvirus, which causes a mosaic in *Commelina diffusa* and *C. benghalensis* [2]. The virus is transmitted by two insect vectors, *Aphis gossypi* and *Myzus persicae*; Aphididae. It is transmitted in a non – persistent manner. The virus is transmitted by mechanical inoculation and not by grafting or contact between plants or by seeds. The isolate for cucumber mosaic virus (CMV) is originally from *Commelina elegans* but it is transmitted by Aphis gossypi, and not *Myzus persicae. Commelina diffusa* is susceptible to Commelina X potexvirus, Commelina yellow mottle badnavirus, Spring beauty latent bromovirus, Tradescantia – *Zebrina potyvirus*, spotted wilt and Cherry leaf roll nepovirus [2]. However, *Commelina elegans* is insusceptible to Tradescantia – *Zebrina potyvirus*. U2- tobacco mosaic virus has also been found infecting *C. communis* and *Z. pendula*. Brome mosaic virus isolates have been identified [70] infecting *C. diffusa* and *C. communis* in Fayetteveille, Arkansas, USA.

6. Methods of management in selected crops

Wilson's review on the control of these weed species was directed towards finding suitable chemicals for their control in the early stages of growth, summarizing results of trials from difference parts of the world [84]. However, he suggested that since dense mats of plant material make chemical weed control of older plants difficult, removal by hand is the only effective control at that stage [84].

Currently, chemical control is still generally considered the only practical means of controlling large infestations of Commelina species [78-82]. However, no single method of control seems to be effective for control of Commelina spp. in any crop. The difficulty lies in its ability for regeneration after attempted management even by cultural, mechanical or chemical control.

An Integrated Management Strategy (IWM) is therefore suggested for the best control of this weed species. A multi-component approach including an effective herbicide for successful management has been suggested [80-82].

7. Chemical management

Herbicides are not usually very effective against most Commelina species. The first verified resistance was registered in 1957, when *C. diffusa* biotypes were identified in the United States [26]. *Commelina elegans* has shown resistance to growth – regulator type herbicides [32]. Control using herbicides is, however, variable depending on the herbicide, accuracy of leaf coverage and environmental conditions [7]. Spraying with a selective or non – selective herbicide may work but repeated treatments are required for regrowth. Plants should not be under moisture stress when sprayed. Surfactants will improve penetration into the waxy-coated leaves.

Many standard herbicides have relatively low activity on species of Commelina [84]. 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, the plants develop a rapid resistance with age [32]. Particular biotypes are resistant to 2,4-D and they may be cross resistant to other Group O / 4 herbicides [83]. It has been found that one biotype of *C. diffusa* could withstand five times the dosage of a susceptible species [83].

In rice, bentazone, molinate, oxyfluorfen and bifenox are herbicides with good activity [7]. Post-emergent sequential treatments of propanil followed by nitrogen or of molinate followed by KN3 controlled *C. diffusa* in rice [61]. In soybean, bentazone and metribuzin are effective [7]. In corn, combination of bromoxynil and 2,4-D butylate produced a synergistic effect in post-emergent control of 3-4 leaf stage *C. communis* [85]. In plantation crops such as banana, paraquat is not always effective but mixture with diuron is recommended [7]. Dinoseb has been found to kill seedlings as well as dalapon but paraquat is reported to be relatively ineffective [32]. Prodiamine has been reported to be effective in ornamental fern beds [62]. Extreme tolerance to glyphosate has been documented [54]. Glyphosate has been shown to be effective but additives or mixtures may be needed for good results at moderate doses [7]. However, *C. diffusa* has been reported to have larger possibilities of recovery after glyphosate application because of its larger starch reservation [71].

Resistance to residual herbicides has also been reported and relatively high doses of simazine and diuron appear to be necessary to achieve control [32]. Recent studies on use of residual herbicides have identified Dual Magnum® (s-metolachlor) (applied as a preplant incorporated, pre-emergent and post-emergent) as providing excellent residual control (>80%) of *C. benghalensis* in peanut [54]. Atrazine and Dual Magnum®, two commonly used corn herbicides used in the USA, also gave good to excellent residual activity on *C. benghalensis* [3]. The most effective herbicide control strategies for *C. benghalensis* involve combinations of both pre-emergence and postemergence conventional herbicides [54]. These include preemergence herbicides with residual activity such as Axiom® (flufenacet + metribuzin), Dual Magnum®

Canopy SP® (metribuzin + chlorimuron) and Sencor® (metribuzin) and postemergence herbicides with fair to good activity such as Basagran®, Classic® (acetochlor) and Pursuit® (Imazethapyr). Gramoxone Max® and Aim® (acetochlor) can be used post-directed. In evaluating the effectiveness of several pre-emergence herbicides in suppressing *C. benghalensis* emergence, it was reported that s-metolachlor (at 1.07 and 1.60 kg a.i./ha), clomazone (at 0.42 and 1.05 kg a.i./ha) and flumetron (at 1.68 kg a.i./ha) provided ≥ 80% control at 6 weeks after treatment (WAT) in cotton [80]. It was stressed that the application of herbicides with soil residual activity will be crucial for the management of *C. benghalensis* [80].

In the Windward Islands, farmers started using paraquat around 1989 and noticed that it was ineffective. In an interview on August 10, 2002, Paddy Thomas, an experienced banana grower and pesticide salesman in St. Vincent and the Grenadines revealed that farmers started using gramocil (paraquat + diuron) at high doses for example and this too was not effective and resistance in Commelina spp. began to show. He also stated that Reglone, Round – up and Talent (paraquat + asulam) have also been used with little success for the control of Commelina species in the Windward Islands. Glufosinate has since been promoted as an environmentally-friendly option for the control of broad-leaved weeds including Commelina species.

Studies were conducted into the efficacy of glufosinate 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 and gardoprim suppressed this perennial weed better [50]. Fomasefen and lactofen have shown good potential for control of this broadleaf weed [10]. Glufosinate (240 g a.i./ha) and fomasefen (WIP 276 g a.i./ha) were used in St. Vincent and the Grenadines in Fairtrade banana fields to compare their efficacy in controlling *C. diffusa* [30]. They were both applied at the early post-emergence, 3-5 leaf stage with a backpack sprayer using a TJ-8002 fan-nozzle. Regrowth of *C. diffusa* and other weeds were observed 6 weeks after application with glufosinate, however, no regrowth was observed for up to 3 months with fomasefen. Fomasefen, however, caused damage by burning banana suckers and leaves (about 30%) of established banana plants [30]. Studies were conducted to evaluate the efficacy of several post-emergence herbicides in controlling *C. communis* in soybean, the results showed that imazethapyr (150 g a.i./ha), cloransulam-methyl (31.5 g a.i./ha), fomesafen (375 g a.i./ha) and mixture (756 g a.i./ha) of fomesafen plus imazethapyr with clomazone provided > 80% control of this weed at 30 days after treatment (DAT) [36, 37, 65, 67]. The efficacy of imazethapyr (90 g a.i./ha) in controlling *C. communis* reduced with increased leaf stage, and the control levels at 15 DAT were 100% (at 1 leaf stage), 89.17% (at 2 leaf stage), 56.45% (at 3 leaf stage) and 52.71% (at 4 leaf stage), respectively [41]. Therefore, the optimal application time of imazethapyr was 1-2 leaf stage of *C. communis* [41].

To screen more suitable herbicides for control of *C. benghalensis* and *C. communis* and determine the level of weed control provided by a single application of selected post-emergence herbicides, greenhouse studies on the laboratory toxicity of 23 herbicides to these weeds were conducted in 2010 [21]. The results indicated that, as for *C. benghalensis*, mesotrione, lactofen, oxyfluorfen, clomazone and flumioxazin provide complete control (100%), oxadiazon, fomesafen, metribuzin, acifluorfen, isoproturon, MCPA-sodium, carfentrazone-ethyl, fluroxypyr, fluoroglycofen-ethyl and bentazone are herbicides with excellent activity (90.0 - 100%

control), paraquat, 2,4-D butylate, rimsulfuron and thifensulfuron-methyl are herbicides with good activity (80.0 - 90.0% control), and nicosulfuron, bensulfuron-methyl, dicamba and glyphosate-isopropylammonium are relatively ineffective (< 80.0% control) at their own recommended dose, respectively. As for *C. communis*, mesotrione and thifensulfuron-methyl provide complete control (100%); metribuzin, paraquat, carfentrazone-ethyl, 2,4-D butylate, nicosulfuron, MCPA-sodium, fluroxypyr, flumioxazin and acifluorfen are herbicides with excellent activity (90.0 - 100% control); rimsulfuron, lactofen and fomesafen are herbicides with good activity (80.0 - 90.0% control); and glyphosate-isopropylammonium, bensulfuron-methyl, fluoroglycofen-ethyl, bentazone, clomazone, oxadiazon, oxyfluorfen, isoproturon and dicamba are relatively ineffective (< 80.0% control) at their own recommended dose, respectively. There are 19 and 14 herbicides which provided good to excellent control (> 80%) to *C. benghalensis* and *C. communis* under greenhouse conditions, respectively. However, the performance of those herbicides applied in different crops to control *C. benghalensis* and *C. communis* also needs to be ascertained.

8. Cultural management

This method depends on the crop infested, land size, level of technology available, value of crop, labour availability and costs, availability of draft power and the associated equipment and availability of herbicides [47]. The document further indicates that the methods currently used include proper land preparation, hand hoeing and pulling, removing the plants from the fields and drying, use of ox-drawn and tractor drawn cultivation, slashing and herbicide application. *Commelina diffusa* is very difficult to control manually as the stolons are cut into small pieces which can easily regenerate. Hand weeding and rolling the weed up like a carpet is considered suitable for removal of small infestations [30], if care is taken to remove every last piece. In Uganda, it was reported that heaping of stubborn weeds of Commelina plants is practical during the rainy season to speed up rotting and reduce the frequency of weeding [48]. In the dry season, heaps are then scattered as the dry conditions desiccate Commelina stems rapidly. A small percent of Ugandan farmers (5.9%) dig ditches and bury Commelina species, turning it into manure. Some farmers in St. Vincent have also tried this technique in the field with varying success.

A potential solution to overcoming Commelina weed infestations in banana is by intercropping 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, Vigna radiata* (mung bean), *V. unguiculata* (cowpea), *Crotalaria juncea, Indigofera endecaphylla, Phaseolus trinervius,* and *Ipomea batatas* (sweet potato) which have rapid canopy coverage to suppress the establishment of weeds. Melon (*Colocynthis citrullus* L.) planted at a density of 5,000 plants/ha suppressed weed growth of *Commelina diffusa* for five months, enhancing establishment and yield of melon in Nigeria [49]. Use of vigorous healthy planting material and close spacing of the crop may also be used. It has been shown that spacings of 1.2 x 1.2 m (6,944 plants/ha) and 1.5 x 1.2 m (4,444 plants/ha) gave high yields and "natural" control of these weeds [8, 66].

Field studies conducted in St. Vincent and the Grenadines in 2003/2004 compared several treatments including 3 cover crops in suppressing *Commelina diffusa* weed infestations in banana at 63 days after application (DAA) [30]. The cover crops included *Arachis pintoi* (wild peanuts) which was sown by seed and stem cuttings, 16 cm apart, *Mucuna pruriens* (velvet beans) drilled 30 cm apart and *Desmodium heterocarpon* var *ovalifolium* (CIAT 13651) broadcast at a rate of 5 kg/ha. Best results were obtained from *Desmodium heterocarpon* (86.7%) followed by *Arachis pintoi* (52.1%) and *Mucuna pruriens* (43.3%). *Desmodium heterocarpon* was also found to be competitive to *C. diffusa* significantly suppressing its growth in Farmer Participatory Research trials also conducted in St. Vincent in 2005/2006 [30].

Mulching is another viable option for management of the weed. Mulching with rice straw, cut bush, grass, coffee hulls, water hyacinth or even the dead or senescent banana leaves, pruned suckers and old stems could significantly suppress weed growth. Black plastic mulch also provides good weed control as it stifles weed seed growth and development when light penetration is reduced. There are no reports of work done on the use of these mulches for suppression of Commelina species. In field studies in St. Vincent and the Grenadines in 2003/2004 three dead mulches were compared using senescent banana leaves (traditional practice of farmers) applied to a depth of 3-5 cm, coffee hulls applied to a depth of 3-5 cm and black plastic polyethylene tarp at 1.0 mils thickness [30]. Results indicate a 94.5% and 95.6% suppression of weeds including *C. diffusa* with coffee hulls and banana mulch treatments respectively and 100% suppression with black plastic mulch.

9. Mechanical management

Commelina diffusa is particularly difficult to control by cultivation, partly because broken pieces of the stem readily take root and underground stems with pale, reduced leaves and flowers are often produced [32]. The plant is easy to rake up, roll up or hand pull and very small infestations can be dug out. It can be bagged and well baked in the sun, however, follow – up work is essential as any small fragment of the stem remaining will regrow and needs to be removed and destroyed off - site. Mechanical control using the weed whacker may also contribute the spread of stem cuttings in addition to damaging the banana root system as much of the plant lies within the top 15 cm of the soil [30].

To investigate the effect of cutting and depth on the regeneration potential of *C. diffusa* greenhouse studies were conducted in 2004/2005 (Isaac et al. unpublished data 2005) using three cutting types: tip cuttings (2 nodes, 2 leaves), 2 node pieces only and 1 node, 1 leaf piece buried at depths including 0 (control), 2.5, 5.0 and 7.0 cm to demonstrate emergence patterns. These cuttings were intended to simulate cuttings made from a weed whacker and the practice of burying the weed. Regeneration was observed from all cuttings from 0 – 5.0 cm depths but no growth was observed at 7.0 cm. *C. diffusa* dry matter (DM) was highest at surface level (0cm - control) for all cuttings and reduced with increased depth. Results indicate that for effective management of *C. diffusa* by cutting, nodes must be reduced to less than half with no leaves which may starve the plants' photosynthetic ability and hence suppress regeneration. Burial should be up to 5.0 cm to ensure that there is no emergence of the weed. Similar studies [5] indicated that cuttings buried deeper than 2 cm failed to regenerate.

Research has shown that soil solarization, a hydrothermal process of heating moist soil, can successfully disinfect soil pests and control weeds [1, 4, 15, 56]. 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 IPM programme for soilborne pests in open fields. In field trials in St. Vincent, soil solarization using clear polyethylene plastic at 0.5 mils under Fairtrade banana plants showed variable suppression of *C. diffusa* as the weed emerged under the clear plastic showing chlorotic and suppressed growth symptoms, resuming its full growth potential after removal of the plastic covering 2 months after application (Isaac et al. unpublished data 2005). Seed germination of *C. benghalensis* was found to increase by soil solarization in studies conducted in Brazil [43].

10. Organic management

Attempts have also been made to find organic treatments for control of Commelina species in banana in St. Vincent and the Grenadines [30]. DTE corn weed blocker (corn gluten meal) pre-emergent weed blocker and slow release fertilizer (9-1-0) which controls emerging weeds was applied at a rate of 10 kg/ha. Burnout® (concentrated vinegar and acetic acid) (20%), urea (20%), and fertilizer solution (20%) were also used to evaluate their efficacy on the control of Commelina species and other weed species. All treatments showed varying levels of control for up to 3 weeks. Best results were obtained from Burnout® which caused phytotoxic damage on the leaves of actively growing plants offering 43% control. This was followed by urea (41%), fertilizer solution (34%) and corn weed blocker (20%). Urea, fertilizer and corn weed blocker treatments resulted in the general stunting of plants in addition to the burning of leaves. However, stems and roots remained intact. Similar results using treatments high in nitrogen were obtained in Russia [59] where seed production of *C. benghalensis* and stunted growth under artificial dense competition in cereals resulted. These results indicate that there is no evidence that this Commelina species competes for nitrogen. In fact the species does not pose any threat in competing for nutrients with banana. Repeat applications of these treatments are therefore necessary for the effective management of Commelina species in organic farming systems.

Studies conducted in Brazil in soybean-wheat rotations under no-tillage conditions showed reductions in the seedbank of *C. benghalensis* in areas infested with *Brachiaria plantaginea* [73]. Analysis of the soluble fraction of *B. plantaginea* indicated a predominance of aconitic acid (AA) among the aliphatic acids and ferulic acid (FA) among the phenolic acids. Laboratory bioassays using *C. benghalensis* were carried out to evaluate phytotoxic effects of pure organic acid solutions and dilute extracts of *B. plantaginea* on seeds germination, root development and fungal germination and AA and FA solutions and the extract of *B. plantaginea* extract reduced

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germination and root length of *C. benghalensis* [73]. Both AA and FA have the potential for use as bio-herbicides.

11. Biological management

There have not been many reports on biological control of Commelina species. *Commelina diffusa* is grazed by small ruminants, pigs and cows. Because this species is very fleshy and has a high moisture content, it is difficult to use it as fodder for domestic stock [27]. 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 [30]. There have also been reports of foraging of this weed by *Gallus domesticus* (chickens) [30].

There are no reports of promising insect candidates for biological control reported on Commelina spp. in the USA [63, 64]. In Korea and China there have been reports of *Lema concinnpennis* and *Lema scutellaris* (Coleoptera: Chrysomelidae) two leaf-feeding species on *C. communis* [86]. *Noelema sexpunctata* (Coleoptera: Chrysomelidae) another leaf-feeding species was also reported on *C. communis* [45].

In Central Virginia, USA, *Pycnodees medius* (Hemiptera: Miridae) was found to cause tissue necrosis on *C. communis* [33]. Various insects were also screened for their potential as biocontrol agents of weeds in rice and it was found that *Necrobis ruficollis* (blue beetle), *Rhaphidopalpa africana* (yellow beetle), *Conocephalus* sp., *Tetragrnathidae* spp. and *Paracinema tricolor* (grasshopper) were promising [45]. Feeding and nymphal development (up to 3rd and 4th instar) of *Cornop aquaticaum* (grasshopper) were reported on *C. africana* L., and *Murdannia africana* (Vahl.) [25]. It was also observed that *Rhaphidopalpa africana* beetles fed more than the others on the weed, *C. benghalensis* L. [25].

There are records of agromyzid leaf miners which may be promising sources of candidate biological control agents [75]. *Liriomyza commelinae* (Diptera: Agromyzidae), a leaf-miner, was however reported on *C. diffusa* in Jamaica [20, 61]. *Commelina diffusa* is the main food plant of *L. commelinae*, however, it is susceptible to predation by the formicid: *Crematogaster brevispinosa* as well as competition and exposure to the sun (high temperatures) which causes high mortality [20].

There are prospects for the management of invasive alien weeds in Latin America using coevolved fungal pathogens in selected species from the genera Commelina [14]. 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), *Phoma herbarum* [14, 23, 76]. These mycobiota would appear to be good potential agents for classical biological control (CBC) [14]. 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 [14]. The uredinal state of a rust was found widespread on *C. diffusa* in Hawaii [22] sometimes causing death of parts above ground. Studies aimed at identifying mycoherbicidal biocontrol agents have been conducted in Brazil on three endemic pathogens of *C. benghalensis* which were: a bacterium (Erwinia sp.) and two fungi (*Corynespora cassiicola* and *Cercospora* sp.) [38, 39].

12. Conclusion and recommendations

The Commelina species are very persistent, noxious weeds which must be managed using an integrated approach to weed management. 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 [51], which is the case with Commelina species in cropping systems. The integrated approach should utilize alternative strategies such as those mentioned in this paper including the most practical options, cultural and mechanical not negating the judicious use of herbicides. Such combinations should provide significant management levels of Commelina species for both conventional as well as organic growers using a pesticide free production PFP approach. Utilization of the useful benefits of Commelina species after uprooting will also serve to check the heavy use of herbicides in cropping systems.

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. Successful management of *C. benghalensis* will require a multi-component approach including an effective herbicide that provides soil residual activity [80]. Recent studies on the management of Commelina species have, however, still 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 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 [52].

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). 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.

Future research in developing effective management strategies for *Commelina benghalensis* should:

- Develop an accurate predictive model for *C. benghalensis* germination

- Evaluate the seedbank longevity of *C. benghalensis*
- Determine the primary dispersal mechanism(s)
- Characterize the environmental limits of *C. benghalensis* in the U.S.A. [80].

Surely this list can be expanded to include other Commelina species such as *C. diffusa* which is definitely a problematic weed in the cropping systems in the Windward Islands. The research direction should also:

- Determine threshold levels of *C. diffusa* in crops such as banana
- Evaluate the allelopathic potential of Commelina species by extracting hydro alcoholic compounds which could be used as a possible bioherbicide in controlling other problem weeds
- Screen for mycobiota with good potential for CBC such as the rust species Uromyces commilinae which has been identified in several Caribbean Islands.
- Determine the reasons for reduced seed production of *C. diffusa* species found under banana fields in the Windward Islands as compared to higher seed numbers (both aerial and underground) of *C. benghalensis* species in the USA.

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