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Combined effects of cover crops and herbicide rotation as proactive weed management in pineapple (*Ananas comosus* L. Merr)

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ABSTRACT

Objective: to evaluate the effect of two proactive strategies for weed management in pineapple (*Ananas comosus*), including (1) cover crop rotation and reduced rate of herbicide (RRH) and (2) cover crop association and RRH.

Design/Methodology/Approach: We conducted pineapple field experiments in Huimanguillo, Tabasco Mexico, using a complete randomized block design for both rotation and association experiments. Weed occurrence were registered and classified. The weed management effect of cover crops such as cowpea (*Vigna unguiculata*), sunnhemp (*Crotalaria juncea*), stylo (*Stylozanthes guanensis*) and velvet bean (*Mucuna pruriens*) were evaluated alone and combined with three herbicides. Data of soil ground cover and weed suppression levels were analyzed by one-way ANOVA and the means were separated by Least Significant Differences (LSD) at P=0.05.

Results: Synergistic interaction was detected for weed suppression in all cover crops and herbicide treatments. Combined effects of metribuzin and pendimethalin herbicides with cover crops varied from 80% - 90% of weed suppression until 90 days after treatment (DAT); however, when cover crops were combined with haloxifop plus diuron, 100% of weed control was achieved until 90 DAT.

Study limitations/implications: Irrigation, weather conditions may affect observations.

Findings/Conclusions: Our results showed that all cover crops, specially *Vigna unguiculata* and *Mucuna pruriens* in a rotation system, along with reduced rate of herbicides is novel approach strategy for weed management in pineapple plantation. Cover crops such as cowpea might improve crop performance, productivity and feasibility for farmers. The reduced rates of preemergence herbicides and cover crops will be very helpful for the farmers and for protection of environment.

Keywords: Cover crops, *Anananas comosus*, herbicide, weed suppression, integrated weed management.

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INTRODUCCIÓN

Weeds causes substantial declining of crop productivity and quality, which are directly related to food security and safety. Approximately one-third yield losses occur worldwide due to weeds, in which contribution of introduced, invasive or noxious weeds is exhaustive. In 2020, 1,209,000 tons of pineapples were produced which leads Mexico to be positioned

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as the world's ninth biggest pineapple producer (SIAP, 2020). However, weeds are one of the major constrains on pineapple production and cause elevated cost of production. Identification of the major weed species, biology and ecology is imperative to develop integrated weed management. On the other hand, herbicide are main tool for managing weeds in many crops including pineapple around the world. However, most registered herbicides in pineapple are older molecules also used in different crops. They are applied up to five times during the plant crop cycle and twice in the ratoon crop period. For more than 15 yr before its banning, farmers typically applied bromacil twice during this period, at the onset of either the plant or ratoon crop (Valverde and Chaves, 2020). However, bromacil has been banned in Costa Rica in 2017, and glyphosate in Mexico is expected to be banned by 2024.

Cover crops are largely known to provide several eco-biological services in agroecosystems (Hunter *et al.*, 2017; Kladivko *et al.*, 2014). In addition, cover crops have increasingly being studied recently for their approach as weed suppression, intentionally to promote a better management of proactive herbicide-resistant weeds strategy, especially in the overuses of glyphosate (Valverde and Chaves, 2020; Norsworthy *et al.*, 2012; Price *et al.*, 2011; Wallace *et al.*, 2019). Wiggins *et al.* (2016) pointed out that some cover crops suppress weeds that are already herbicide resistant, thereby reducing the intensity of selection for future resistance. Furthermore, weed cover abundance and biomass in the soil ground cover crop are reduced due to suppression of seedling emergence from the seedbank (Wallace *et al.*, 2019). Also, mixing a grass or legume cover crop in intercropping cash crops system results in greater productivity, low impact of plant diseases and stability, and weed suppression compared with cash crop monoculture (Brainard *et al.*, 2011; Garcia-De la Cruz *et al.*, 2002). For instance, the velvet bean (*Mucuna pruriens* (L.) is cultivated in sustainable and organic cropping systems and to increase the productivity crops such as corn and pineapple (Sasamoto *et al.*, 2013; Ortiz-Ceballos *et al.*, 2012; Garcia-De la Cruz *et al.*, 2006). Research on *Crotalaria* sp. has focused on nematode suppression. However, its vigorous growing provide good ground coverage for weed control. Phophy *et al.* (2017) pointed out that that cowpea and lablab are effective for weed suppression in conservation agricultural systems.

We wanted to answer the following questions. Is a intercropping of cover crops more effective at suppressing weeds compared with crop rotation grown in monoculture or combined with minimum rate application of herbicide? In addition, if cover crop performance is expected to be feasible and less variable from year to year in terms of the weed-suppressive effects? To address these questions, we conducted 2-yr cicle experiments, each involving a different suite of cover crop species grown as monocultures and three herbicides at different time of application in which we quantified weed ground cover, weed abundance, weed suppression levels and soil ground cover crops.

MATERIALS AND METHODS

Site description

Two-field experiment were conducted at the Ejido La Esperanza municipality of Huimanguillo, Tabasco, México NM (431955 N y 1980750 W, 24 m). The soil type is cutanic umbric acrisol (Salgado *et al.*, 2017). According to Murillo-Hernandez *et al.* (2019) the pH is strong acid, no salinity, high organic matter content and nitrogen, intermediate levels of phosphorus content and very low in P, Ca and Mg. High content of Fe, Zn and Co.

Experimental design set up and cultural practices

Crop rotation experiment

The cover crop plots (2×2 m each) were established in a randomized complete block design with eighteen treatments with four replications. The cover crop treatments included cover crops *Mucuna pruriens*, *Crotalaria juncea*, *Sylosanthes guanensis, Vigna unguiculata*, weedy check (control without cover crop) and weedy check (without herbicide). In the rotation experiment, after cover crop fallow finalization, three herbicides (pendimethalin, metribuzin and mixture of haloxyfop-r-methyl and diuron were evaluated in each of the six treatments cover crops. Cover crops and herbicides were applied according to Table 1. Cover crops were established in May 2016 and repeated in 2018 (Figure 1). Herbicides

Table 1. Detail of cover crops and herbicide rate treatments in the field experiment.

Trade name	Common name	Application time	MOA	Dose g. a. i. ha^{-1}
Velvet bean	*Mucuna pruriens*	PRE, POST	Allelopathy	10 kg
Stlylo	*Stylosanthes guanensis*	PRE, POST	Cover crop	5 Kg
Sunnhemp	*Crotalaria juncea*	PRE, POST	Allelopathy	47 Kg
Cowpea	*Vigna unguiculata*	PRE, POST	Allelopathy	10 kg
Prowl	Pendimethalin	PSI, PRE	Mitosis inhibitor	700
Sencor	Metribuzin	PRE	Photosynthesis inhibitor	560
Galant	Haloxyfop r- methyl	POST	ACCase inhibitor	200
Karmex	Diuron	PRE, POST	Photosynthesis inhibitor	800
Weedy check	a) no cover crop b) no herbicide			-CC -H

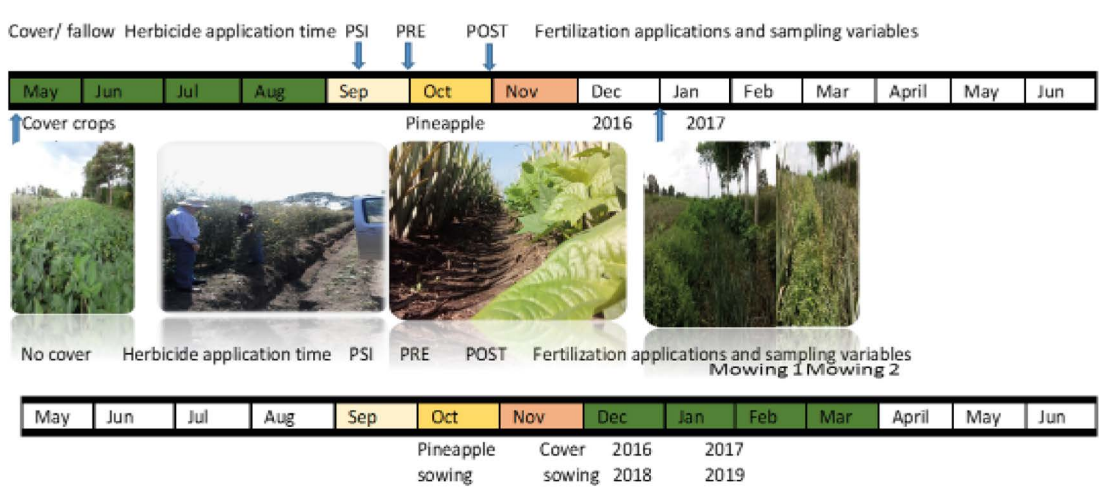

Figure 1. Schematic timeline showing the field work under crop rotation (up) and association (dawn) experiments in Huimanguillo, Tabasco, Mexico.

were applied at different times according their mode of action and time of application (Figure 1). Suckers of pineapple were sown in October 2016 and repeated sown in 2018. Both weed soil ground cover and cover crop ground cover were evaluated four five times during the growing season at 15, 30, 60, and 90 days after treatments (DAT) and expressed in percentage (%) using a scale from 0 to 100% (0% meaning no cover, 100% meaning plot completely covered).

Crop association (Intercropping) experiment.

The experiment started with the planting of pineapple and then cover crops were sown in a randomized complete block design with 18 treatments as in the previous rotation experiment. Pineapple was intercropped with: (i) *M. pruriens*, (ii) *C. juncea*, (iii) *S. guanensis*, (iv) *V. unguiculata* (v) weedy check without cover crops and (vi) weedy check without herbicide. All cover crops were seeded as shown in Table 1. The experimental design was a randomized complete block with four replications. Each experimental plots were one-intercrop beds and two pineapple beds. Each bed was 2 m×4 m. Prior to pineapple planting, plots were amended with lime (200 kg/ha). Cover crops were sown at the same time as pineapple between two pairs of pineapple rows (Table 1). Pineapples were fertilized according to standard plantation practice (400 kg/ha/year for N and K, and 5 kg/ha/year for Fe). At 90 days after cover crops plantation, each experimental cover crop plots were mowed (Figure 2). Visual rating of weed infestation and cover crop ground cover was based on 1 to 10 where 1 represents complete weed free situation while 10 represents complete weed cover. Weed samples were collected using quadrants of 1 m^2, placed randomly in each plot. The weed samples were separated into broad leaves, sedges and grasses.

RESULTS AND DISCUSSION

This study revealed 14 weed species belonging to 13 genera and 7 families. The weeds were predominantly grasses and all of them have an invasive status in Mexico (Table 2). The family order of abundance in their occurrence were Poaceae, Asteraceae, Euphorbiaceae, Cucurbitaceae, Cyperaceae, Rubiaceae and Phylantaceae. Also, some of these weeds were introduced and have an invasive status in Mexico (Table 2). Thus, they might have been threatened and displacing the original flora in the savanna of Huimanguillo, Tabasco, Mexico. The intermediate level of abundance of the broadleaved weed species could be attributed to the frequently disturbed conventional tillage practices being carried out in the experimental site, coupled with the high use of nitrogen fertilizer. According to Streit *et al.*, (2003) tillage practices and nitrogen fertilizer application increases the abundance of broadleaved weeds. We observed high abundance of *Momordica charantia*, present in the field site. The weed community present in the field site experiment and surrounding areas was made up primarily of grasses species (making up to 90% of the total weed composition). High abundance of large crabgrass [*Digitaria sanguinalis* (L.) Scop.] being the dominant species followed by *Eleusine indica*. This high abundance of grasses might be attributed to agricultural practices such as intensive tillage and herbicide resistance, due the fact that high doses and repeated application of herbicides such as glyphosate, bromacil and diuron have been used during many years in this region. The success of *D. sanguinalis* as

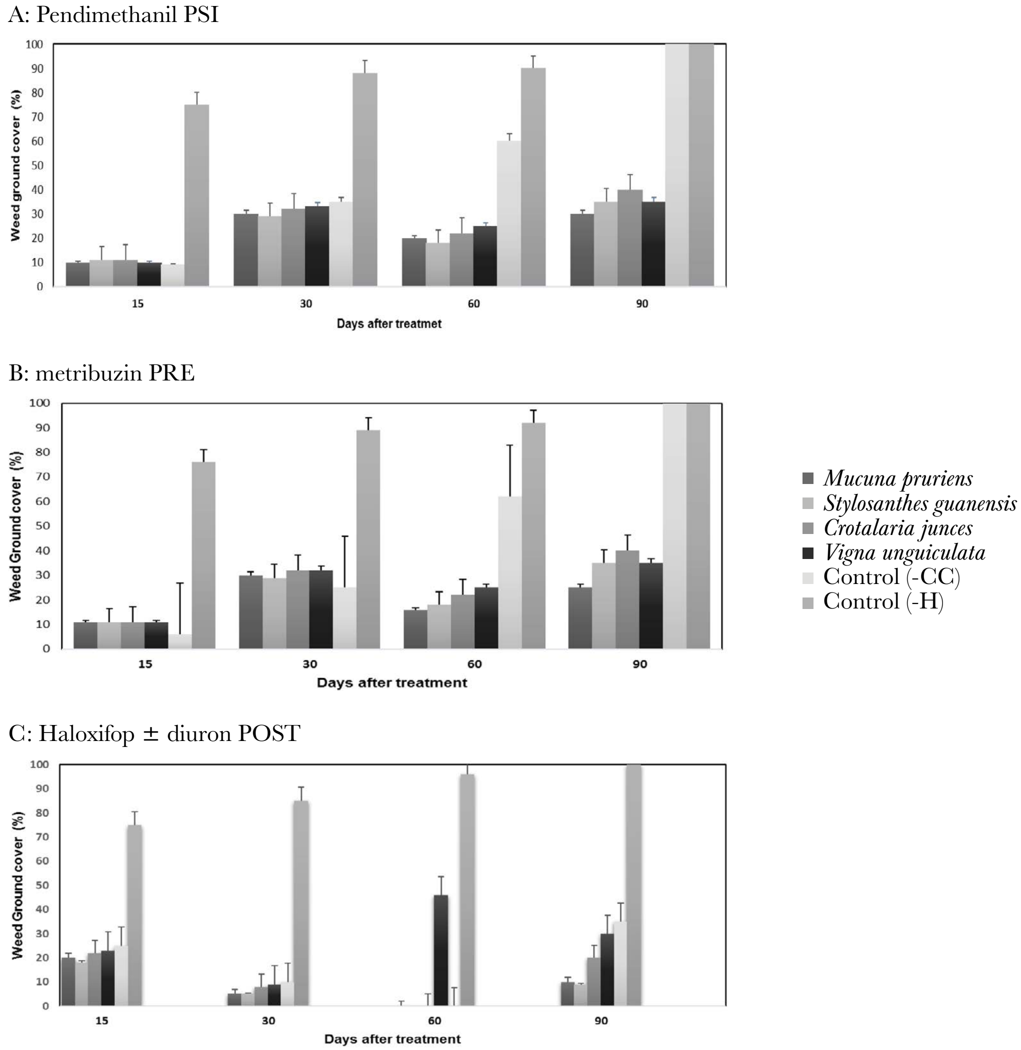

Figure 2. Synergistic effects of herbicide and cover crop in the association experiment (Intercropping). -CC= weedy check without cover crop; -H=weedy check without herbicide. Vertical bars represent ±1 standard error of the mean.

a weed in extensive crops is mainly due to its high seed production and the long period of seedling emergence in the field, distributed from spring to mid-summer (Gallart *et al*., 2010; Cardina *et al*., 2011). *E. indica*, was found to be the most prevalent grass (82.2%) in immature oil palm plantations throughout Malaysia (Maizatul-Suriza and Idris, 2017). The presence of *E. indica* biotypes with resistance to some groups of herbicides is likely to become a concern. Thus, ecological approaches for weedy grass management is an unexploded strategy to overcome herbicide resistance.

In the field, all the cover crops had good establishment *M. pruriens* produced the highest ground cover, which was significantly higher than the cover produced by other fabaces, at both 30, 60 and 90 days after sowing (DAS) (Table 3). The treatments with the lowest weed coverage were the combination of both *M. pruriens*, and *S. guanensis* with both pendimethalin and metribuzin herbicide in a preemergence time application at 30 and 60 DAT. In the

Table 2. Common weed flora, level of occurrence and invasiveness status.

Family	Weed species	Level of infestation	Invasiveness status/origin
a) Broadleaves			
Euphorbiaceae	*Croton hirtus*	+	Native/America
Euphorbiaceae	*Croton lobatus*	+	Native/America
Astereaceae	*Vernonia cinerea*	+	Exotic /Africa
Astereaceae	*Eupatorium pycnocephalum*	+	Native/Mexico
Cucurbitaceae	*Momordica charantia*	+++	Invasive/africa
Euphorbiaceae	*Euphorbia heterophylla*	++	Native/America
Rubiaceae	*Borreria leavis*	+	Native/America
Asteraceae	*Emilia sonchifolia*	+	Native/America
Phyllanthaceae	*Phylanthus* spp.	+	Exotic/Asia
b) Sedge			
Cyperaceae	*Cyperus rotundus*	++	Exotic/Asia
c) Grasses			
Poacea	*Eleusine indica*	+++	Invasive/Asia
Poacea	*Digitaria sanguinalis*	+++	Invasive/Europe
Poacea	*Sorghum halepense*	++	Invasive/Asia
Poacea	*Bothriochloa pertusa*	++	Invasive/África

+++ High infestation (60 - 90% occurrence)
++ moderate infestation (30 - 59% occurrence)
+ low infestation (1 - 29% occurrence)

rotation experiment, after the end on cover crops monocultures, 60% of weed ground cover was observed (Figure 2 A, B). Both pendimethalin, a preplant or pre-sown incorporate (PSI), and metribuzin, a pre-emergence, herbicides have broad-spectrum weed control, affecting seed bank, and seed emergence. The synergism effect observed between cover crops and herbicide might have delayed weed emergence in the intercropping system. However, in the rotation experiment grass weed density was not positively affected by the legume cover crops in both years (2016-2017, 2018-2019). However, *S. guianensis* at 15 and 30 DAS produced significantly low grass weed density while broadleaved weed density was generally low in all the plots. Weed suppression levels, ground cover crop, and weed cover were similar for *S. guanenesis* and *C. juncea* both intercropping and monocultures experiments across the time evaluated. However better weed control was resulted when combined with pre and postemergence herbicide. Herbicide effect alone has positive effect on weed suppression ranging from 85-100% depending on the time of application (Table 3). Performance of herbicide and crop rotation resulted in delayed weed emergence, which was observed at 60 DAT (Figure 3), however weed reemergence was observed at 90 DAT. Haloxyfop plus diuron treatments along with cover crops have the best weed control achievement in both experiment with 100% efficacy until 90 DAT (Table 3). While time and rotation of herbicides provided a proactive management of resistance, overuse of herbicides such as bromacil, glyphosate and the evolution of glyphosate-resistant weeds poses one the greatest threats to conservation tillage as it has forced some farmers to revert

Table 3. Weed suppression (WS) and cover crop ground cover (GC) levels (%) at 30 and 60 days after herbicide treatment (DAT).

Cover crop (CC)	Herbicide (H)	Intercrop- cc- pineapple				Rotation cc-pineapple	
		30 DAT		60 DAT		30 DAT	60 DAT
		WS %	GC %	WS %	GC %	WS %	WS %
Mucuna pruriens	pendimethalin	70	50	85	78	92	80
	metribuzin	70	51	85	78	89	80
	haloxyfop + diuron	95	50	100	80	100	100
	- H	50	55	75	81	30	20
Crotalaria juncea	pendimethalin	65	40	80	60	85	78
	metribuzin	65	40	80	61	85	78
	haloxyfop + diuron	94	45	100	61	100	100
	-H	45	44	70	62	29	18
Stylozanthes guanensis	pendimethalin	72	52	86	81	86	75
	metribuzin	72	52	86	81	85	78
	haloxyfop + diuron	95	50	100	80	100	100
	-H	51	52	76	80	28	15
Vingna unguiculata	pendimethalin	69	46	82	74	84	70
	metribuzin	69	46	82	73	84	75
	haloxyfop + diuron	94	47	100	74	100	100
	-H	45	46	69	75	30	16
- CC	pendimethalin	65	0	55	0	89	75
	metribuzin	65	0	50	0	90	75
	haloxyfop + diuron	88	0	100	0	100	90
	-H	0	0	0	0	0	0

to conventional tillage for effective weed control. Cover crops have the potential to delay weed emergence, decrease weed size, and decrease weed number. In addition to the weed suppression and ecological benefits from the all cover crops used. Our results supports previous research indicating that utilizing soil-residual herbicides along with cover crops improves control of palmer amaranth and/or waterhemp (Perkins *et al.*, 2021). The use of cowpea as monoculture before pineapple plantation but also as intercrop is highly important as food source. After harvesting, the living mulch leads to a considerable reduction in weed coverage (about 65% at 90 DAS a density of 20 plants/m^2). However, this weed control level was more efficient combined with low dose rate rotation with pre-plant or pre-emergence herbicides. Previous research by Soti and Raceli (2020) demonstrated that methanol and ethyl acetate extracts of cowpea contained allelopathic compounds and that might has phytotoxicity properties. Thus, identification and isolation of the allelochemicals from all cover crops used in these experiments will be useful.

In general, the highest levels of weed suppression were associated with the *M. pruriens* when combined with all three herbicides, ranging from 95% to 100%. The high level of weed suppression (100%) were observed when *M. pruriens* where combined with treatments with post emergence herbicides (diuron and haloxyfop) (Table 3). The treatments with the

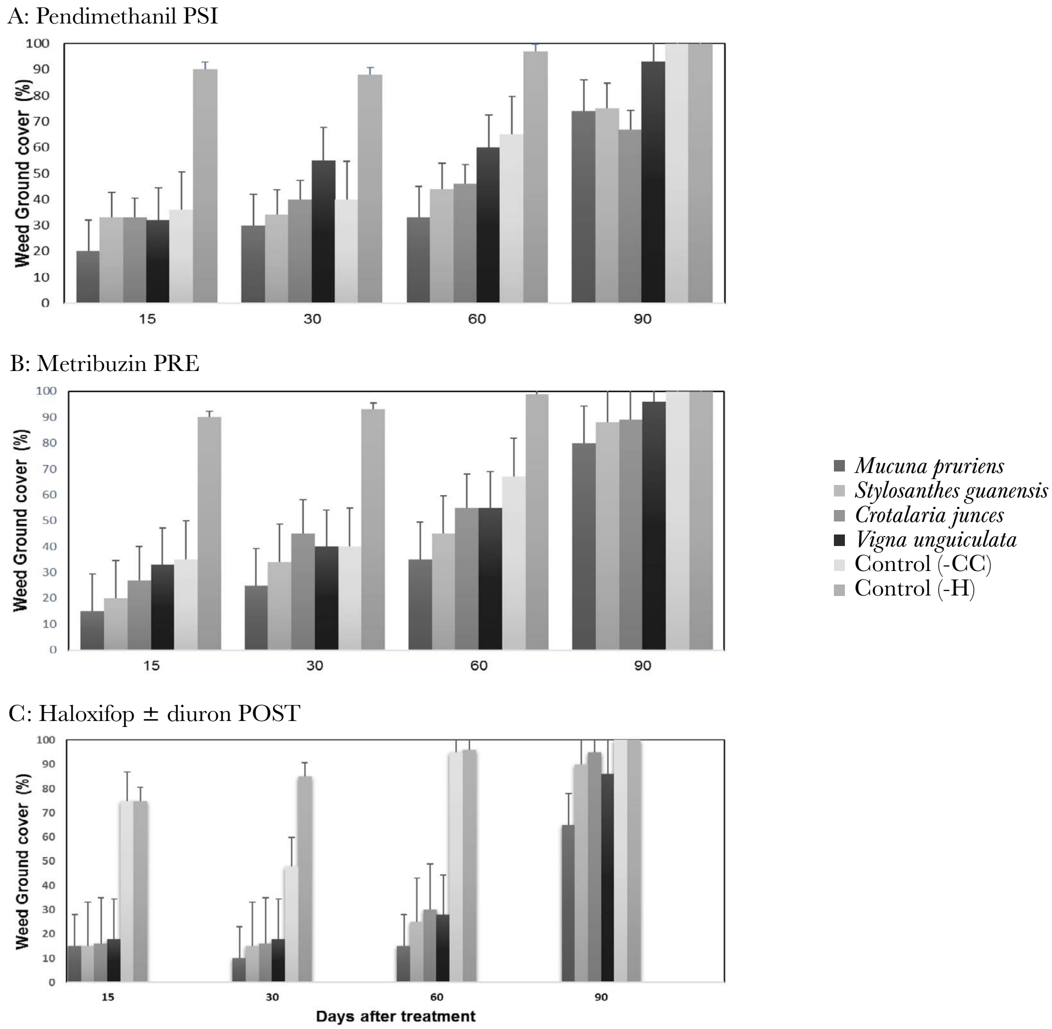

Figure 3. Combined effects of herbicide and cover crops in the rotation experiment. -CC=without cover crop; -H=weedy check without herbicide. Vertical bars represent ±1 standard error of the mean.

highest levels of weed suppression were also those that produced the highest ground cover crop (Table 3). These results support the hypothesis that dual approach with cover crop along with low dose herbicide rate strategy provide greater weed-suppression benefits than the most-suppressive cover crop grown as a monoculture. Our results are congruent with previous research showing cover crop have weed suppressive abilities (Osipitan *et al.*, 2019). However, we are aware that there might be other mechanisms of action to suppress weeds, rather that ground cover crop canopy alone. For instance, the action of biological control agents that inhabits the cover crop as well as allelopathy, which has unexploited potential in integrated weed management and ought to be further studied in our research laboratory and facilities. Prediction changes in seedbank level, timing of seedling emergence in the field are strictly related to the dormancy state of the seedbank (Batlla & Benech-Arnold, 2010) and could be useful to decide the crop sowing date or the timing of herbicides applications. A large body of research in literature indicate that weed population density and biomass production may be markedly reduced using crop rotation and intercropping strategies. In a meta-analysis study, Osipitan *et al.*, (2019) pointed out that crop rotation resulted in emerged weed densities in test crops that were lower in 21 cases, higher in 1 case, and equivalent in five cases in comparison to monoculture systems. In 12 cases where weed seed density was reported, seed density in crop rotation was lower in 9 cases and equivalent in three cases when compared to monocultures of the component crops. In addition, weed biomass in the intercrop was lower in 47 cases and higher in four cases than in the main crop grown alone. For the previous studies, it seems that success of cover crop rotation for weed suppression appears to be based on the use of crop sequences that create varying patterns of resource competition, allelopathic interference, soil disturbance, and mechanical damage to provide an unstable and frequently inhospitable environment that prevents the proliferation of a particular weed species (Osipitan *et al.*, 2019). Alternatively, intercropping with fabaces such as cowpea, as food source may provide yield advantages without suppressing weed growth below levels observed in component sole crops if intercrops use resources that are not exploitable by weeds or convert resources to harvestable material more efficiently than sole crops. Parameters such as weed seed longevity, weed seedling emergence, weed seed production and dormancy, endophytes biological control agents of weed mortality, and allelopathic interactions needs to be investigated. Compatibility of these strategies with current technologies and farming practices might become more accessible and feasible to farmers.

CONCLUSION

Intermediate to high weed suppression levels with cover crops was resulted within the population at the time of herbicide application. Integration of cover crops as a complementary tactic in herbicide based production systems seems to be feasible. This study shows that *M. pruriens*, *S. guanensis*, *C. juncea* and *V. unguiculata* achieve effective weed suppression alone, however synergism effects were observed when combined with herbicides in both experiments. Intercropped cover crops and herbicides did not affect pineapple growth visually; however, weed control improved with herbicide application in

Figure 4. Cover crop with *Vingna unguiculata* in intercropped with pineapple at 30 DAS. March 16, 2018.

crop rotation or fallow. Integrating cover crops into the agricultural systems as an effective strategy to enhance crop production sustainability and resiliency is a friendly and feasible new approach for farmers.

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